4G Mobile Broadband Evolution

3GPP Release 11 & Release 12 and Beyond

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1 INTRODUCTION

Contemporary drivers' license test question: "What do you do at a red light?" Answer: "Check my email." (Not the correct answer, unfortunately!)

While this is fictional, the fact that it rings true to many of us testifies to the role of mobility in our lives. Of the 6.8 billion mobile subscriptions in the world today, 2.1 billion are mobile broadband, which is three times the number of fixed-broadband accounts. Moreover, almost every edition of 4G Americas' white papers on 3GPP standards (now ten years of history) started by stating in some form that the number of cell phone accounts are expected to "soon" exceed the number of human beings on the planet—however, this is no longer the case since "soon" is now. According to the International Telecommunications Union (ITU), the number of mobile subscriptions will rise to 7.3 billion in 2014, compared to the global population of 7 billion.

The resource of mobile communications could almost be compared to other invaluable resources like potable water and tillable soil, as it advances human and economic development from providing basic access to health information to making cash payments, spurring job creation and stimulating citizen involvement in democratic processes. However, there are deficiencies. Two-thirds of the world population still has no internet access. While 75 percent of households in developing countries have television, only 20 percent are connected to the web. However, mobile use is a global phenomenon; there are more than one hundred countries throughout the world, where the number of cell phones exceeds the countries' populations.

In the words of ITU Secretary-General, Dr. Hamadoun I. Touré, "… looking at the trends, I am personally confident that over the next decade or so we will see every household, village, school, and hospital fully connected to the Internet, and that Internet will be affordable."[1]

At the grassroots level, this confidence may be attributed to the careful science of technology standards developed by the 3rd Generation Partnership Project (3GPP). The standards work by 3GPP, the foundation of the world's mobile broadband infrastructure, is delivering international communications technologies to the masses via the Global System for Mobile Communications (GSM) family of technologies, which is interchangeably called the 3GPP family of technologies as they are based on the evolution of standards developed for GSM, Enhanced Data Rates for GSM Evolution (EDGE), Universal Mobile Telecommunication System (UMTS), High Speed Packet Access (HSPA), HSPA+, Long Term Evolution (LTE) and LTE-Advanced.

It may be helpful to consider the historical development of the 3GPP UMTS standards. Beginning with the inception of UMTS in 1995, UMTS was first standardized by the European Telecommunications Standards Institute (ETSI) in January 1998 in Release 99 (Rel-99). This first release of the Third Generation (3G) specifications was essentially a consolidation of the underlying GSM specifications and the development of the new Universal Terrestrial Radio Access Network (UTRAN). The foundations were laid for future high-speed traffic transfer in both circuit-switched and packet-switched modes. The first commercial launch (Freedom of Mobile Multimedia Access (FOMA), a derivation of UMTS) was by Japan's NTT DoCoMo in 2001.

In April 2001, a follow up release to Rel-99 was standardized in 3GPP, termed Release 4 (Rel-4), which provided minor improvements of the UMTS transport, radio interface and architecture.

The rapid growth of UMTS led to a focus on its next significant evolutionary phase, namely Release 5 (Rel-5) which was frozen in June 2002. 3GPP Rel-5 – first deployed in 2005 – had many important enhancements that were easy upgrades to the initially deployed Rel-99 UMTS networks. Rel-5 provided wireless operators with the improvements needed to offer customers higher-speed wireless data services with vastly improved spectral efficiencies through the High Speed Downlink Packet Access (HSDPA) feature. In addition to HSDPA, Rel-5 introduced the Internet Protocol Multimedia

[1] State of the Union Address, ITU Council, 4 July 2012, Geneva, Switzerland.

Subsystem (IMS) architecture that promised to greatly enhance the end-user experience for integrated multimedia applications and offer mobile operators a more efficient means for offering such services.

UMTS Rel-5 also introduced the IP UTRAN concept to recognize transport network efficiencies and reduce transport network costs.

Release 6 (Rel-6), published in March 2005, defined features such as the uplink Enhanced Dedicated Channel (E-DCH), improved minimum performance specifications for support of advanced receivers at the terminal and support of multicast and broadcast services through the Multimedia Broadcast/Multicast Services (MBMS) feature. E-DCH was one of the key Rel-6 features that offered significantly higher data capacity and data user speeds on the uplink compared to Rel-99 UMTS through the use of a scheduled uplink with shorter Transmission Time Intervals (TTIs as low as 2 ms) and the addition of Hybrid Automatic Retransmission Request (HARQ) processing. Through E-DCH, operators benefitted from a technology that provided improved end-user experience for uplink intensive applications such as email with attachment transfers or the sending of video (e.g. videophone or sending pictures). In addition to E-DCH, UMTS Rel-6 introduced improved minimum performance specifications for the support of advanced receivers. Examples of advanced receiver structures include mobile receive diversity, which improves downlink spectral efficiency by up to 50 percent, and equalization, which significantly improves downlink performance, particularly at very high data speeds. UMTS Rel-6 also introduced the MBMS feature for support of broadcast/multicast services. MBMS more efficiently supported services where specific content is intended for a large number of users such as streaming audio or video broadcast.

Release 7 (Rel-7) moved beyond HSPA in its evolution to HSPA+ and also the standardization of Evolved EDGE; the final Stage 3 was published in March 2007. The evolution to 3GPP Rel-7 improved support and performance for real-time conversational and interactive services such as Push-to-Talk Over Cellular (PoC), picture and video sharing, and Voice and Video over Internet Protocol (VoIP) through the introduction of features like Multiple-Input Multiple-Output (MIMO), Continuous Packet Connectivity (CPC) and Higher Order Modulations (HOMs). These Rel-7 enhancements are called Evolved HSPA or HSPA+. Since the HSPA+ enhancements are fully backwards compatible with Rel-99/Rel-5/Rel-6, the evolution to HSPA+ was made smooth and simple for operators.

Release 8 (Rel-8) specifications, frozen in December 2008 and published in March 2009, included enhancements to the Evolved HSPA (HSPA+) technology, as well as the introduction of the Evolved Packet System (EPS) which consists of a flat IP-based all-packet core System Architecture Evolution/Evolved Packet Core (SAE/EPC) coupled with a new Orthogonal Frequency Division Multiplexing Access (OFDMA)-based Radio Access Network (RAN) (Evolved Universal Terrestrial Radio Access Network) (E-UTRAN/LTE)).

Note: The complete packet system consisting of the E-UTRAN and the EPC is called the EPS. In this paper, the terms LTE and E-UTRAN will both be used to refer to the evolved air interface and radio access network based on OFDMA, while the terms SAE and EPC will both be used to refer to the evolved flatter-IP core network. Additionally, at times EPS will be used when referring to the overall system architecture.

While the work towards completion and publication of Rel-8 was ongoing, planning for content in Release 9 (Rel-9) and Release 10 (Rel-10) began. In addition to further enhancements to HSPA+, Rel-9 was focused on LTE/EPC enhancements. Due to the aggressive schedule for Rel-8, it was necessary to limit the LTE/EPC content of Rel-8 to essential features (namely the functions and procedures to support LTE/EPC access and interoperation with legacy 3GPP and 3GPP2 radio accesses) plus a handful of high priority features (such as Single Radio Voice Call Continuity (SRVCC), generic support for non-3GPP accesses, local breakout and Circuit Switched (CS) fallback). The aggressive schedule for Rel-8 was driven by the desire for fast time-to-market LTE solutions without compromising the most critical feature content. 3GPP targeted a Rel-9 specification that would quickly follow Rel-8 to enhance the initial Rel-8 LTE/EPC specification.

At the same time that these Rel-9 enhancements were being developed, 3GPP recognized the need to develop a solution and specification to be submitted to the ITU for meeting the IMT-Advanced requirements. Therefore, in parallel with Rel-9 work, 3GPP worked on a study item called LTE-Advanced, which defined the bulk of the content for Rel-10, to include significant new technology enhancements to LTE/EPC for meeting the very aggressive IMT-Advanced requirements. On

October 7, 2009, 3GPP proposed LTE-Advanced at the ITU Geneva conference as a candidate technology for IMT-Advanced and one year later in October 2010, LTE-Advanced was approved by ITU-Radiotelecommunication Sector (ITU-R) as having met all the requirements for IMT-Advanced (final ratification by the ITU occurred in November 2010). Rel-11 built on that work and further refined topics were Coordinated Multi-Point Transmission and Reception (CoMP), Carrier Aggregation (CA), Heterogeneous Network (HetNet) and Self-Optimizing or Self-Organizing Network (SON)

Tracking these standards, 3G Americas, and now 4G Americas, has annually published a white paper to provide the most current "understanding" of the 3GPP standards work, beginning in 2003 with a focus on Release 1999 (Rel-99) through October 2012 and the publication of 4G Mobile Broadband Evolution: Release 10, Release 11 and Beyond - HSPA, SAE/LTE and LTE-Advanced. The latter paper provided detailed discussions of Release 11 enhancements to LTE/EPC (called LTE-Advanced). This paper, as a follow-up, is focused on updating LTE-Advanced and HSPA+ in Release 11 (Rel-11) items as the standardization was finalized at the end of 2012, and provides a detailed view of the ongoing Release 12 (Rel-12) features that are nearing finalization. Rel-12 continues to build on LTE-Advanced and HSPA+ with further focus on downlink enhancements, needed strengthening to various small cell features, expanding carrier aggregation, enabling Machine Type Communications (MTC) and Wi-Fi integration, as well as looking at system capacity and stability. It has been prepared by a working group of 4G Americas' member companies and the material represents the combined efforts of many leading experts from 4G Americas' membership.

2 GLOBAL MARKET TRENDS, MILESTONES AND STANDARDIZATION

Almost 50 percent of all people worldwide are now covered by a 3G network, according to the International Telecommunications Union (ITU). Mobile broadband connections over 3G (HSPA and Code Division Multiple Access (CDMA) Evolution Data Optimized (EV-DO)) and LTE networks are growing at an average annual rate of 40 percent, with a total of 2.1 billion mobile-broadband subscriptions and a global penetration rate of almost 30 percent.[2]

Mobile broadband enables advanced data services, and data traffic now significantly outweighs voice traffic; it more than doubled in 2011 and again in 2012, and could nearly double again in 2013.[3]

In its annual Visual Networking Index Forecast 2012-2017, Cisco Systems reported that global mobile data traffic will increase 113 percent year-over-year between 2012 and 2017. The report also predicts that mobile data traffic will grow at a compound annual growth rate of 66 percent from 2012 to 2017, which is equivalent to the consumption of 11.2 Exabytes per month by the end of 2017.[4]

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[2] ITU, Measuring the Information Society report, 7 October 2013.

[3] Ericsson Mobility Report, Interim Update. August 2013.

[4] Cisco: Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017, February 2013.

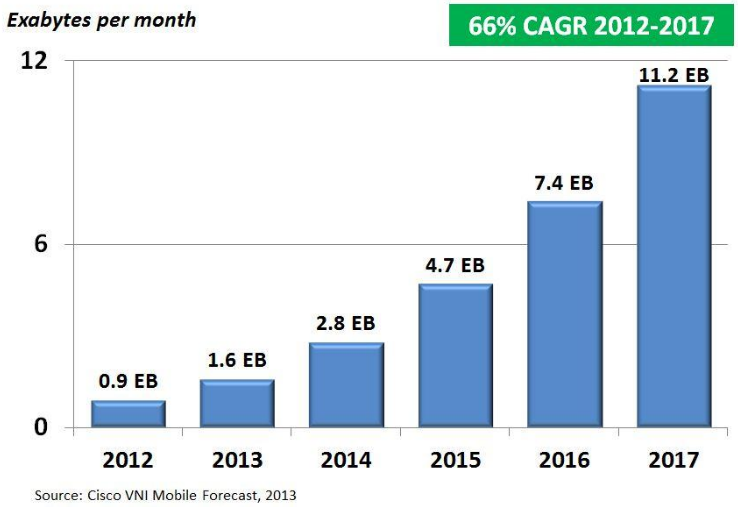

Figure 2.1. Global Mobile Data Traffic 2012 to 2017.[5]

The exponential increase in data consumption will be driven by powerful smartphones and tablets capable of running on average speeds of 5.244 Mbps on LTE and Wi-Fi networks. According to Cisco, in 2017, 4G will be 10 percent of connections, but 45 percent of total traffic, and a 4G connection will generate 8 times more traffic on average than a non-4G connection. Mobile network connection speeds will increase 7-fold by 2017.

Ericsson's November 2013 Mobility Report revealed that mobile subscriptions are expected to reach 9.3 billion by 2019, and more than 60 percent of these (5.6 billion) will be for smartphones. To support the smartphone user experience, Wideband Code Division Multiple Access (WCDMA)/HSPA networks are predicted to cover 90 percent of the world's population by 2019. Moreover, almost two-thirds (65 percent) of the world's population will be covered by 4G/LTE networks.[6]

Mobile network connection speeds more than doubled in 2012. Globally the average mobile network downstream speed in 2012 was 526 kilobits per second (kbps) up from 248 kbps in 2011. The average mobile network connection speed will exceed 3.9 Mbps in 2017. However, average speeds for smartphones and tablets are considerably higher; 2,064 kbps for smartphones and 3,683 kbps for tablets in 2012.[7]

The decline of global Second Generation (2G) GSM connections began in 2013 and the trending growth of 3G and Fourth Generation (4G) mobile broadband HSPA and LTE technologies continues unabated. Of the estimated 6.8 billion total wireless subscriptions as of the end of 2013, there were 1.6 billion HSPA and LTE mobile broadband subscriptions. This number is expected to grow to 5.6 billion in another five years.[8]

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5 Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, Cisco, February 2013.

6 Ericsson's Mobility Report. 11 November 2013.

7 Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017, February 2013.

8 Informa Telecoms & Media, WCIS+ Estimates, December 2013

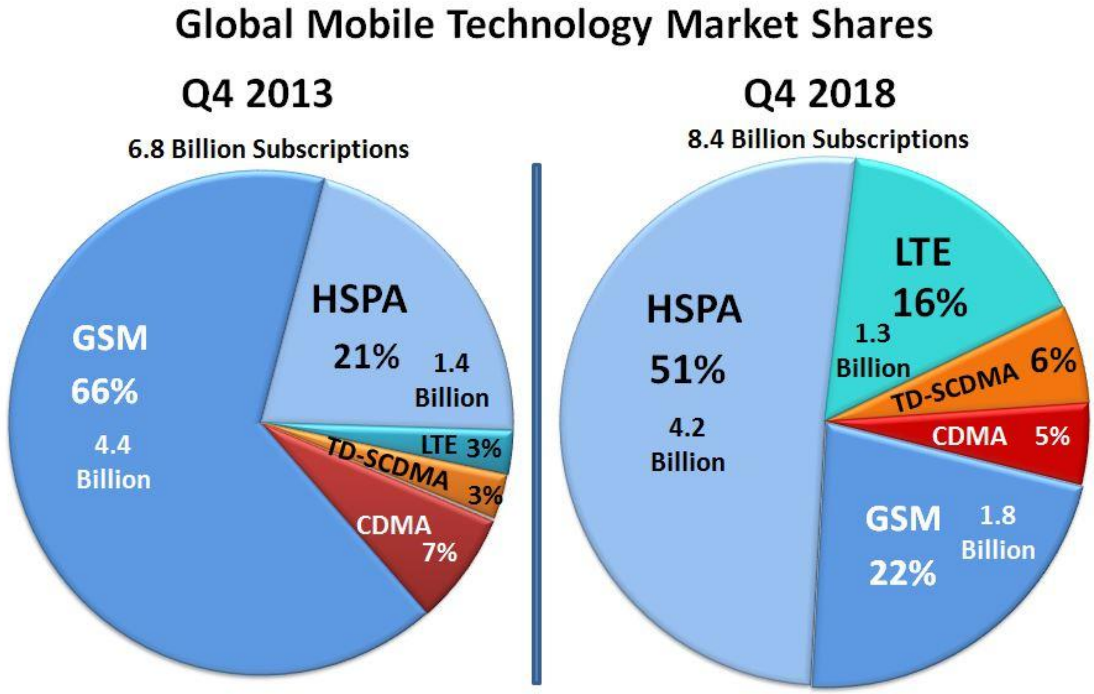

Figure 2.2. Global Mobile Technology Shares 4Q 2013 – Forecast 4Q 2018.[9]

While GSM represents 66 percent of the global market in 2013, this will decline to 22 percent worldwide GSM market share in five years. HSPA will more than double and LTE will grow 8-fold. The shift from 2G is evident; some service providers (e.g., AT&T) have announced sunsetting their 2G networks by 2017 to allow their customers advanced notice to properly plan in areas such as Machine-to-Machine (M2M) communications and other connected devices. The need for service providers to sunset their networks weighs heavily on their available spectrum assets, refarming their spectrum and getting the best efficiencies by using more advanced 4G technology in those limited spectral resources.

Ericsson reported that global mobile broadband subscriptions grew by around 40 percent year-on-year at the third quarter, with around 150 million additions. LTE is growing rapidly and reached 150 million subscriptions, with around 25 million additions in Q3 2013 alone. WCDMA/HSPA had the highest net additions at around 80 million. Almost all of these 3G/4G subscriptions have access to GSM/EDGE as a fallback. The number of GSM/EDGE-only subscriptions did not increase.[10] Ericsson expects LTE subscriptions to exceed 1 billion in 2017, driven by more capable devices and demand for data-intensive services such as video.[11]

Global mobile broadband subscriptions passed 2 billion in 2013 and are predicted to grow 4 times by 2019, reaching 8 billion. LTE is being deployed and built-out in all regions and will reach around 2.6 billion subscriptions in 2019.[12]

In North America, LTE will represent the majority of subscriptions in the region in 2016, growing to around 85 percent in 2019. GSM/EDGE-only subscriptions will progressively decline. This fast growth in LTE subscriptions is driven by strong competition and consumer demand, following CDMA operators' early decisions to migrate to LTE.[13]

9 WCIS+, 4Q 2013 Estimates & Forecast. Informa Telecoms & Media.
10 Ericsson Mobility Report. 11 November 2013.
11 Ericsson Mobility Report. June 2013.
12 Ericsson's Mobility Report. 11 November 2013.
13 *Ibid.*

In November 2013, AT&T reported that traffic on their HSPA+ subscription growth had peaked as more and more customers were using LTE devices. AT&T reported that at the end of the third quarter, 42 percent of its postpaid smartphone customers were using an LTE device.[14]

Latin America had a large GSM/EDGE subscriber base of about 70 percent in 2013. The strong growth in subscriptions in this region will be driven by economic development and consumer demand. In 2019, WCDMA/HSPA will be the dominant technology with about 70 percent market share and LTE expected to have a slightly higher percentage of the market than GSM/EDGE-only subscriptions. [15]

In this section, the global market trends of wireless data are demonstrated by examples of increased operator Average Revenue Per User (ARPU) from data services, uptake of mobile broadband applications for consumers and the enterprise and analysts' predictions for their growth as well as the introduction of a greater variety of wireless data devices such as smartphones, tablets and M2M or connected devices. In addition, the increasing LTE deployments that are being built upon HSPA and HSPA+ mobile broadband commercial networks worldwide are charted. Finally, the 3GPP technology commercial milestones achieved by numerous leading operators and manufacturers worldwide on the new standards in Release 9 through Release 12 are outlined.

2.1 MOBILE DATA GROWTH FORECASTS AND TRENDS

The number of mobile data subscriptions is increasing rapidly along with a continuous increase in the average data volume per subscription, driving growth in data traffic. Data traffic grew around 10 percent between Q2 and Q3 2013 and there was an 80 percent growth in data traffic between Q3 2012 and Q3 2013.[16]

Mobile data traffic will continue to grow significantly in the coming years, driven mainly by video. According to numerous sources, overall data traffic is expected to grow 12-fold by the end of 2018. Among the reasons for increased usage is the amount of available content and applications as well as the improved network speeds that come with HSPA and LTE development. Owing to the build out of HSPA and LTE, network speeds have improved, and so has the user experience.[17]

In 2013, total mobile traffic generated by mobile phones exceeded that from mobile PCs, tablets and mobile routers for the first time. Traffic in the mobile phone segment is primarily generated by smartphones. By 2019, smartphone subscriptions are expected to triple, resulting in rapid traffic growth. Total monthly smartphone traffic over mobile networks will increase around 10 times between 2013 and 2019.[18]

Video makes up the largest segment of data traffic in networks, and it is expected to grow around 60 percent annually up until the end of 2018. Video consumption is on average 2.6 GB per subscription per month in some networks**.**[19]

Research firm Strategy Analytics predicts strong growth in mobile phone data traffic, over 300 percent growth by 2017 to 21 exabytes up from 5 exabytes of data per year in 2012. Video and web traffic will drive this rise, with compound annual growth of 42 percent and 30 percent respectively. This presents network challenges for carriers to ensure end user satisfaction with data-hungry smartphones.[20]

14 AT&T: Traffic on HSPA+ network 'has peaked'. Fiercewireless, Phil Goldstein. 12 November 2013.
15 Ericsson's Mobility Report. 11 November 2013.
16 *Ibid.*
17 Ericsson Mobility Report. June 2013.
18 Ericsson's Mobility Report. 11 November 2013.
19 Ericsson Mobility Report. June 2013.
20 Handset Data Traffic to grow over 300% by 2017 to 21 Exabytes Strategy Analytics, July 2013.

2.2 WIRELESS DATA REVENUE

Global mobile data service revenue, made up of mobile internet and messaging revenue, will rise by 21.4 percent between 2012 and 2014 to represent 40.4 percent of the US$1 trillion mobile customers who will be spending on their mobile phone services according to ABI Research in their April 2013 study. Due to strong commitments to LTE network deployment in Latin America and Africa (not just the developed markets), growth rates in these regions will be substantially faster as the increase in usage outstrips mobile data pricing decline. ABI believes this represents a significant opportunity for regional mobile content and application developers, which will stimulate a very nascent mobile apps and content market-place.[21]

"While global messaging service revenue is in gradual decline, mobile internet service revenue is very much the main driver of revenue growth (2012: US$ 244.2 billion, 21 percent year-on-year)," noted Jake Saunders, VP and Practice Director, Core Forecasting at ABI Research. "As smartphones have become the entertainment hub in our lives, music, video and TV streaming's contribution of mobile internet service revenue has jumped to 26 percent in 2012."[22]

The U.S. continues to be a strong market for operator data revenues. Industry Analyst, Chetan Sharma, reported that data represented 48 percent of the U.S. mobile industry service revenues by the end of the third quarter of 2013, with an expected $90 billion in mobile data service revenues for the U.S. market for the year 2013.[23] Sharma expected the crossover point of 50 percent share for voice and data respectively to be roughly equal for U.S. carriers in the fourth quarter of 2013.

AT&T's total wireless revenues, which include equipment sales, were up 5.1 percent year over year to $17.5 billion at the third quarter of 2013. Wireless service revenues increased 3.7 percent in the third quarter to $15.4 billion; wireless data revenues increased 17.6 percent from the year-earlier quarter to $5.5 billion. Third-quarter wireless operating expenses totaled $12.9 billion, up 5.7 percent versus the year-earlier quarter, and wireless operating income was $4.6 billion, up 3.4 percent year-over-year.[24]

Subscriptions were also still on the rise for some leading operators including AT&T which reported a net increase of nearly one million total wireless subscribers in the third quarter 2013, including postpaid net adds of 363,000, more than twice as many as the year-ago quarter. Postpaid net additions included 178,000 smartphones and 388,000 tablets. Prepaid gained 192,000 subscribers following the introduction of LTE-capable GoPhones and new pricing plans. When including acquisitions, the company added more than 1 million retail postpaid and prepaid subscribers in the quarter. Connected device net additions were 719,000.[25]

AT&T added 1.2 million postpaid *smartphone* subscribers in the third quarter. At the end of the quarter, 75 percent, or 50.6 million, of AT&T's postpaid phone subscribers had smartphones, up from 66 percent, or 44.5 million, a year earlier. The company sold a third-quarter record 6.7 million smartphones. Smartphones accounted for a record 89 percent of postpaid phone sales in the quarter. AT&T's ARPU for smartphones is more than twice that of non-smartphone subscribers. About 42 percent of AT&T's postpaid smartphone customers now use an LTE device and 70 percent use a 4G-capable device (LTE/HSPA+).[26]

The number of AT&T subscribers on usage-based data plans (tiered data and Mobile Share plans) continued to increase in the third quarter 2013. About 72 percent, or 36.4 million, of postpaid smartphone subscribers were on usage-based

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21 Global Mobile Data Will Exceed 40% of Total Service Revenue by 2014. ABI Research. 20 March 2013.
22 *Ibid.*
23 US Mobile Data Market Update 3Q 2013. Chetan Sharma. November 2013.
24 AT&T Reports Strong EPS Growth with Solid Wireless Gains, Record U-verse Results in the Third Quarter. AT&T. 23 October 2013.
25 *Ibid.*
26 *Ibid.*

data plans compared to 64 percent a year ago. About 80 percent of customers on usage-based data plans chose the medium- and higher-data plans: 22 percent chose the higher plans, compared to 9 percent in the year-ago quarter.[27]

T-Mobile US, Inc.'s results for the third quarter of 2013 were highlighted by positive branded postpaid and prepaid net customer additions, continued strong customer uptake of the Simple Choice rate plan options, the introduction of the industry leading JUMP!™ upgrade program, expanded 4G LTE coverage, and the successful launch of the Apple® iPhone® 5s and iPhone 5c. T-Mobile reported at the third quarter 2013 that total revenues increased by 7.4 percent quarter-over-quarter primarily due to the inclusion of MetroPCS results for the full quarter and higher equipment revenues due to record smartphone sales.[28] T-Mobile additionally reported that 77 percent of the total branded postpaid customer base used 3G/4G smartphones versus 72 percent in the second quarter of 2013 and 57 percent in the third quarter of 2012. There were 16.5 million 3G/4G postpaid smartphones on the T-Mobile network at the end of the third quarter of 2013, compared to 15.0 million at the end of the second quarter of 2013 and 11.8 million at the end of the third quarter of 2012.[29] Total 3G/4G smartphones used by branded prepaid customers accounted for 11.9 million or 80 percent of total branded prepaid customers, an increase from 77 percent, or 11.4 million in the second quarter of 2013.[30]

In Canada, Rogers Wireless had wireless data revenue growth of 15 percent from last year at the 3rd quarter 2013, with data revenue now representing 48 percent of all wireless network revenue compared to 46 percent at the end of the second quarter and 41 percent in the same period last year. Total wireless revenue had a 2 percent decline in wireless revenue mainly due to a 1 percent decline in network revenue related to the introduction of lower priced roaming plans and pricing changes over the past year. LTE U.S. wireless roaming was launched with AT&T, making Rogers the first Canadian carrier to offer LTE roaming for customers traveling to the U.S. Wireless data revenue was higher this quarter and year to date compared to last year mainly because of the continued penetration and growing use of smartphones, tablet devices and wireless laptops, which increased the use of e-mail, wireless, Internet access, text messaging, data roaming and other wireless data services.[31]

Rogers Wireless activated and upgraded approximately 574,000 smartphones in third quarter 2013, compared to approximately 707,000 in the same period last year, of which approximately 38 percent were new subscribers. The decrease was mainly the result of a 24 percent reduction in hardware upgrades by existing customers during the quarter. The percentage of subscribers with smartphones increased to 73 percent of the total postpaid subscriber base at September 30, 2013, compared to 65 percent last year. Rogers' smartphone subscribers typically generate significantly higher ARPU, are less likely to churn and more likely to commit to term contracts than non-smartphone subscribers.[32]

Cable & Wireless/LIME in the Caribbean reported in their 3Q 2013 earnings that they are setting the standard for mobile data in our markets, and customers are responding. Mobile data revenue rose 29 percent over the half with all regions seeing growth. C&W is continuing to invest in mobile data, particularly in LTE networks, which they will launch in The Bahamas and Cayman in the second half 2013.[33]

In the Caribbean, C&W reported that mobile revenue rose 3 percent in the first half to $935 million as demand for mobile data continued to increase with data revenue growing 49 percent in the third quarter.[34]

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27 AT&T Reports Strong EPS Growth with Solid Wireless Gains, Record U-verse Results in the Third Quarter. AT&T. 23 October 2013.

28 T-Mobile US Reports Third Quarter 2013 Results and Leads the Industry in Phone Customer Acquisition for the Second Consecutive Quarter. T-Mobile US. 5 November 2013.

29 Changing the Game Investor Quarterly. T-Mobile. Third Quarter 2013.

30 *Ibid.*

31 Rogers Communications Reports Third Quarter 2013 Results. Rogers Communications. 24 October 2013.

32 *Ibid.*

33 Cable & Wireless Communications PLC Half Yearly Report For The Six Months Ended 30 September 2013. Cable & Wireless. 7 November 2013.

34 *Ibid.*

In Panama, C&W reported that mobile revenue at $168 million was 6 percent higher than the prior year and 2 percent higher than H2 2012/13. This was the fourth consecutive period of sequential half yearly mobile service revenue growth. Subscribers increased, driven by prepaid activations for data plans as more affordable smart devices entered the market. Data revenue was up 49 percent on the prior year more than offsetting reduced voice revenue which was affected by a lower voice rate per minute. Data penetration of subscribers increased by 7 percentage points to 33 percent as the wider range of data plans stimulated prepaid usage. ARPU was in line with 2012 but lower than the second half of last year due to a reduction in roaming traffic.[35]

America Movíl reported 3.1 million subscribers added in the third quarter of 2013 for a total of 265 million wireless subscribers, with their postpaid base rising 11.3 percent from the year-earlier quarter to 41.5 million. In Brazil, 960,000 new subscribers were obtained—twice as many as in the third quarter of last year—whereas in Colombia, 559,000 new subscribers, and in both Mexico and Central America slightly less than 500,000 additions.[36]

Mobile data and PayTV continued to be America Movíl's more dynamic business lines in the third quarter 2013, with revenues expanding at a rate of 22.4 percent and 21.7 percent respectively, whereas fixed-data revenues were up nearly 10 percent. Voice revenues were down on both the mobile and the fixed-line platforms by the same measure.[37]

In the U.S. market, America Movíl reported that data revenues kept rapidly expanding rapidly in the third quarter of 2013: 50 percent year-on-year and represent 42.5 percent of TracFone's service revenues. Voice revenues were growing roughly in line with subscriber growth in the third quarter 2013.[38]

Telefónica Latin America showed organic growth of 10.9 percent in the third quarter of 2013, another double digit year-on-year growth trend. This performance was underpinned by the company's position in the higher value segments, reflected in the strong growth in the mobile contract segment and in the expansion of the fixed and mobile broadband businesses. It is important to note that Telefónica Latin America registered record high net contract additions in the quarter (+79 percent year-on-year), further strengthening the company's leadership in the region in this segment. Thus, at the end of September 2013, Telefónica Latinoamérica managed a total of 217.9 million accesses in the region, up 4 percent year-on-year. CapEx was up 2.9 percent year-on-year in reported terms and 17 percent in organic terms, reflecting significant investment efforts, mainly devoted to the continued improvement of the network in order to provide innovative services.[39]

Telefónica Brazil continued its leadership position in the high value segments. Thus, for the second consecutive quarter, Telefónica Brazil reached a new record for net additions in the mobile contract segment, capturing most of the market's growth.[40]As a result, Telefónica managed 91.9 million accesses in Brazil at the end of September, and remained devoted to the development and increase in the capacity of 3G and 4G networks and the rollout of the fiber network.[41]

Telefónica Argentina maintained its market leadership offering to its customers an integrated services portfolio of fixed and mobile broadband bundles. The company achieved a new record high for gross and net additions for the third quarter in a row thanks to its successful strategy of bundling fixed services and expanding data in the mobile business. Thus, Telefónica Argentina's mobile connections stood at 20.3 million with year-on-year growth accelerating to 18 percent, underpinned by the strong growth in smartphones (+91 percent year-on-year), which accounted for 27 percent of connections (+10 percentage points year-on-year).[42]

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35 *Ibid.*

36 Third Quarter of 2013 Financial and Operating Report. America Móvil. 24 October 2013.

37 *Ibid.*

38 *Ibid.*

39 Telefónica's Net Profit totals 3,145 million Euros up to September and the Company Meets Annual Earnings and Debt Reduction Targets 3 Months in Advance. Telefonica 3Q Earnings Report. 11 November 2013.

40 *Ibid.*

41 *Ibid.*

42 *Ibid.*

Telefónica Chile (Movistar) aimed at increasing the usage of mobile broadband through bundles with different data volumes, voice minutes and Short Message Service (SMS). Mobile connections stood at 10.3 million, up 6 percent year-on-year, after reporting net additions of 280 thousand connections in the nine months at the third quarter 2013. Movistar launched a commercial 4G LTE offering in the 2.6 GHz band with 14 smartphones, including the latest iPhone 5, in November 2013. Movistar demonstrated speeds of 95 Mbps download and 36 Mbps upload and launched with national coverage for LTE. At the third quarter 2013, 40 percent of Movistar's mobile data traffic was video. The company also launched IPTV in 2013.[43]

Speaking during Movistar's November 2013 launch, Jorge Atton, the head of Chile's telecoms regulator SUBTEL, said the 4G LTE launches were another important step that Chile's telecoms industry had taken during the last four years of the government of Sebastián Piñera. He also mentioned the overhaul of emergency telecommunications infrastructure following the 2010 earthquake, the launch of number portability, elimination of national long distance and the upcoming spectrum auction for 700 MHz scheduled for next year which is aimed at consolidating mobile broadband coverage all over the country.[44]

Telefónica Peru's mobile connections totaled 15.7 million, up 6 percent year-on-year and one year after the merger between Telefónica Móviles Colombia, S.A. and Colombia Telecomunicaciones, S.A. in June 2012. In the third quarter Telefónica Colombia maintained the trend of gradual improvement in its commercial and financial performance seen throughout the year.[45]

Telefónica Mexico managed 19.1 million mobile connections, virtually stable year-on-year (+0.4 percent). Mobile broadband connections are the main driver of mobile subscription growth, increasing by 36 percent year-on-year thanks to the strong growth of smartphones (+50 percent year-on-year) to achieve a penetration of 13 percent of total mobile connections (+4 percentage points year-on-year).[46]

Telefónica Venezuela maintained a solid set of results that again reflected its unique position in the market, with a particular focus on service innovation and network and service quality. Commercial activity in the third quarter of 2013 continued focus on boosting the data business. Notable in this regard was the positive take-up of the "Movistar Full" plans, which offer customers different packages depending on their data requirements. Telefónica managed 10.7 million mobile connections, up 6 percent year-on-year, following net additions of 95,000 connections in the third quarter (123,000 in the January-September period). Mobile broadband connections were the main driver of the growth in high-value customers, advancing 29 percent year-on-year in the third quarter of 2013.[47]

Entel in Chile reported for the third quarter of 2013 that total mobile customers reached 11.8 million, up 19 percent when compared to third quarter of 2012. Excluding Nextel Perú, total mobile customers reached 10.2 million, increasing 4 percent when compared to 3Q 2012. Within this, the postpaid subscriber base (voice and MBB) increased 9 percent, reaching 33 percent of the total customer base; while prepaid (voice and MBB) increased 1 percent. Mobile broadband subscribers (MBB) reached 1,034,338 (including M2M data cards). Entel's revenues reached Ch$408.1 billion, 16 percent growth when compared to 3Q12 (including Ch$12.2 billion from Nextel Perú).[48]

Entel continued expanding mobile data usage, consolidating a variety of multi-media plan offerings backed by a range of high tier devices. In third quarter of 2013, 53 percent of postpaid customers had data or multi-media plan contracts, showing strong growth in the use of mobile data services when compared to the 39 percent reported in the third quarter of

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[43] Movistar Launches 4G LTE Network with National Coverage. BN Americas, Patrick Nixon. 14 November 2013.
[44] *Ibid.*
[45] Telefónica's Net Profit totals 3,145 million Euros up to September and the Company Meets Annual Earnings and Debt Reduction Targets 3 Months in Advance. Telefonica 3Q Earnings Report. 11 November 2013.
[46] *Ibid.*
[47] *Ibid.*
[48] Third Quarter 2013 Results. Empresa Nacional de Telecommunicaciónes S.A. (Bolsa de Comercio de Santiago: ENTEL). 4 November 2013.

2012. In the prepaid segment, Entel was intensifying the offering of smartphone devices and more flexible data alternatives, including per day charges for limited data usage. For the eleventh consecutive year, Entel was awarded first place in the National Consumer Prize within the “Mobile” category. The award was the result of ongoing efforts to maintain a high-quality standard of service based on best quality network infrastructure and user experience.[49]

According to Bank of America Merrill Lynch, average data contribution to ARPU in Latin America as of Q2 2013 was 31 percent with mobile penetration at 119 percent in the region. Countries with the highest data contribution to ARPU were Argentina (45 percent), Mexico, (37 percent), Brazil (25 percent) and Colombia (25 percent).[50]

A study by analyst firm Frost & Sullivan in April 2013 noted, increasing investments in 3G and 4G network expansion along with mobile operators’ focus on enhanced quality of services, are propelling the growth of the Latin American mobile services market. The report attributed the proliferation of smartphones, tablets and notebooks, which popularized data and value-added services, to increased market revenues in the region. Frost & Sullivan reported that the market earned revenues of more than $86.32 billion in 2012 and estimated this to reach $112.45 billion in 2017. "The production of smart devices locally has decreased their costs, especially in Brazil, thereby fuelling the use of mobile services," said Frost & Sullivan Information and Communication Technology (ICT) Research Analyst, Georgia Jordan. "Subsidized prices and installment schemes also facilitate the purchase of these devices, and in turn, accelerate the uptake of mobile services in Latin America."[51]

2.3 MOBILE BROADBAND DEVICES

At the end of 2013, global smartphone penetration will have exploded from 5 percent of the global population in 2009, to 22 percent-- an increase of nearly 1.3 billion smartphones in four years. As of mid-year 2013, one of every five people in the world owned a smartphone; one of every 17 people worldwide owned a tablet.

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49 *Ibid.*

50 Global Wireless Matrix 3Q13. Bank of America Merrill Lynch. 30 September 2013.

51 Increasing Investments in Network Expansion Fuel Mobile Services Market in Latin America. Frost & Sullivan. April 30, 2013.

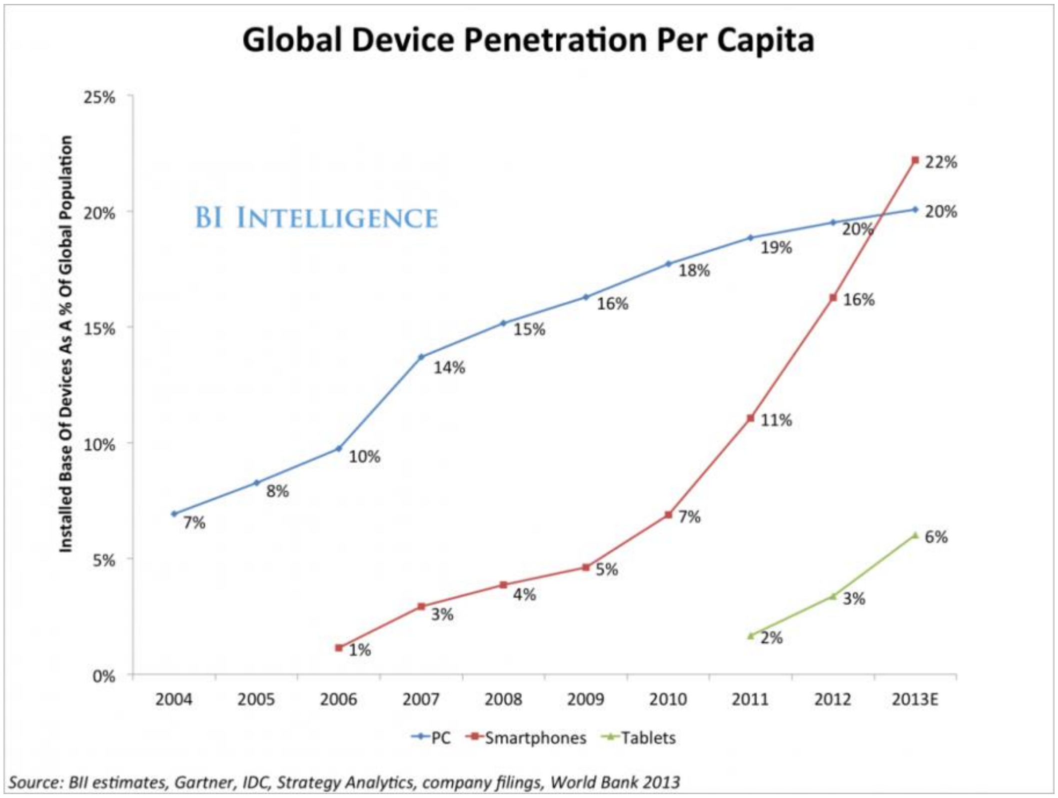

Figure 2.3. Global Device Penetration Per Capita.[52]

Tablets are showing even faster adoption rates than smartphones. It took nearly four years for smartphones to reach 6 percent penetration from when the devices first started to register on a global level. Tablets accomplished this in just two years.

With global smartphone penetration at 22 percent and continuing to rise**,** the opportunity that lies ahead is still substantial.[53] Despite rapid uptake of LTE, HSPA remained the biggest driver in the smartphone market in the second quarter 2013 in terms of shipments and revenue, according to Infonetics analyst Richard Webb. Infonetics Research reported that Frequency Division Duplex (FDD)-LTE devices were the second largest smartphone segment, expected to overtake HSPA in a few years. The research firm also noted that in the second quarter of 2013, sales of mobile broadband embedded tablets rose 10 percent sequentially and consumer demand for 3G Universal Serial Bus (USB) mobile broadband cards is softening in developed countries, where embedded device penetration is rising. Enterprise demand for 3G USBs remained healthy as businesses increasingly seek to mobilize their workforces without relying on Wi-Fi availability.[54]

According to Ericsson, smartphones accounted for around half of all global mobile phone sales in 1Q 2013, and 55 percent of all mobile phone sales in 2Q 2013, compared with roughly 40 percent for the whole of 2012.[55]

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52 One in Every 5 People Own a Smartphone, One in Every 17 Own a Tablet, John Heggestuen, BI Intelligence for Business Insider. 18 October 2013.

53 W-CDMA driving worldwide smartphone market, Infonetics Research. 18 September 2013.

54 *Ibid.*

55 Ericsson Mobility Report - Interim Update. August 2013.

The U.S. is the leading market for HSPA+ and LTE mobile broadband and serves as an indication of what is in store for other markets. Smartphones passed the 60 percent mark in the U.S. in the 2Q 2013 and continued to sell at a brisk pace accounting for almost 87 percent of the devices sold in the quarter according to industry analyst, Chetan Sharma. While the U.S. penetration of smartphones was 60 percent, that 60 percent of the subscription base was concentrated in only 35 percent of the households thus leaving plenty of growth in the marketplace.[56] Nielsen reported that in the three month period from March to May 2013, smartphone sales were up more than 10 percent since smartphones became the mobile majority in early 2012 in the U.S.[57]

Not only are the number of smartphones and tablets increasing, but more devices, from cameras to cars, are getting connected. The average data usage per device is on the rise, but so is the total number of connected devices each person owns. The result is an explosion of mobile data consumption across another explosion of new devices, even if the number of actual subscribers is only increasing incrementally. There are 4.3 billion mobile subscribers today, by Cisco's estimates and less than a billion will be added to that figure by 2017.[58]

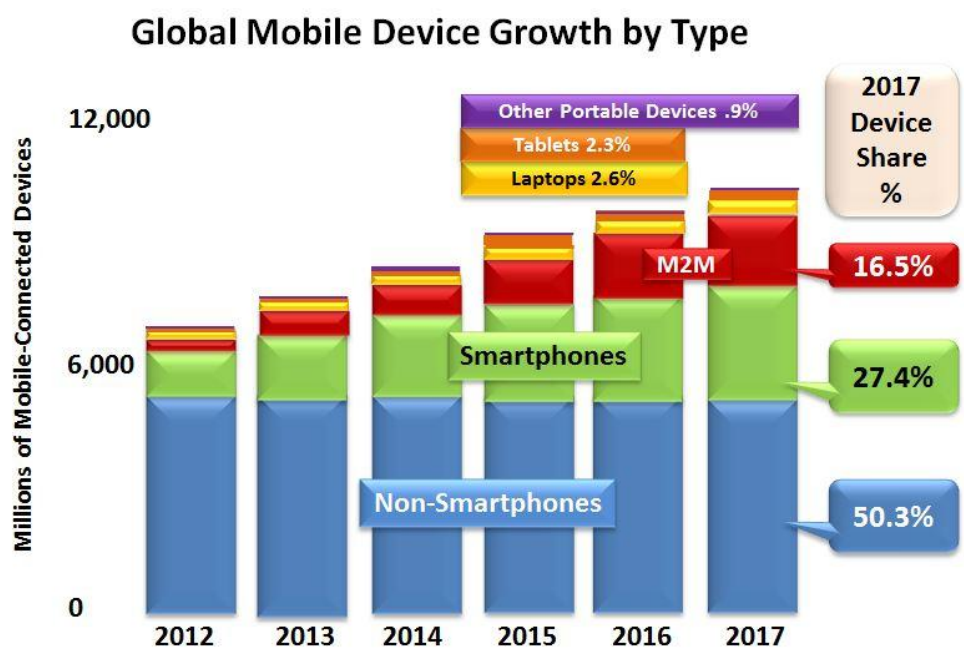

Figure 2.4 Global Mobile Device Growth by Type.[59]

LTE subscriptions continue to be the big drivers behind data applications and devices. LTE phone shipments exploded in the fourth quarter of 2012, increasing 1,100 percent year-over-year, according to Strategy Analytics. They also predicted that LTE smartphone shipments would triple in 2013, reaching 275 million units.[60]

LTE devices are now mainstream; 1,064 LTE user devices were launched by 111 suppliers with 647 new devices between July 2012 and October 2013 alone.[61] This included 322 LTE 1800 MHz terminals and 360 LTE smartphones with frequency/carrier variants—more than four times the number of devices available than the previous year. The 1,064 LTE

56 US Market Mobile Update Q2 2013. Chetan Sharma. 13 August 2013.
57 Mobile Majority: U.S. Smartphone ownership tops 60%. Nielsen. 6 June 2013.
58 Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update. 2012-2017, February 2013
59 Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast 2012-2017. February 2013
60 LTE phone shipments jump more than 1,000 percent, Strategy Analytics. 4 March 2013.
61 Status of the LTE Ecosystem. GSA. 25 August 2013.

total included 222 products supporting Time Division Duplex (TDD) mode although 1800 MHz was the dominant band for LTE deployments used in 43 percent of networks.[62]

The spread of mobile broadband networks, the emergence of new mobile device categories and the expansion of mobile service propositions is establishing an "Internet of Things" (IoT). Within the next decade, billions of new devices will be connected to mobile networks, providing consumers and businesses with an array of applications, services and experiences. This will usher in the "Connected Future" in which users are always connected, anywhere and at any time.

Analyst firm, IDC, expects IoT technology and services spending to generate global revenues of $4.8 trillion in 2012 and $8.9 trillion by 2020, growing at a compound annual rate of 7.9 percent. They also expect the installed base of the IoT to be approximately 212 billion “things” globally by the end of 2020. This will include 30.1 billion installed “connected (autonomous) things” in 2020. This is largely driven by intelligent systems that will be installed and collecting data across both consumer and enterprise applications.[63]

Products such as game consoles, ATMs and a host of other M2M applications, eBook readers, digital picture frames and connected cameras have already illustrated the possibilities in creating new mobile computing categories for the enterprise and consumer. In a world where some experts and companies foresee a future of 50 billion connected devices by 2020,[64] there is good reason to anticipate that the variety and quantity of connected devices will only be limited by the imagination.

The global number of mobile network connections used for wireless M2M communication will increase by 22 percent in 2013 to reach 164.5 million according to Berg Insight research.[65] East Asia, Western Europe and North America are the main regional markets, accounting for around 75 percent of the installed base. In the next five years, the global number of wireless M2M connections is forecasted to grow at a compound annual growth rate of 24.4 percent to reach 489.2 million in 2018.[66]

Connected enterprise and big data analytics are two of the main trends that will shape the global wireless M2M industry in 2014. The automotive industry, where leading global car brands now offer a wide selection of connected applications, ranging from remote diagnostics, safety and security to LTE-powered infotainment services such as streaming music, is a good example of the future vertical industry applications and types of connected devices.

More than 8 billion Internet-connected video devices will be installed worldwide in 2017, exceeding the population of the planet, according to research firm Broadband Technology Service, IHS. The installed base of video-enabled devices that are connected to the Internet—a category that includes diverse product such as tablets, smart TVs, game consoles, smartphones, connected set-top boxes, Blu-ray players, and PCs—will expand to 8.2 billion units in 2017. This will represent a nearly 90 percent increase from 4.3 billion in 2013. With the world’s population amounting to 7.4 billion people in 2017, this means that there will be 1.1 Internet-connected video devices installed for each global citizen. On average, every human being in the world will possess more than one Internet-connected video device by the year 2017, a major milestone for the electronics market. In practice, ownership of Internet connected hardware will be concentrated among users whose homes are equipped with broadband connections. We’re quickly approaching a world where the average broadband household contains 10 connected, video-enabled devices. This means that each TV set installed in a broadband-equipped home will be surrounded by three Internet-connected devices.[67]

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62 *Ibid.*

63 The Internet of Things is Poised to Change Everything, Says IDC. IDC. 3 October 2013.

64 M2M: The Direct Opportunity for Rural and Small, Facilities-Based Mobile Operators. Wireless Week. 03 July 2012.

65 The connected enterprise and big data analytics will be the top M2M trends in 2014. Berg Insight, M2M Research Series. 1 October 2013.

66 *Ibid.*

67 Installed Base of Internet-Connected Video Devices to Exceed Global Population in 2017, IHS Inc. 8 October 2013.

Another new device segment is wearables. According to research firm Berg Insight, sales of smart glasses, smart watches and wearable fitness trackers reached 8.3 million units worldwide in 2012, up from 3.1 million devices in the previous year. Growing at a compound annual growth rate of 50.6 percent, total shipments of wearable technology devices are expected to reach 64 million units in 2017.[68]

Americans are rapidly and aggressively adopting a mobile lifestyle, using smartphones to help navigate their lives and increasingly using tablets as their conduit to all forms of online video. A report by Frank N. Magid Associates states that the evolution is a broad one, affecting all demographics regardless of gender. Nearly three-quarters of U.S. consumers use smartphones and more than half of all mobile consumers had used a tablet as of August 2013.[69] Mobile technology has reached an incredibly high penetration in an exceptionally short period of time, said Magid, with smartphones and tablets "becoming the beating heart of content and commerce over the past year."

2.4 MOBILE BROADBAND APPLICATIONS

"Consumers have made the clear leap into mobile long-form," says Andrew Hare, Magid Research Director. "Beyond just TV and traditional video consumption however, the visual culture has taken over with the growth of Instagram, Tumblr, Pinterest, Snapchat and Vine showing consumers increasingly prefer to communicate through images and video." The Magid report showed 44 percent of smartphone users and 61 percent of tablet users regularly watch video on their devices. And not just short clips and YouTube any more, as the study reveals 45 percent of smartphone viewers and 71 percent tablet viewers now watch long-form TV, movie and sports content on those devices.[70]

In the September 2013 study from the Pew Internet & American Life Project, it was reported that two-thirds of cellphone-owning Americans used their phones to surf the Web and check e-mail, double the amount from 2009, when only 31 percent of people said they used their phones to go online. For a growing segment of people, phones aren't just a secondary way to check the news or send off a quick e-mail. According to Pew, 21 percent of phone owners use their devices as their primary way of accessing the Internet, more than PCs and tablets.[71]

To say that the number and usage of mobile apps is increasing is a huge understatement. As smartphone penetration grows, average mobile users will consume 14 times more megabytes of applications by 2016, according to Informa Telecoms & Media.[72]

According to Google's *Our Mobile Planet* data, the average global smartphone user downloads 26 apps, a bit over 20 free apps and 5 paid apps each.[73] Of the countries studied, South Korea, came in number one on the list with the average smartphone user downloading about 40 apps, although South Korea is also the least likely of the top countries to go for paid apps, as 37 of the average 40 downloads are free apps. Users in Japan are far more likely to download paid apps with an average of 17.5 paid app downloads per smartphone user and a bit over 36 app total for Japanese users. In the U.S., smartphone users download just under 33 apps each, with a fraction over 25 of those being free apps.[74]

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68 Shipments of wearable technology devices will reach 64 million in 2017. Berg Insight. 4 Oct 2013.

69 50% of mobile users consume video on tablets. The Convergence. 9 October 2013 and The Heartbeat of Connected Culture: Smartphones and Tablet. Frank N. Magid Associates report. October 2013.

70 *Ibid.*

71 Mobile Internet Usage Doubles Since 2009. Pew Research. September 2013.

72 Mobile data consumption to grow tenfold over the next five years. Informa Telecoms & Media. 15 May 2012

73 The average global smartphone user has downloaded 26 apps. Phonearena.com, posted by Michael H. 6 September 2013.

74 *Ibid.*

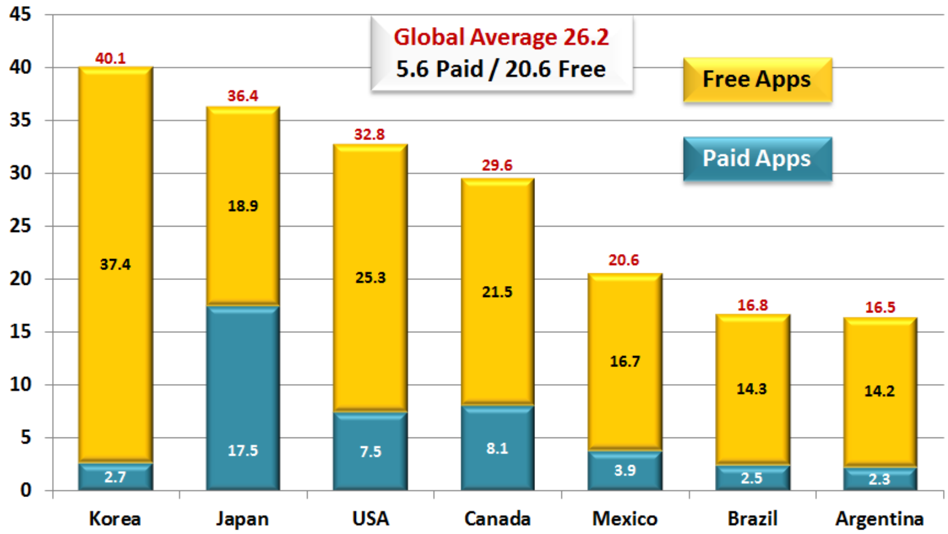

Figure 2.5. Average Number of Installed Apps per Smartphone User in Selected Countries.[75]

By the end of 2013, the total count for mobile apps downloaded will reach 102 billion, according to projections, and that number pales in comparison to the number of app downloads expected by 2017, which is more than 268 million according to Gartner.[76] The chart below projects app downloads each year through 2017, using data from Gartner. The chart projects that the number of paid apps downloaded will increase slightly, but not as exponentially as the increase in free apps.

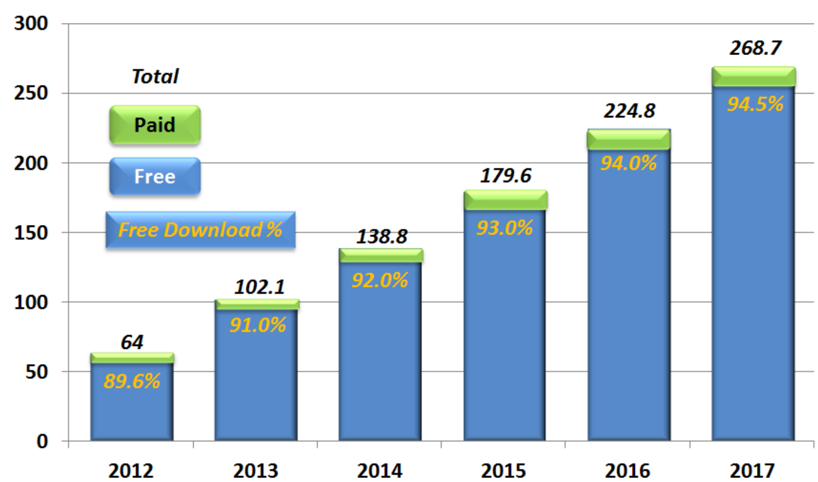

Figure 2.6. Estimated Mobile App Downloads Worldwide.[77]

Globally, smartphone and tablet mobile app expenditure will reach $15.5 billion by the close of 2013, which equates to more than the figures for 2010, 2011 and 2012 combined, reports Trusted Reviews.[78] According to the research from IHS,

75 Google's Our Mobile Planet chart generator. Data downloaded 8 November 2013

76 Gartner Says Mobile App Stores Will See Annual Downloads Reach 102 Billion in 2013. Gartner. 19 September 2013.

77 *Ibid.*

78 Smartphone users will spend nearly £100 billion on apps this year. Trusted Reviews. 16 October 2013.

over 90 billion smartphone and tablets apps will be downloaded during 2013, doubling last year's total of 49 billion.[79] Apple's App Store and the Google Play Store account for 85 percent of this expenditure, as they are the leading providers across the world.[80]

In October 2013, Apple reported that 60 billion apps have been installed since the iTunes App Store opened in July 2008. In May, Google reported that their Play Store download total had reached 48 billion. Overall, it would seem that 120 billion apps have probably been installed by iOS and Android users. On iOS alone, over 60 million apps are downloaded for the first time every day.[81]

A fall 2013 study from the Pew Research Center's Internet & American Life Project illustrates the relevance of mobile apps for consumer engagement. With nine in 10 American adults owning a cellphone as of 2013, consumers are beginning to use these devices for an increasingly broader number of everyday tasks. Sending and receiving text messages only scratches the tip of the iceberg, with many Americans using apps to get directions to places, find product and service recommendations, listen to music, participate in video chats and "check-in" to share their locations. A whopping 50 percent of cell phone owners now download apps, which has more than doubled from the 22 percent who did so in 2009. When entrepreneurs consider the fact that only approximately 60 percent of mobile subscribers have app-friendly smartphones, it is clear that the number will grow over the next few years.[82]

It is also worth noting that young millennial consumers between the ages of 18 and 29 are even more likely to download and use apps. Approximately three-fourths or 77 percent of cell phone owners in this age bracket have downloaded apps to their mobile devices. This age range is typically the target audience for many businesses, as these consumers often have fewer life responsibilities and more disposable income to spend. Mobile apps can be a pivotal means of engaging millennials in that regard.[83] Millennials consume the majority of their video content via smartphone (about 20 percent), just over 15 percent via tablet devices, just under 15 percent via PC, less than 10 percent via live TV, and less than 7.5 percent via DVR devices, according to research from digital ad firm YuMe and the IPG Media Lab.[84] Viewing videos via smartphone is not relegated to mobile situations; 99 percent of millennials reported watching videos at friends' homes, with in-person social video viewing.[85] The use of smartphones has become so multi-functional that it is replacing the TV remote.

Juniper Research reported that the number of users of mobile video calling services is forecast to increase four-fold to almost 160 million by 2017, driven by improvements in both the user-interface and the underlying technology.[86]

The largest and fastest growing mobile data traffic segment is video. Average values from measurements in a selected number of commercial HSPA and LTE networks in Asia, Europe and the Americas showed that regardless of device type, video was the largest contributor to traffic volumes (30-50 percent).[87] It is expected to increase by around 55 percent annually up until the end of 2019, at which point it is forecasted to account for more than 50 percent of global mobile traffic.[88]

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79 *Ibid.*
80 *Ibid.*
81 Appocalypse Now, Howard Dediu, 28 October 2013.
82 More Americans downloading mobile apps, capturecode, 17 October 2013.
83 *Ibid.*
84 Millennials Point Toward Mobile-First Future. Online Media Daily, Gavin O'Malley. 13 November 2013.
85 *Ibid.*
86 Mobile Video Calling Users to Exceed 160 Million by 2017 Finds New Juniper Research Report. Juniper Research. 5 February 2013.
87 Ericsson's Mobility Report. 11 November 2013.
88 *Ibid.*

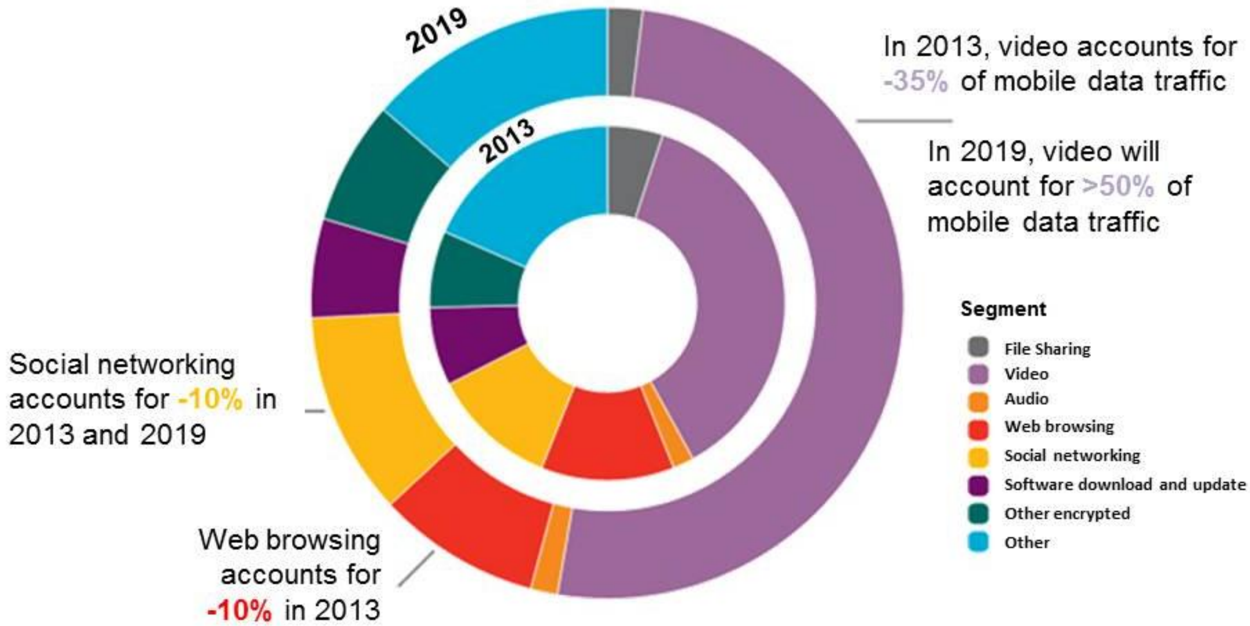

Figure 2.7. Mobile Application Traffic Outlook.[89]

Music streaming is gaining popularity, but functions such as caching of content and offline playlists limit the impact on traffic growth. Audio traffic is still expected to increase at an annual rate of around 40 percent, which is in line with the total mobile traffic growth.[90]

Today, web browsing and social networking each constitutes around 10 percent of total mobile data traffic. The share will remain at the same level in 2019, even though a typical web page will increase in data volume and social networking increasingly will include data-rich content.[91]

For smartphones, social networking is already the second largest traffic volume contributor with an average share of over 15 percent in these networks. During 2013, the percentage of both social networking traffic on smartphones and video traffic on tablets and mobile PCs has increased. Traffic drawn from mobile PCs is notable for having higher file sharing activity than other devices. Online audio and email are important contributors to data traffic on tablets and smartphone devices. The part of file sharing that is associated with smartphones and tablets are predominantly from tethering traffic.[92]

Vertical markets have been taking major steps to make use of the benefits offered by the mobile computing space. Significant work is taking place in areas such as mHealth, mRetail, mCommerce, mEducation, mEnergy and others. Innovative startups have made use of the computing capabilities of devices to turn them into full-fledge medical instruments.

By a vast margin, North America remains the dominant sales region for mobile video surveillance equipment, according to a recent report from IHS, a global market research firm. In 2012, the U.S. and Canada contributed $346.6 million in revenue or 70 percent of the global share. The report predicts that by 2017, North American sales will climb to $489 million, compared to $116.2 million for Europe, the Middle East and Africa, and $91.8 million for Asia. School buses

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89 Ericsson's Mobility Report. 11 November 2013.
90 *Ibid.*
91 *Ibid.*
92 *Ibid.*

represent a particularly fertile North American vertical, if only because the market is primarily U.S. specific. The other major vertical driving growth in mobile video surveillance is police cars.[93]

As previously covered in this section, data traffic is expected to continue growing significantly. The introduction of laptops, tablets and high-end mobile handsets onto mobile networks are key drivers of traffic, since they offer content and applications not supported by the previous generations of mobile devices.

2.5 MOBILE BROADBAND DEPLOYMENTS AND SPECTRUM

LTE has seen the most aggressive deployment of any mobile technology in history. From the first launch of LTE by TeliaSonera in Sweden and Norway in 2009, the technology deployments have grown consistently. In the chart below, the deployments of LTE are shown on an annual timeline since the first launch in 2009.

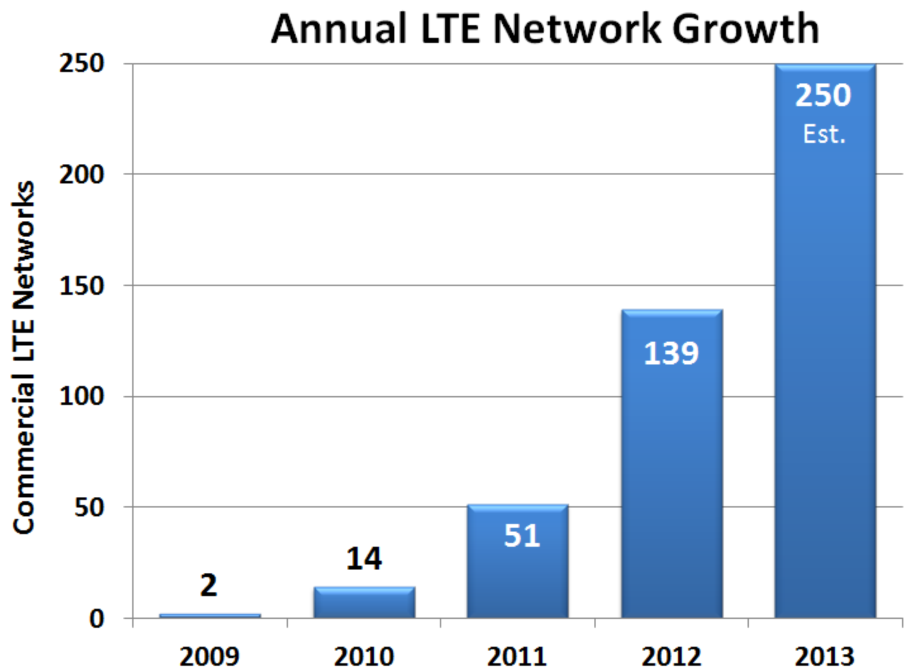

Figure 2.8. Annual LTE Network Growth.

The reasons for LTE's success include the careful development of the 3GPP standards. The challenge has been the allocation by governments of premium internationally harmonized licensed spectrum. In fact, the ITU studied the spectral requirements for the growing demand of wireless data and confirmed that there is a gross deficit in current allocations in many countries.

There is an impending spectrum crisis as pressure on spectrum resources increases, almost forcing operators to invest in the most efficient technologies. LTE can be deployed in existing 2G or 3G bands through refarming and in new spectrum (e.g., 2.6 GHz or digital dividend bands—700 or 800 MHz depending on region) and for that reason, there is growing concern and interest in the allocation of globally harmonized spectrum bands for LTE. In the U.S., LTE typically uses the 700 MHz (primarily band 13 or band 17) or AWS (1.7/2.1 GHz) bands. New digital dividend spectrum is being allocated in Europe, Asia and elsewhere, enabling extended geographical coverage and improved in-building performance. Commercial LTE services are running on several networks using 800 MHz (band 20), often targeting rural broadband needs and improved indoor coverage. The capacity band in most regions is 2.6 GHz. There is high interest in refarming

[93] North America Owns 70 Percent of Mobile Video Surveillance Market. Security Systems News. 7 October 2013.

2G spectrum for LTE, especially 1800 MHz, and in a few cases, 900 MHz. Most regulators adopt a technology neutral approach. Initial LTE FDD deployments in Japan use 800/850 MHz, 1.5 GHz, 1.7 GHz and 2.1 GHz (operator dependent). New 700 MHz (APT700) spectrum has been allocated ready for future use. 1800 MHz may be the most widely used band for LTE deployments globally. LTE on the 1800 MHz band serves subscribers on around 43 percent of all LTE networks worldwide.[94]

Once governments successfully auction spectrum, more operators will be deploying LTE. There are more than 440 operators worldwide who have announced their commitment to deploy LTE in the future. Appendix B has a complete list of LTE commitments and deployments.

In its *Report ITU-R M. 2078*, the International Telecommunication Union (ITU) outlines the need for a minimum amount of spectrum for the years 2010, 2015 and 2020 depending on the market development status (referring to two Radio Access Techniques Groups, RATG1 and RATG2). For the sake of simplicity, the markets are categorized as either lower market setting or higher market setting.

Table 2.1. Predicted spectrum requirements for IMT and IMT-Advanced Technologies.[95]

Market Setting	**Spectrum Requirement for RATG 1 (MHz)**			**Spectrum Requirement for RATG 2 (MHz)**			**Total Spectrum Requirement (MHz)**		
Year	***2010***	***2015***	***2020***	***2010***	***2015***	***2020***	***2010***	***2015***	***2020***
Higher Market Setting	840	880	880	0	420	840	840	1300	1720
Lower Market Setting	760	800	800	0	500	480	760	1300	1280

The target spectrum requirements represent the total amount of spectrum in a given country market. An example of a country that would fall into the category of a higher market setting would be the U.S., and its need for additional spectrum is evident. New services and applications, new devices and continued increases in usage of smartphones, tablets and connected machines are only amplifying the need for additional spectrum.[96]

Of growing significance is the deployment of LTE TDD which does not used paired licensed bands such as LTE FDD. As of December 2013, there were 25 commercial LTE TDD networks of which 12 are both LTE TDD and LTE FDD. The following table shows the numerous bands in which LTE has been deployed worldwide.

94 Evolution to LTE Report. GSA. 17 October 2013.
95 Report ITU-R M. 2078. International Telecommunications Union. 4 October 2007.
96 *Ibid.*

Table 2.2. LTE TDD and FDD Bands.[97]

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
29	N/A			717 MHz	–	728 MHz	FDD[2]
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD

NOTE 1: Band 6 is not applicable
NOTE 2: Restricted to E-UTRA operation when carrier aggregation is configured. The downlink operating band is paired with the uplink operating band (external) of the carrier aggregation configuration that is supporting the configured Pcell.

97 3GPP Technical Specification 36.105, V11.4.0

4G Americas published a white paper titled, *Meeting the 1000X Data Challenge* in October 2013 that provides detailed information on the necessity for spectrum in addition to the enhancements available for 3GPP technologies to achieve a solution to the increasing pressure on network operators for capacity issues.[98]

2.6 MILESTONES FROM RELEASE 99 TO RELEASE 12: UMTS/EVOLVED HSPA (HSPA+) AND LTE/EPC/LTE-ADVANCED

This section summarizes the commercial progress of the 3GPP standards beginning with Rel-99 through Rel-12 and includes several important milestones in the industry. It is historical in nature, building to the success of LTE as the next generation global mobile industry standard and the ongoing commercialization of LTE-Advanced.

Leading manufacturers and service providers worldwide support the 3GPP evolution. To illustrate the rapid progress and growth of UMTS, participating 4G Americas member companies have each provided detailed descriptions of recent accomplishments on Rel-99 through Rel-12, which are included in Member Progress of this white paper.

2.6.1 HSPA AND HSPA+ PROGRESS TIMELINE

The 3GPP Rel-99 UMTS specifications were initially standardized in early to mid-1999 and published by 3GPP in March 2000, establishing the evolutionary path for GSM, General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE) technologies. Rel-99 enabled more spectrally efficient and better performing voice and data services through the introduction of a 5 MHz UMTS carrier.

Rel-4, completed in March 2001, introduced call and bearer separation in the Core Network. Rel-5 introduced significant enhancements to UMTS, including HSDPA, IP Multimedia Subsystem (IMS) and Internet Protocol (IP) UTRAN and was published in March 2002.[99] Rel-6, completed in March 2005, introduced further enhancements to UMTS HSUPA (High Speed Uplink Packet Access or E-DCH), MBMS and Advanced Receivers.[100]

Uplink speeds for HSUPA increased from peak 2 Mbps initially, up to 5.8 Mbps using 2 milliseconds (ms) Transmission Time Interval (TTI). HSUPA eliminates bottlenecks in uplink capacity, increases data throughput and reduces latency resulting in an improved user experience for applications such as gaming, VoIP, etc.

HSPA Rel-6 mobile broadband equipment supports peak theoretical throughput rates up to 14 Mbps downlink and up to 5.8 Mbps uplink, capabilities that are typically added to existing networks using a simple software-only upgrade, which can be downloaded remotely to the UMTS Radio Network Controller (RNC) and NodeB.

Most leading operators moved forward with deployment of Rel-7 HSPA+. Nearly all vendors have existing NodeB modules that are already HSPA+ capable and the activation is done on a software-only basis.

For HSPA, Rel-9 introduced support for uplink dual-cell, as well as the capability to enable downlink dual-cell deployments across non-contiguous frequency bands. Also added in Rel-9 was the support of simultaneous MIMO and Dual Carrier-High Speed Packet Access (DC-HSPA) operation, as well as enhancements to the transmit diversity modes to improve performance with non-MIMO capable devices.

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98 Meeting the 1000X Challenge: The Need for Spectrum, Technology and Policy Innovation. 4G Americas. October 2013.

99 3GPP Rel-5 and Beyond - The Evolution of UMTS. 3G Americas. November 2004.

100 The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond. 3G Americas. December 2005.

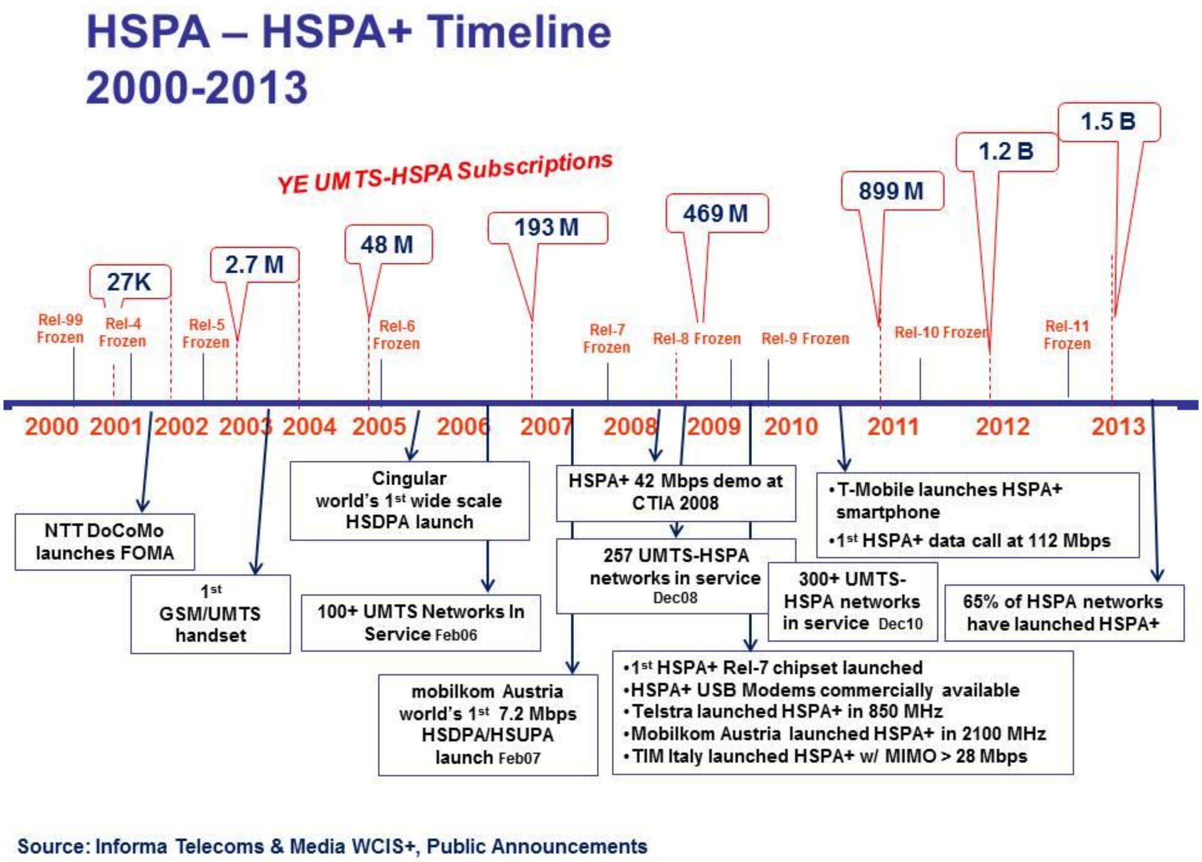

Figure 2.9. HSPA – HSPA+ Timeline 2000-2013.

The first commercial deployment of UMTS networks began with the launch of FOMA by NTT DoCoMo in 2001, with 2003 as the year when Rel-99 UMTS networks were more widely commercialized. The number of commercially deployed UMTS systems grew rapidly, as substantiated by more than 370 commercial UMTS networks as of year-end 2010.

In November 2003, HSDPA was first demonstrated on a commercially available UMTS base station in Swindon, U.K. It was first commercially launched on a wide-scale basis by Cingular Wireless (now AT&T) in December 2005 with notebook modem cards, followed closely thereafter by Manx Telecom and Telekom Austria. In June 2006, "Bitė Lietuva" of Lithuania became the first operator to launch HSDPA at 3.6 Mbps, which at the time was a record speed. As of December 2013, there were more than 543 commercial HSPA networks in 199 countries (see Appendix B). Nearly all UMTS deployments are upgraded to HSPA and the point of differentiation has passed; references to HSPA are all-inclusive of UMTS.

Initial network deployments of HSDPA were launched with PC data cards in 2005. HSDPA handsets were made commercially available in Q2 2006 with HSDPA handhelds first launched in South Korea in May 2006 and later in North America by Cingular (now AT&T) in July 2006. In addition to offering data downloads at up to 1.8 Mbps, the initial handsets offered such applications as satellite-transmitted Digital Multimedia Broadcasting (DMB) TV programs, with two to three megapixel cameras, Bluetooth, radios and stereo speakers for a variety of multimedia and messaging capabilities.

Mobilkom Austria completed the first live HSUPA demonstration in Europe in November 2006. One month later, the first HSUPA mobile data connection on a commercial network (of 3 Italia) was established. In 2007, Mobilkom Austria launched the world's first commercial HSUPA and 7.2 Mbps HSDPA network in February, followed by commercial 7.2 USB modems in April and 7.2 data cards in May. There were numerous announcements of commercial network upgrades to Rel-6 HSUPA throughout 2H 2007 and as of December 2008, there were 60 commercial networks and 101 operators who had already announced plans to deploy HSUPA.[101] AT&T was the first U.S. operator to deploy enhanced upload speeds through HSUPA in its HSPA networks in 2007 with average user upload speeds between 500 kbps and 1.2 Mbps and average user download speeds ranging up to 1.7 Mbps.

The ecosystem of HSPA devices continues to expand and evolve. As of December 2013, suppliers commercially offered more than 4,000 devices,[102] including smartphones, data cards, notebooks, wireless routers, USB modems, embedded modules and supporting speeds up to 42 Mbps on the downlink.

HSPA base stations support most IMT frequency bands including the 1.7/2.1 GHz Advanced Wireless Spectrum (AWS) band and the 700 MHz band in the U.S. and Canada. A top vendor has been providing LTE-capable multi-standard base stations since 2001, offering many options to operators, including a smooth transition to new technology while minimizing Operating Expenses (OPEX) and reducing environmental impact.

Over the course of 2006 to 2007, there was significant progress on Rel-7 standards which were finalized in mid-2007. Rel-7 features were commercially introduced as HSPA+ and trials began as early as Q3 2007, including several planned commercial announcements made in the 2007 to 2008 timeframe. The world's first data call using HSPA+ was completed in July 2008, achieving a data transfer rate of more than 20 Mbps in a 5 MHz channel. The industry's first HSPA+ Rel-7 chipset was launched in early 2009 which set the state for the first commercial launch of HSPA+ by Telstra. In February 2009, Telstra in Australia became the first operator in the world to launch Rel-7 HSPA+ using the 850 MHz band and a data card, and one month later in Austria, Mobilkom launched in the 2100 MHz band; both operators initially provided peak theoretical downlink speeds of 21 Mbps. Rogers was the first mobile operator in the Americas to commercially launch HSPA+ at 21 Mbps in July 2009, more than doubling the speeds of its HSPA network. By the end of 2009, there were 38 commercial launches of HSPA+ in 24 countries including Rogers, Telus and Bell Canada, as well as T-Mobile USA in North America. By the end of 2010, the number of commercial launches of HSPA+ had risen to 103 worldwide in 54 countries. That number stood at 354 commercial HSPA+ networks (21 Mbps or higher peak theoretical speeds) in 153 countries as of December 2013 (see Appendix B).

T-Mobile USA launched its first HSPA+ Rel-7 market in Philadelphia in the fall of 2009, beginning a nationwide rollout of the technology throughout 2010 with the goal of deploying HSPA+ across the breadth of its 3G footprint, covering 100 metropolitan areas and 185 million people. In November 2011, T-Mobile USA announced that its HSPA+ network at 21 Mbps covered more than 200 million people in 208 markets including dual-carrier HSPA+ at 42 Mbps available for nearly 180 million Americans in 163 markets. In February 2012, T-Mobile announced a $4 billion 4G network evolution plan, which included the installation of new equipment at 37,000 cell sites with a deployment of HSPA+ at 42 Mbps in its PCS 1900 MHz band by refarming from GSM, while refarming its 1900 MHz Personal Communications System (PCS) and 1700 MHz AWS spectrum holdings to make room for LTE in 2013. In the second quarter of 2012, T-Mobile USA announced an agreement with Verizon Wireless for the purchase and exchange of certain AWS spectrum licenses which improved T-Mobile's network coverage in 15 of the top 25 markets in the U.S. T-Mobile also completed the AT&T "break up" deal of AWS license transfers that expanded T-Mobile's coverage in 12 of the top 20 U.S. markets. In October of 2012, T-Mobile also announced a spectrum exchange agreement with Leap Wireless International, Inc. that furthered 4G coverage in four states. This is a ideal example of how mobile network operators are compelled to piece together spectrum resources for their capacity requirements and future expansion.

The global breakdown of 543 total HSPA and HSPA+ network deployments as of December 2013 is as follows:

- HSPA (7.2 or 14.4) 186 deployments Rel-6
- HSPA+ (21 Mbps) 205 deployments Rel-7

[101] 4G Mobile Broadband Evolution: Release 10, Release 11 and Beyond - HSPA+, SAE/LTE and LTE-Advanced, Global Deployment Status HSPA-LTE, Appendix B. 4G Americas. 1 September 2012.
[102] WCDMA-LTE Press Backgrounder. Ericsson. February 2013.

- HSPA+ (28 Mbps) 4 deployments Rel-7
- HSPA+ (42 Mbps) 148 deployments Rel-8

Hence, the advantages of HSPA+ include its cost-efficient scaling of the network for rapidly growing data traffic volumes, the ability to work with all HSPA devices and an improved end-user experience by reducing latency. The majority of HSPA operators have deployed HSPA+, and in fact, the percentage of HSPA operators who had commercially launched HSPA+ was at 65 percent by December 2013.

In Rel-11, HSPA+ introduces new capabilities including eight-carrier downlink operation, downlink 4-branch MIMO to double maximum theoretical downlink rates to 336 Mbps, downlink multi-flow transmission, uplink dual-antenna beamforming, uplink MIMO with 64-Quadrature Amplitude Modulation (64QAM), several CELL_FACH (Forward Access Channel) state enhancements (for smartphone type traffic) and non-contiguous HSDPA carrier aggregation. Detailed information on these features is presented in *Section 3* of this white paper.

2.6.2 LTE AND LTE-ADVANCED PROGRESS TIMELINE

After 3GPP approved specifications for Rel-8 standards in January 2008, work continued throughout the year, and in March 2009, the completed final standards on HSPA+, LTE and EPC/SAE enhancements were published.

Rel-8 saw the introduction of the Evolved Packet System (EPS) consisting of a new flat-IP core network called the Evolved Packet Core (EPC) coupled with a new air interface based on Orthogonal Frequency Division Multiplexing (OFDM), called Long Term Evolution (LTE) or Evolved UTRAN (E-UTRAN). The EPS architecture was designed to not only provide a smooth evolution from the 2G/3G packet architectures consisting of NodeBs, RNCs, Serving GPRS Support Nodes (SGSNs) and Gateway GPRS Support Nodes (GGSNs), but also provide support for non-3GPP accesses (e.g. Wi-Fi), improved policy control and charging, a wider range of QoS capabilities, advanced security/authentication mechanisms and flexible roaming.

In Rel-8, LTE defined new physical layer specifications consisting of an OFDMA based downlink and SC-FDMA[103] based uplink that supports carrier bandwidths from 1.4 MHz up to 20 MHz. Rel-8 defined options for both FDD and TDD LTE carriers. Rel-8 also defined a suite of MIMO capabilities supporting open and closed loop techniques, Spatial Multiplexing (SM), Multi-User MIMO (MU-MIMO) schemes and Beamforming (BF). Because OFDMA and Synchronization Channel-Frequency Division Multiple Access (SC-FDMA) are narrowband based technologies, LTE supports various forms of interference avoidance or coordination techniques called Inter-Cell Interference Coordination (ICIC).

Rel-8 has provided several other enhancements related to Common IMS, Multimedia Priority Service (MPS), support for packet cable access and service brokering, Voice Call Continuity (VCC) enhancements, IMS Centralized Services (ICS), Service Continuity (SC) voice call continuity between LTE-HSPA VoIP and CS domain (called Single Radio VCC or SRVCC) and User Interface Control Channel enhancements. Voice over LTE (or VoLTE) with Single Radio Voice Call Continuity (SRVCC) to improve voice coverage by handing over the voice session from LTE to 2/3G CS domain was standardized in Rel-8.

Live 2X2 LTE solutions in 20 MHz for Rel-8 were demonstrated in 2008. Among the new exciting applications demonstrated on LTE networks at various bands, including the new 1.7/2.1 GHz AWS band, were: HD video blogging, HD video-on-demand and video streaming, multi-user video collaboration, video surveillance, online gaming and even CDMA-to-LTE handover displaying the migration possible from CDMA and EV-DO to LTE.

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[103] SC-FDMA was chosen for the uplink instead of OFDMA in order to reduce peak-to-average power ratios in device amplifiers, thus improving battery life.

One of key elements of the LTE/SAE network is the new enhanced base station, or Evolved NodeB (eNodeB), per 3GPP Rel-8 standards. This enhanced BTS provides the LTE interface and performs radio resource management for the evolved access system. The eNodeB base stations offer a zero footprint LTE solution, addressing the full scope of wireless carriers' deployment needs and providing an advanced LTE RAN solution to meet size and deployment cost criteria. The flexible eNodeB LTE base stations support FDD or TDD and are available in a range of frequencies from 700 MHz to 2.6 GHz with bandwidths from 1.4 MHz to 20 MHz. The first Rel-8 compliant LTE eNodeB ready for large-scale commercial deployment was launched in July 2009 and was capable of supporting a peak theoretical rate of up to 150 Mbps on the downlink.

In Rel-9, features and capabilities were added as enhancements upon the initial Rel-8 LTE technology, specifically:

- The support of emergency services, location services and emergency warning broadcast services. These features are critical for introducing VoIP over LTE because they are required for VoLTE to meet e911 requirements
- Enhancements (particularly for idle mode camping) to the Circuit Switched Fall Back (CSFB) feature that was introduced in Rel-8
- MBMS to enable broadcast capabilities over LTE
- Self-Organizing Network (SON) enhancements to optimize handover performance, improve load balancing capabilities (within LTE and between LTE and 2G/3G), optimize Random Access Channel (RACH) performance and improve energy savings

Other enhancements include the support of dual layer beamforming to improve peak rates when in beamforming mode, the support of vocoder rate adaptation based on cell loading, architecture enhancements in support of Home NodeB/eNodeB (i.e. femtocells), IMS enhancements to IMS Centralized Services and IMS Service Continuity, Universal Subscriber Identity Module (USIM) enhancements for M2M, femtocells and Near Field Communications (NFC).

As operators evolve their networks toward LTE and EPS architecture and consider software solutions, they can build upon the capabilities of their proven Home Location Register (HLR) to incorporate carrier-grade Remote Authentication Dial In User Service for Authentication, Authorization, and Accounting (RADIUS AAA) for packet-switched traffic, Diameter-based AAA and Home Subscriber Server (HSS) support for the IMS core. Inclusive functional suites take full advantage of the communications and media software solutions to ensure data-level coherence and behavioral consistency of the overall mobility management solution across all access domains and technology generations. Linked with pan-generational mobility and data management products that are able to service multiple fixed and mobile access domains, operators can leverage the Communication and Media Solutions (CMS) Policy Controller to assure Quality of Service (QoS) and provide a fine degree of control for service offerings consistent with the Open Mobile Alliance (OMA) and 3GPP Rel-8 specifications.

The increasing traffic challenge for operators is how to manage their network traffic. Solutions are being offered for agile intelligent mobile networks, solutions like web optimizers that will support Rel-8 and beyond networks by using compression, caching and transcoding techniques to increase data transfer rates while decreasing the amount of traffic flowing over the network. Web and media optimizing are intelligent, content-aware solutions that work to automatically trigger optimization when the network reaches pre-determined thresholds. Media optimization will address the growing richness of the mobile internet video content.

The first live demonstrations of the future-proof solutions that formed an integral building block for the Evolved Packet Core (EPC) or System Architecture Evolution (SAE) occurred at the Mobile World Congress (MWC) and Cellular Telecommunication Industry Association (CTIA) Wireless in 2007, including support for an integrated Voice Call Continuity (VCC) solution for GSM-WLAN handover. In November 2007, LTE test calls were completed between infrastructure vendors and device vendors using mobile prototypes representing the first multivendor over-the-air LTE interoperability testing initiatives. Field trials in realistic urban deployment scenarios were created for LTE as early as December 2007. With a 2X2 MIMO antenna system, the trials reached peak data rates of up to 173 Mbps and more than 100 Mbps over distances of several hundred meters. Trials demonstrated that future LTE networks could run on existing base station sites.

Many lab and field trials for LTE were conducted in 2008. By the end of 2009, more than 100 operators had indicated their intentions to trial or deploy LTE, and that number grew to more than 350 operators by September of 2012. (For a complete list of LTE commitments and deployments see Appendix B.) TeliaSonera launched the first commercial LTE networks in Oslo, Norway and Stockholm, Sweden in December 2009. In August 2012, the milestone of 100 commercial LTE networks, including 9 Time Division LTE (TD-LTE) networks, was achieved and by August 2013, commercial LTE networks topped 200. As of December 2013, there were 252 commercial LTE networks worldwide including 25 LTE TDD systems in 20 countries, 12 of which were combined LTE-TDD and LTE-FDD networks.

In October 2009, T-Mobile completed testing on the world's first LTE Self-Organizing Network (SON) in Innsbruck, Austria. Also in October, a manufacturer announced a revolutionary base station commissioning process called "SON Plug and Play." AT&T employed SON solutions on its network, optimizing its UMTS RAN. In 2012, AT&T and other leading service providers expanded this SON solution to support their LTE mobile internet products with numerous additional deployments throughout 2013.

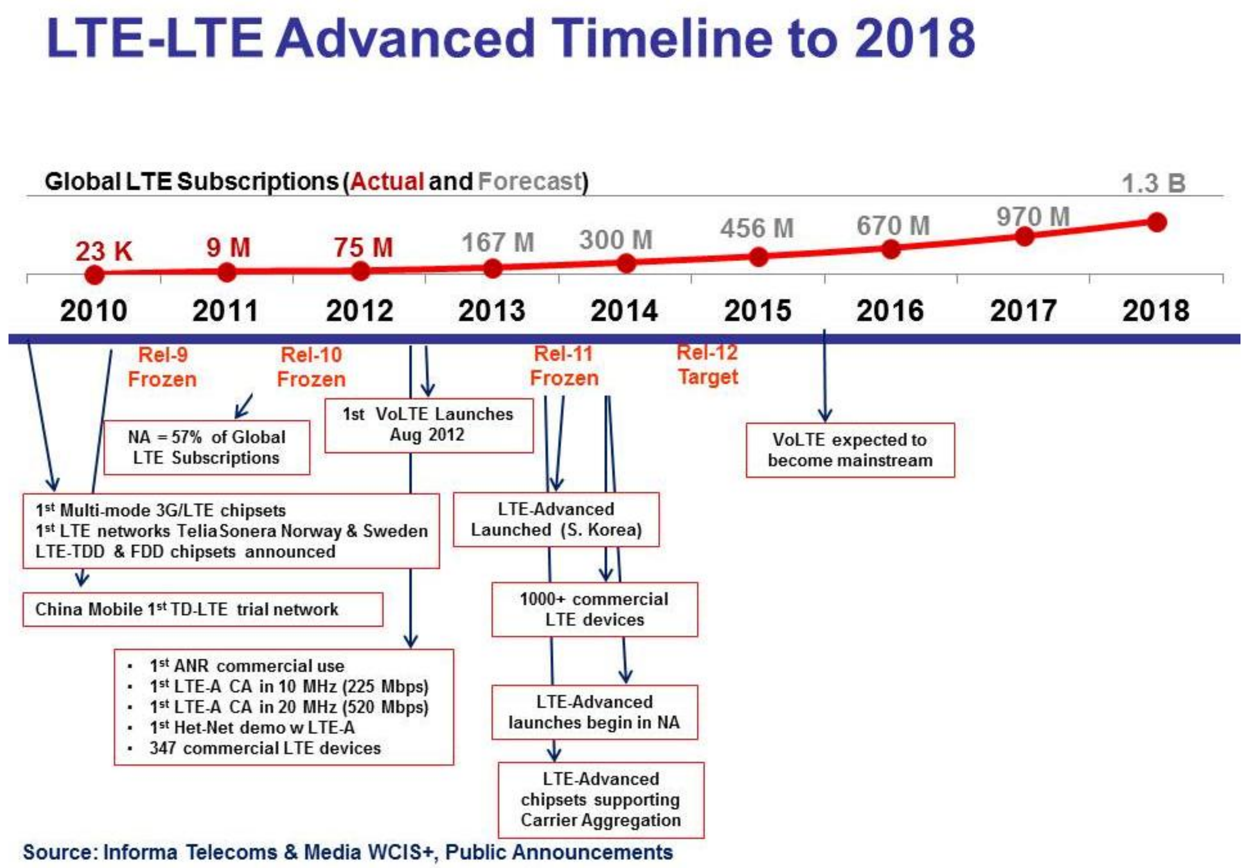

Figure 2.10. LTE and LTE-Advanced Timeline 2010-2018.

Evolved Packet Core (EPC) is the IP-based core network defined by 3GPP in Rel-8 for use by LTE and other access technologies. The goal of EPC is to provide simplified all-IP core network architecture to efficiently give access to various services such as the ones provided in IMS. EPC consists essentially of a Mobility Management Entity (MME), a Serving Gateway (S-GW) that interfaces with the E-UTRAN and a Public Data Network Gateway (P-GW) that interfaces to external packet data networks. EPC for LTE networks were announced by numerous vendors beginning in February 2009, allowing operators to modernize their core data networks to support a wide variety of access types using a common core network. EPC solutions typically include backhaul, network management solutions, video solutions that monetize LTE investment and a complete portfolio of professional services.

Telstra, Australia was first to go live in September 2011 with a combined GSM, UMTS-HSPA, LTE core and triple-access SGSN-MME pool based on a leading vendor's portfolio, thereby leading in the commercialization of the EPC.

VoLTE is expected to become mainstream in 2015; as of year end 2013, VoLTE was deployed in South Korea by SK Telecom, LG U+ and KT Corp. MetroPCS in the U.S. offered VoLTE service in 2013 on select devices and T-Mobile has stated it will continue to maintain VoLTE service for its MetroPCS division.

3GPP LTE Rel-10 and beyond, also known as LTE-Advanced, is intended to meet the diverse requirements of advanced applications that will become common in the wireless marketplace in the foreseeable future. It will also dramatically lower the Capital Expenses (CAPEX) and Operating Expenses (OPEX) of future broadband wireless networks. Moreover, LTE-Advanced will provide for backward compatibility with LTE and will meet or exceed all IMT-Advanced requirements. 3GPP Release 10 was functionally frozen (Stage 3 ratified) in March 2011.

Detailed information of these LTE Rel-10 enhancements is available in the 4G Americas' October 2012 white paper, *4G Mobile Broadband Evolution*, in Section 5.

While 3GPP Rel-9 focused on enhancements to HSPA+ and LTE, Rel-10 focuses on the next generation of LTE for the ITU's IMT-Advanced requirements and both were developed nearly simultaneously by 3GPP standards working groups. Several milestones have been achieved by vendors in recent years for both Rel-9 and Rel-10.

Vendors anticipate that the steps in progress for HSPA+ will lead up to 168 Mbps peak theoretical downlink throughput speeds and more than 20 Mbps uplink speeds in Rel-10. At Mobile World Congress 2010, the world's first HSPA+ data call with a peak throughput of 112 Mbps was demonstrated by a leading vendor.

Vendors are already progressing beyond LTE with the next generation of technologies in Rel-10 for IMT-Advanced, called LTE-Advanced, demonstrating that the evolution of LTE is secure and future-proof. In October 2009, 3GPP submitted LTE-Advanced to the ITU as a proposed candidate IMT-Advanced technology. The final ratification by the ITU of LTE-Advanced (Rel-10) as 4G IMT-Advanced occurred in November 2010 and for which specifications became available in 2011.

Milestones have already been achieved in the commercialization of Rel-10 and beyond. As early as December 2008, researchers conducted the world's first demonstration of Rel-10 LTE-Advanced technology, breaking new ground with mobile broadband communications beyond LTE. A leading infrastructure company's researchers successfully demonstrated Relaying technology proposed for LTE-Advanced in Germany. The demonstration illustrated how advances to Relaying technology could further improve the quality and coverage consistency of a network at the cell edge where users were furthest from the mobile broadband base station. Relaying technology, which can also be integrated in normal base station platforms, is cost-efficient and easy to deploy as it does not require additional backhaul. The demonstration of LTE-Advanced indicated how operators could plan their LTE network investments knowing that the already best-in-class LTE radio performance, including cell edge data rates, could be further improved and that the technological development path for the next stage of LTE is secure and future-proof.

There were five commercial LTE-Advanced networks (Feb 2014); SK Telecom and LG U+ in South Korea launched the first commercial LTE-Advanced networks with capable devices and carrier aggregation in July 2013; KT Corp (South Korea) launched in August 2013, followed by EE (UK) in November 2013 and Saudi Telecom Company (Saudi Arabia) in February 2014. It is expected that in North America, the four major carriers—AT&T, T-Mobile, Verizon and Sprint—will deploy LTE-Advanced based on 3GPP Release 10 standards in 2014.

AT&T's entire LTE network architecture was ready to be upgraded to LTE-Advanced Release 10 and beyond via software patches as of third quarter 2013. In addition, AT&T reported in October 2013 their plans to trial carrier aggregation technology in 2013, although, they did not state which spectrum bands would be involved in the trials, other than it would likely involve high-band and low-band spectrum. AT&T's holding stretches from 700 MHz to 2.3 GHz.[104]

LTE Broadcast uses evolved Multimedia Broadcast Multicast Service (eMBMS) to allow the same content to be sent to a large number of subscribers at the same time, resulting in a more efficient use of network resources than each user requesting the same content, then having the content unicast to each user. AT&T disclosed plans in September 2013 to use the 700 MHz Lower D and E Block licenses it acquired in 2011 from Qualcomm for an LTE Broadcast service.[105]AT&T's focus now is almost "all about architecting networks to deliver video" and that will be where AT&T will spend much of its capital over the next three years. The company will develop a "broadcast capability" to remove video traffic from its wide area network. Timing of the launch of LTE Broadcast was not announced, although it was stated that, "you will see it mature in scale within the three-year time horizon." AT&T previously advised the Federal Communications Commission (FCC) in June 2013 that it cannot deploy LTE over its 700 MHz Lower D and E Block spectrum until mid-to-late 2014 because the necessary interoperability test cases for LTE Advanced carrier aggregation are still in development at 3GPP. Verizon expects to first deploy LTE Broadcast early in 2014.[106]

Other developments for LTE and LTE-Advanced include the following:

- The first video conversation using one vendor's branded lightRadio LTE technology was demonstrated by China Mobile to connect locations in China and the U.S.
- First launch of Automatic Neighbor Relation (ANR) into commercial use on LTE network in Cologne (February 2012)
- World's first SingleRAN WiMAX/LTE commercial network (Mobily in Saudi Arabia)
- World's first SingleSON trial on Hong Kong's GUL network (June 2012)
- World's first inter-band LTE-Advanced Carrier Aggregation (10 MHz @ 800 MHz and 20 MHz @ 2.6 GHz) conducted by Vodaphone with peak Downlink (DL) rates over 225 Mbps
- World's first LTE-Advanced Carrier Aggregation (20 MHz @ 2.6 GHz and 20 MHz @ 2.6 GHz, 4x4 MIMO) based on LTE TDD with peak DL rates over 520 Mbps by leading vendor

While Release 10 is the mainstay, LTE-Advanced is further refined in 3GPP Release 11. Rel-11 features were frozen in September 2012 with the core network protocols stable in December 2012 and radio access protocols stable in March 2013, though parts of the RAN may not have been complete until June 2013.

For LTE, Rel-11 provides enhancements to Rel-10 technologies such as CA, MBMS, SON and CoMP for coordinated scheduling and/or beamforming and better cell edge performance, Enhanced Physical Downlink Control Channel (EPDCCH) and Further Enhanced Inter-Cell Interference Coordination (FeICIC) for devices with interference cancellation.

Rel-11 also looks beyond phones and beyond the 3GPP technologies by addressing MTC/M2M, IMS and Wi-Fi integration, plus enhanced support for femtocells (Home NodeB and Home e-Node B).

104 AT&T expects to launch first volte smartphone this year. Fiercewireless, Phil Goldstein. 8 October 2013.
105 AT&T to use Lower 700 mhz D nd E Block spectrum for LTE Broadcast. Fiercewireless, Phil Goldstein. 24 September 2013.
106 *Ibid.*

LTE-Advanced progress is being made by numerous operators, some progress in commercial networks, such as SK Telecom's, and others in field tests, such as Turkcell's which reported peak speeds of 900 Mbps and approaching the 1 Gbps which is the official definition of '4G'. However, commercial LTE-Advanced deployments are actually implementing just a small subset of the large menu of options included in 3GPP Rel-10 and Rel-11 standards. The early focus is heavily on CA, with eICIC (for HetNets) and advanced MIMO also popular early choices. While LTE-Advanced will remain a small part of the commercial 4G landscape for a couple of years, confined to the most advanced and/or capacity-challenged Mobile Network Operators (MNOs), these efforts are certainly moving the technology forward at a faster rate than was seen in previous generations.

Telstra of Australia is another carrier pushing the limits in terms of wireless speeds in deploying carrier aggregation across its 900 MHz and 1.8 GHz bands and was the first CA deployment to use the combination of frequencies (both refarmed from 2G). Smart of the Philippines also tested LTE-Advanced and has already achieved downlink speeds of 209 Mbps in the lab. Other LTE operators, including LG U+ and KT, as well as SK Telecom (Korea), EE (U.K.) and Saudi Telecom Company (Saudi Arabia) also used LTE-Advanced carrier aggregation. SK Telecom has taken a leadership role as the first carrier to claim a commercial 'LTE-Advanced' service and was already reaping rewards from its early investments by the 1Q 2013 when they achieved 300,000 subscribers a month after launch, having doubled their 4G speeds to a peak of 150Mbps with carrier aggregation. Although as of February 2014, there were five LTE-Advanced commercial networks, many more LTE-Advanced launches are anticipated in 2014, with at least 25 in various stages of deployment in 2013.

2.7 3GPP RELEASE 12 STANDARDIZATION

Completion of the Stage 3 Rel-11 core specifications functional freeze in December 2012 capped a 21- month Work Item including a three month extension. Meanwhile, 3GPP held a June 2012 RAN Workshop on Release 12 and onwards to identify common requirements for future 3GPP radio access technologies. For Rel-12, an 18-month timeframe for completion has been planned, following the completion of Rel-11. This would put the core specifications freezing for Rel-12 in June of 2014, with the ASN.1 freezing for Rel-12 in September of 2014, as shown in Figure 2.11 below.

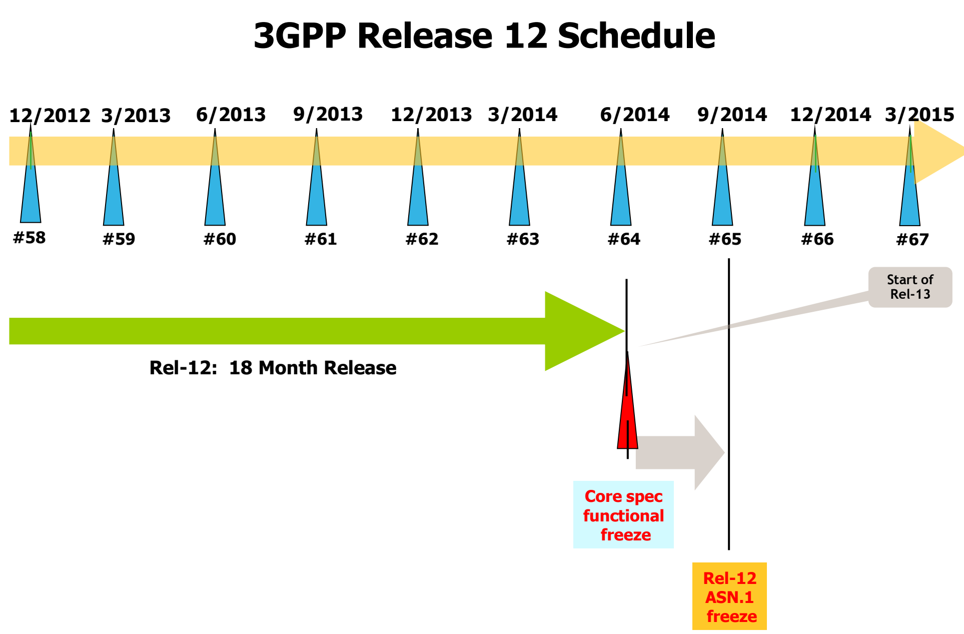

Figure 2.11. 3GPP Rel-12 Standardization Timeline

In line with the rapidly evolving uptake of mobile data consumption and the resulting stress this creates on operators' networks, most of the requirements were directly related to coping with this traffic explosion: capacity increase, energy saving, cost efficiency, the support for diverse application and traffic types, all coupled with higher user experience/data rates and enhancements of the backhaul required.[107]

There were more than fifty presentations by leading operators and equipment vendors with new proposals about interference coordination/management, dynamic TDD, frequency separation between macro and small cells, inter-site carrier aggregation, wireless backhaul for small cells and more. In addition, LTE multi-antenna and -site technologies such as 3D MIMO and beamforming, as well as further work needed on existing CoMP and MIMO specifications and future enhancements were debated. Other items included the aforementioned support for diverse traffic types (control signaling reduction and MTC), interworking between HSPA, Wi-Fi and LTE, and SON.

Overall, the high level strong themes coming from these workshops were for Release 12 to focus on enhancements in the following three broad categories: LTE small cell and heterogeneous networks; LTE multi-antennas (i.e., MIMO and beam forming); and LTE procedures for supporting diverse traffic types.

On the LTE small cell and heterogeneous networks side, both small cell enhancements and femto enhancements are being discussed. For small cells, potential enhancements to improve the spectral efficiency, mechanisms to ensure efficient operation of a small cell layer composed of small cell clusters, and synchronization mechanisms are being looked at. Dual connectivity to macro and small cell layers served by different or same carriers and identifying potential architecture (such as an Interface between eNBs (X2) gateway for Home eNodeBs (HeNBs)) and protocol enhancements are another topic. For both small cells and femto, mobility enhancements and SON (including load balancing topics) are featured in Release 12.

For Wi-Fi integration and interworking, there is a RAN level focus on the study of solutions enhancing mobility between LTE/UMTS and Wi-Fi for access points deployed and controlled by cellular operators and their partners. Prior to Rel-12, User Equipment (UEs) could already establish a PDN connection via a trusted WLAN or perform non-seamless offload with certain limitations. Rel-12 SaMOG addresses those limitations and enables flexibility by having two types of UEs: single PDN connection UEs and multiple PDN connection UEs. Next to this, optimized offloading to WLAN in 3GPP-RAT mobility by improved network and interface selection for this traffic was studied. Also studied were LIPA/SIPTO enhancements, including the offloading of the internet traffic from the RAN node itself through an embedded P-GW function, as well as enabling the offloading of the internet traffic through a P-GW function located above the RAN node.

As for LTE multi-antennas i.e., MIMO and beam forming, Active Antenna Systems (AAS) that introduce base stations using multiple transceivers on an antenna array to produce a radiation pattern that can be dynamically adjusted as well as downlink MIMO enhancements were considered. In the latter category it was found in simulations that enhanced Channel State Information (CSI) feedback gives benefits in dynamic network traffic conditions, e.g., with non-full buffer traffic. Two CSI feedback enhancements were agreed to be included in Rel-12: 4Tx Precoding Matrix Index (PMI) feedback codebook enhancement and aperiodic feedback (Physical Uplink Shared Channel (PUSCH) mode 3-2).

In the category LTE procedures for supporting diverse traffic types, Machine Type Communications (MTC) feature prominently. Included in Rel-12 are items on low cost and extended coverage (following a Study Item which started during the Rel-11 time-frame) and the evaluation of a few solutions identified as part of a system-wise work item on Machine Type and other mobile data applications' Communications Enhancements (MTCe). In particular the two areas involving RAN study were power consumptions optimizations and small data and device triggering enhancements. On the networks and service side, a third release of improvements is being developed for MTC devices and mobile data applications

[107] RP-120838, "Summary of 3GPP TSG-RAN Workshop on Release 12 and Onward," TSG-RAN Chairman, RAN#56, June 2012.

running in smart phones: device triggering enhancements and small data transmission (over Non Access Stratum (NAS)) and UE power consumption optimizations.

For broadcast traffic, two MBMS enhancements were looked at: 1) recovery in case a node/interface failure event happens in order to maintain the delivery of services and 2) measurements to be reported to the network in order to help monitor the signal quality at the UE.

Public safety, while not exactly a "diverse traffic type" nonetheless implies specific traffic patterns. The two main areas of 3GPP LTE enhancements for public safety are Proximity Services (ProSec, which includes RAN part) and Group Call System Enablers for LTE (GCSE_LTE).

Other LTE aspects such as UE enhancements, FDD and TDD carrier aggregation and TDD improvements, energy saving, policy and charging enhancements providing application awareness without service level signaling, Web Real-Time Communication (WebRTC) and new codecs, as well as so-called release independent features (e.g., carrier aggregation combinations) are also covered. Of course, UMTS is also evolving, with heterogenous network enhancements, scalability, uplink improvements, emergency warning, mobility and positioning as well as MTC for UTRAN and Dedicated Channels (DCH) enhancements rounding off the HSPA+ items.

Detailed information on the standardization work of Rel-12 and technical contents can be found in section 4 of this white paper; progress of the 3GPP standards by members of 4G Americas is presented in Appendix C.

3 STATUS OF 3GPP RELEASE 11: LTE-ADVANCED AND HSPA+ ENHANCEMENTS

3.1 LTE-ADVANCED ENHANCEMENTS

3.1.1 COORDINATED MULTI-POINT (COMP) TRANSMISSION AND RECEPTION

Coordinated Multi-Point transmission/reception (CoMP) is considered by 3GPP as a tool to improve coverage, cell-edge throughput and/or spectral efficiency. A study item was initiated in 3GPP to evaluate this technology in Rel-11, followed by a work item for Rel-11 which was completed in December 2012.

3.1.1.1 PRINCIPLE

The main idea of CoMP is as follows: depending on a UE's location, it may be able to receive signals from multiple cell sites, and the UE's transmissions may be received at multiple cell sites regardless of the system load. For the DL, if the transmissions from the multiple cell sites are coordinated, the performance can be increased significantly. This coordination can be simple, as in the techniques that focus on interference avoidance, or more complex, as in the case where the same data is transmitted from multiple cell sites. For the Uplink (UL), the system can take advantage of reception at multiple cell sites to significantly improve the link performance (e.g., through techniques such as interference cancellation). In the following sections, the CoMP architecture and the different CoMP schemes will be discussed.

3.1.1.2 COMP ARCHITECTURE

CoMP transmissions can be either intra-site or inter-site as shown in Figure 3.1. An advantage of intra-site CoMP is that a significant amount of information exchange is possible between the cooperating cells since backhaul connections between base stations are not involved. Inter-site CoMP involves the coordination of multiple sites for CoMP transmission. Consequently, the exchange of information involves backhaul transport. This type of CoMP may put additional burden and requirements upon the backhaul design.

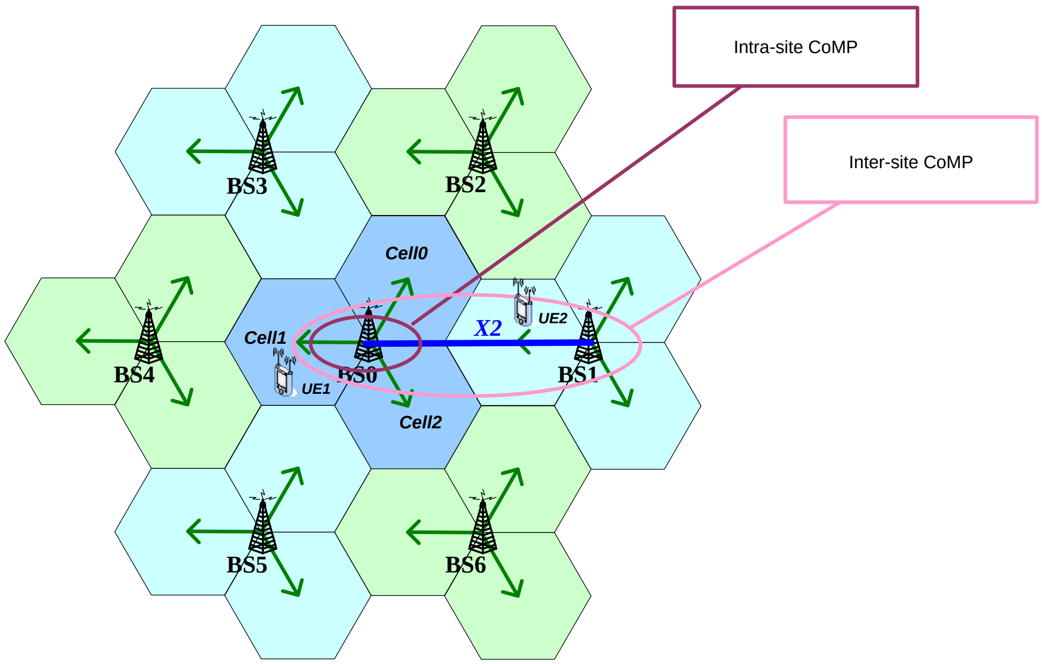

Figure 3.1. An Illustration of the Inter-Site and Intra-Site CoMP.

A special case of the inter-site CoMP architecture comprises a distributed Evolved NodeB (eNB), depicted in Figure 3.2. In this particular illustration, the Radio Remote Units (RRU) of an eNB are located at different locations in space. With this architecture, although the CoMP coordination is within a single eNB, the CoMP transmission can behave like inter-site CoMP instead.

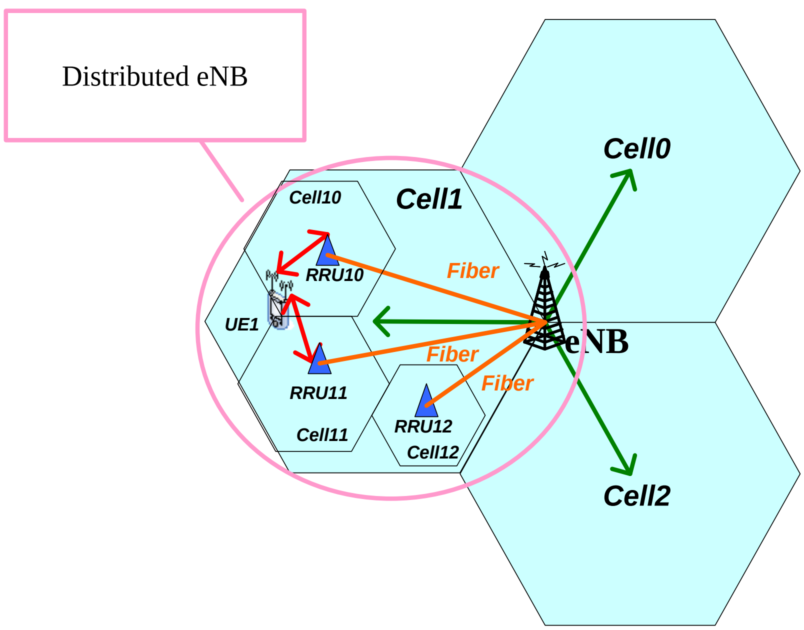

Figure 3.2. An Illustration of Intra-eNB CoMP with a Distributed eNB.

The following four scenarios were evaluated by 3GPP under the assumption of ideal backhaul characteristics:

- Scenario 1: Homogeneous macro-cellular network with intra-site CoMP

- Scenario 2: Homogeneous macro-cellular network with inter-site CoMP
- Scenario 3: Heterogeneous network with CoMP operation between the macrocell and low power small cells within the macrocell coverage area, where the low power small cells have different cell IDs from the macro cell
- Scenario 4: Heterogeneous network with low power RRHs within the macrocell coverage where the transmission/reception points created by the RRHs have the same cell Identifications (IDs) as the macro cell

3.1.1.3 DL COMP

In terms of downlink CoMP, three different approaches were studied: Coordinated Scheduling or Coordinated Beamforming (CS/CB), Dynamic Point Selection (DPS) and Joint Processing/Joint Transmission (JP/JT). In the first approach, the transmission to a single UE is transmitted from the serving cell only, same as in the case of non-CoMP transmission. Each UE's data only needs to be available at one serving transmission point. However, the scheduling, including any Beamforming functionality in the case of CB, is dynamically coordinated between the cells in order to control and/or reduce the interference between transmissions from different transmission points. In principle, the best serving set of users will be selected so that the transmitter beams are constructed to reduce the interference to other neighboring users, while increasing the served user's signal strength.

For dynamic point selection, the UE, at any one time, is being served by a single transmission point. However, this single point can change dynamically from subframe to subframe within a set of possible transmission points. In this case, each UE's data has to be available at all the possible transmission points ready for selection.

In JP/JT, the transmission to a single UE is simultaneously transmitted from multiple transmission points, across cell sites. The multi-point transmissions will be coordinated as a single transmitter with antennas that are geographically separated. This scheme has the potential for higher performance, compared to coordination only in the scheduling, but comes at the expense of more stringent requirement on backhaul communication. JT is normally assumed to be "coherent", meaning that co-phasing of the signals from the different cooperating transmission points is performed by means of precoding at the transmitters.

The main enhancement in LTE-Advanced Rel-11 for supporting DL CoMP is the provision of a new Physical Downlink Shared Channel (PDSCH) Transmission Mode 10 (TM10), which includes a common feedback and signaling framework that can support CS/CB and DPS. The common framework allows for multiple non-zero-power Channel-State Information-Reference Symbol (CSI-RS) resources, zero power Channel-State Information Reference Symbol (CSI-RS) resources, and interference measurement Channel-State Information-Interference Measurement (CSI-IM) resources to be configured for a UE via Radio Resource Control (RRC) signaling for the measurements of the channel and interference respectively. The set of CSI-RS resources that is being used by the UE to measure and report channel state information is defined as the CoMP measurement set. The maximum size of the CoMP measurement set is three. In order to provide CSI for multiple CoMP transmission hypotheses to support CS/CB and DPS, multiple CSI feedback processes can be configured for a UE, where each CSI feedback process provides CSI corresponding to a defined combination of a channel measurement from a non-zero-power CSI-RS resource and an interference measurement from a CSI-IM resource. Up to 4 CSI feedback processes can be configured for a UE, depending on the UE capability.

To support CS/CB, different CSI processes would be configured corresponding to different cooperating transmission points. A given UE's CSI feedback on the CSI process of the serving cell provides the Channel Quality Indications (CQI) (decodable transport block size) and PMI (preferred precoder) for the serving cell's transmissions to that UE, while the same UE's PMIs for other transmission points (fed back using other CSI processes) would indicate the precoders to be avoided by the other transmission points (i.e. the precoders that would generate the greatest interference).

To support DPS, each CSI process provides the preferred CSI and PMI for a different transmission point. Dynamic downlink control signaling indicates the PDSCH rate matching and resource-element mapping according to the selected transmission point in each subframe. This includes the CRS ports around which the PDSCH data is mapped, starting

OFDM symbol for the data in the subframe, and the locations of the zero-power CSI-RS. The dynamic control signaling also indicates with which CSI-RS the demodulation RS may be assumed to be "quasi-co-located."

Quasi-co-location of reference signal (RS) antenna ports is a new concept introduced in Rel-11. Reference signal antenna ports that are assumed by the UE to be quasi-co-located have the same large-term channel properties, including some or all of delay spread, Doppler spread, Doppler shift, average gain, and average delay. When the CoMP transmission mode is configured, a Rel-11 UE can be configured with either of two quasi-co-location assumptions: one assumption is that all the reference signal antenna ports are quasi-co-located; the other provides additional signaling to indicate a Cell Specfic Reference Signals (CRS) port that may be assumed to be quasi-co-located with each CSI-RS port.

No explicit support is provided for JT in Rel-11, although in TDD systems it is often possible to exploit channel reciprocity to acquire the necessary inter-transmission-point channel state information to support JT.

3.1.1.4 UL COMP

Uplink coordinated multi-point reception implies reception of the transmitted signal at multiple geographically separated points. Scheduling decisions can be coordinated among cells to control interference. Since UL CoMP mainly impacts the scheduler and receiver, it is mainly a network implementation issue.

To support standardized UL CoMP, a UE-specific PUSCH Demodulation Reference Signal (DMRS) base sequence and cyclic shift hopping that can be configured via RRC signaling is defined to aid demodulation by reducing the interference or increasing the reuse factor of DMRS. Furthermore, since the UL reception points may be decoupled (therefore, different) from the DL transmission points, the implicit correspondence between the DL assignment and the Physical Uplink Control Channel (PUCCH) Acknowledgement/Negative Acknowledgement (ACK/NACK) feedback may no longer apply. A new dynamic ACK/NACK region is thus defined where the base sequence and cyclic shift hopping of the PUCCH are generated by replacing the cell ID with a UE-specific parameter.

3.1.1.5 COMP PERFORMANCE

The potential performance of CoMP was investigated in 3GPP RAN1, the outcome of which is documented in 3GPP TR 36.819 v11.1.0[108]. According to this report, for the case of resource utilization below 35 percent, CoMP may provide a 5.8 percent performance gain on the downlink for the mean user throughput and a 17 percent gain for cell-edge users relative to heterogeneous networks without eICIC. For resource utilization of more than 35 percent, CoMP may provide a 17 percent mean gain and a 40 percent cell-edge gain.

3.1.2 CARRIER AGGREGATION (CA) ENHANCEMENTS

Carrier Aggregation (CA) is a feature that was first introduced for LTE-Advanced in Rel-10 where multiple Rel-8 component carriers were allowed to be aggregated together intra-band and offer a means to increase both the peak data rate and throughput.

Rel-11 provides some key enhancements that will support inter-band carrier aggregation where the component carriers can be in different frequency bands. The following sections provide a brief description of the main enhancements.

108 3GPP TR 36.819, "Technical Specifcation Group Radio Access Network; Coordinated Multi-Point Operation for LTE Physical Layer Aspects (Release 11)", V11.1.0 (2011-2012).

3.1.2.1 CA ENHANCEMENTS FOR TDD

These enhancements provides better support for Time Division Duplex (TDD) configuration in which the TDD UL and DL can be configured differently on each of the component carriers and bands either in a full-duplex or in a half-duplex duplex mode. Basically, Component Carriers (CCs) of different UL-DL subframe configuration can be aggregated for TDD mode of operation.

For the full duplex operation for TDD with inter-band CA, Rel-11 provides specific UE capability to be signaled for each band combination as a mandatory feature with Feature Group Indicator (FGI).

It is important to note that there was not a new timeline introduced to support this feature. For each carrier aggregated TDD UL-DL configuration pair, an existing UL/DL configuration is selected to represent the reference configuration. While the timeline corresponding to the reference configuration is followed, it is not necessary that a DL reference configuration be the same as the UL reference configuration for a given aggregation scenario.

PDSCH Scheduling and HARQ Timing

As for PDSCH, cross-carrier scheduling is supported where PDCCH control channel on a given serving cell in subframe *n* can schedule a resource on PDSCH on other serving cells in the same subframe *n.*

The timing for PDSCH HARQ for self scheduling is classified into three categories:

- Case A: SCell downlink subframes are a subset of PCell. In this case, PCell follows its own System Information Block Type 1 (SIB-1) UL-DL configuration timeline. SCell follows the PCell SIB-1 UL-DL configuration timeline for the case A due to the HARQ feedback being sent on PCell.
- Case B: SCell downlink subframes are a superset of PCell. The SCell follows its own SIB-1 UL-DL configuration timeline for the case B because the HARQ feedback is sent on PCell.
- Case C: SCell downlink subframes are neither a superset nor a subset of PCell. The timing table in this case is as follows:

PDSCH HARQ timing on SCell follows TDD UL-DL configuration #		Pcell SIB-1 UL-DL Configuration						
		0	1	2	3	4	5	6
Scell SIB-1 UL-DL Configuration	0		1	2	3	4	5	6
	1	1		2	4	4	5	1
	2	2	2		5	5	5	2
	3	3	4	5		4	5	3
	4	4	4	5	4		5	4
	5	5	5	5	5	5		5
	6	6	1	2	3	4	5	
Notes: *The number in the grid is the reference UL-DL configuration which SCell PDSCH HARQ timing follows.*			**Case A**	**Case B**	**Case C**			

Figure 3.3. Primary Cell (Pcell) BIB UL-DL Configuration.

In the case of cross-scheduling, the SCell PDSCH HARQ timing reference configuration is the same as the SIB-1 UL-DL configuration of the PCell for all cases.

PUSCH Scheduling and HARQ Timing

Cross-carrier scheduling is supported for PUSCH also. The timing for PUSCH HARQ for self scheduling is classified into four categories in the case of cross-scheduling:

- Case A: For this case, SCell uplink subframes are a subset of the UL subframes indicated by the scheduling cell SIB-1 configuration and the PUSCH RTT of the scheduling cell SIB1 configuration is 10ms. In this case, SCell PUSCH HARQ/scheduling timing follows the scheduling cell's PUSCH timing.

- Case B: SCell UL subframes are a superset of the UL subframes indicated by the scheduling cell SIB-1 configuration and the PUSCH RTT of the scheduling cell SIB-1 configuration is 10ms. In this case, SCell PUSCH HARQ/scheduling timing follows the scheduled cell timing for PUSCH.

- Case C: SCell downlink subframes are neither a superset nor a subset of the UL subframes indicated by the scheduling cell SIB-1 configuration and the PUSCH RTT of the scheduling cell SIB-1 configuration is 10ms. Similar to Case B, SCell PUSCH HARQ/scheduling timing follows the scheduled cell timing for PUSCH.

- Case D: PUSCH RTT of the scheduling cell SIB-1 configuration is not 10ms. In this case, for the combinations {6, 2}, {6, 5}, {0, 2}, {0, 4}, {0, 5}, UL scheduling/HARQ timing should follow TDD configuration 1, and others follow the timing of the scheduled cell.

HARQ/scheduling timing of PUSCH on Scheduled Cell follows TDD UL-DL Configuration #		Scheduling cell SIB-1 UL-DL Configuration						
		0	1	2	3	4	5	6
Scheduled cell SIB-1 UL-DL Configuration	0		0	0	0	0	0	0
	1	1		1	1	1	1	1
	2	1	1		2	2	2	1
	3	3	3	3		3	3	3
	4	1	1	4	3		4	4
	5	1	1	2	3	4		1
	6	6	6	6	6	6	6	
		Case A	Case B	Case C	Case D			

Figure 3.4. Scheduling cell SIB-1 UL-DL Configuration.

In the case of self-scheduling, each cell follows its own SIB-1 UL-DL configuration timeline irrespective if it is a PCell or a SCell.

Access Network Feedback

For TDD inter-band CA with different UL-DL configurations on different bands, a UE can be configured with PUCCH format 3 or PUCCH format 1b with channel selection for HARQ-ACK transmission. The same approach is used for self-carrier scheduling and for cross-carrier scheduling, except if there is a difference in PDSCH HARQ reference timing on Scell. For a UE configured with PUCCH format 1b with channel selection for HARQ-ACK transmission, the Rel-10 rules apply.

For a UE configured with PUCCH format 3 for HARQ-ACK transmission, the HARQ-ACK transmission will follow the overall Rel-10 design barring the few exceptions for which Rel-11 specifies appropriate rules.

3.1.2.2 HALF-DUPLEX OPERATION

Another important feature provided by Rel-11 is support for CA for Half Duplex Operation. In this case, rules are laid out for different combination of subframes in downlink and uplink for PCells and SCells. If the subframe type of SCell is different from that of the PCell in a subframe, the normal UE behavior applies with the following constraints:

- For the subframe with “D” on the Pcell and “U” on the Scell, the UE is not expected to transmit any signal/channel on the Scell.
- For the subframe with “U” on the Pcell and “D” on the Scell, the UE is not expected to receive any signal/channel on the Scell.
- For the subframe with “D” on the Pcell and “S” on the Scell, the UE is not expected to transmit any signal/channel in the Uplink Pilot Time Slot (UpPTS) on the Scell.
- For the subframe with “S” on the Pcell and “D” on the Scell, the UE is not expected to receive PDSCH/EPDCCH/PMCH/ Positioning Reference Channel (PRS) on the Scell. In addition, on the Scell, the UE is not expected to receive any other signal in OFDM symbols that overlaps with the guard period and/or UpPTS of PCell.

3.1.2.3 MULTIPLE TIMING ADJUSTMENT GROUPS

Another important feature in Rel-11 for CA is the provision for Multiple Timing Adjustment Groups (TAG). Rel-11 allows for multiple timing advances in User Equipment (UE), different for each component carrier to support cases where the transmission delays from the UE to the eNB are significantly different. This is essential in supporting cases where different uplink bands would require different timing advances. It can also support the use of repeaters in one of the bands or to compensate for the differences in the internal delays of the band specific repeaters.

In general, LTE supports a synchronized uplink using the Timing Advance (TA) procedure. The CA feature was first introduced in Rel-10 and allowed for a single uplink TA value for all component carriers which implied that the base stations of different component carriers should be collocated and should not have different propagation delays. Rel-11 essentially includes new enhancements in CA that will support non-collocated cells. To enable this feature, particularly for scenarios that include Remote Radio heads or a combination of macro and small cells with different frequencies and different coverage profiles, the use of multiple timing advances are required for the component carriers.

Since multiple cells can be associated with CA, Rel-11 defines TAG as a group of serving cells that is configured by RRC, and in particular, for the cells with an UL configured that use the same timing reference cell and the same timing Advance value. There are two types of TAGs:

1. If the Timing Advance Group contains the PCell, then it is called as Primary Timing Advance Group (pTAG).
2. If the Timing Advance Group contains only the SCell(s), then it is called as Secondary Timing Advance Group (sTAG).

The signaling provides support up to 4 TAGs. The number of TAGs that can be configured depends on capability of the UE to be able to support multiple timing advancements. Furthermore, there is only one TAG per band and there are different TAGs for possible inter-band aggregations. UE may use any activated SCell from the TAG as timing reference. In the sTAG, the path loss estimation reference is the SIB2-linked DL and it is not explicitly configurable.

For pTAG, UE performs RACH to obtain synchronization, but for sTAG, non-contention RACH is performed upon reception of the PDCCH order from eNB. The synchronization status of the UE follows that of the pTAG. To achieve the initial UL time alignment of sTAG, the eNB first initiates random access procedure similar to the initial timing advance for a single carrier in 3GPP Rel-8.

The SCell in a sTAG is basically configured with RACH resources. The eNB requests RACH access on the SCell to determine timing advance. Essentially, the eNB initiates the RACH transmission on the secondary cells by a PDCCH order send on the primary cell. In response to a SCell preamble, the PCell sends in a message using Random Access Radio Network Temporary Identifier (RA-RNTI) that is in compliance with Rel-8. Following this, the UE tracks the downlink frame timing change of the SCell and adjusts UL transmission timing based on the timing advance commands.

When the timer associated with pTAG is not running, there will be no timer associated with a sTAG. The value of the timer associated to a sTAG is managed through dedicated signaling between the UE and the eNB. The timers associated with different sTAGs can be configured to different values. The timer of a sTAG is normally restarted whenever a new timing advance is given by the eNB for the corresponding sTAG.

3.1.2.4 MULTI-CELL HARQ-ACK AND PERIODIC CSI MULTIPLEXING

Uplink signaling in Rel-11 is enhanced with the support of multi-cell periodic Channel State Information (CSI) multiplexing, multi-cell Hybrid Automatic Repeat Request Acknowledgement (HARQ-ACK) and periodic CSI.

A Rel-11 UE that supports PUCCH Format 3 is utilized where it is configured for simultaneous transmission of multi-cell HARQ-ACK feedback, SR and periodic CSI report for one serving cell on PUCCH Format 3.

When PUCCH format 2 is configured for CSI transmission and PUCCH format 1b with channel selection is used for multi-cell HARQ-ACK transmission, simultaneous transmission of multi-cell HARQ-ACK feedback and a periodic CSI report on CSI PUCCH Format 2/2a/2b is not supported. The Rel-10 behavior is supported where the periodic CSI report is multiplexed with HARQ-ACK on PUCCH format 2/2a/2b if the HARQ-ACK corresponds to a PDSCH transmission or a PDCCH indicating downlink SPS releases only on the primary cell, otherwise CSI is dropped.

3.1.2.5 TRANSMIT DIVERSITY FOR PUCCH FORMAT 1B WITH CHANNEL SELECTION

One of the features supported in Rel-11 as part of CA, is transmit diversity for PUCCH for the case of HARQ-ACK multiplexing with channel selection. The basic scheme used is the Spatial Orthogonal-Resource Transmit Diversity (SORTD).

With SORTD, UE transmits uplink control signaling on different antennas where PUCCCH transmissions from two different antennas are equivalent to PUCCH transmissions from two different terminals. It should be noted that the transmit Diversity can be used only if the UE is capable of carrier aggregation or configured with more than one cell.

The transmit diversity feature in Rel-11 includes format 1b channel selection in addition to Rel-10 support for the rest of the PUCCH formats. Resource allocation for carrier aggregation of PUCCH format 1b with channel selection is clearly specified in Rel-11: for antenna port 0, this is kept the same as in Rel-10; whereas for antenna port 1, the resources are explicitly configured to fixed values and are not dynamically altered.

3.1.3 FURTHER HETEROGENEOUS NETWORKS ENHANCEMENTS (FEICIC)

Rel-11 defines further enhancements to non-carrier aggregation based Enhanced Inter-Cell Interference Coordination (feICIC or Further enhanced Inter-Cell Interference Coordination). It includes further reduction in interference through cancellation of interference on common control channels of Almost Blank Subframes (ABS) caused by Cell Specific Reference Signals (CRS) of high power macro cells and better detection in the cell range extension region around a pico cell of critical broadcast system information (SIB-1). The interference cancellation receiver fully handles colliding and non-colliding CRS scenarios and removes the need for cell planning of heterogeneous deployment.

Without an Interference Cancellation (IC) capable UE receiver, heterogeneous networks' eICIC can only work effectively for non-colliding CRS cases. In Rel-11, the network can signal assistance information to UE for CRS interference cancellation which involves signaling of interfering neighbor macro cells information. To help the UE better detect the System Information Block Type 1, the network uses dedicated signaling of the broadcast System Information Block Type 1.

3.1.4 ENHANCED PHYSICAL DOWNLINK PHYSICAL CONTROL CHANNEL (EPDCCH)

Two other enhancements to the downlink were investigated in Rel-11: downlink signaling enhancement with a new control channel (EPDCCH) and the downlink MIMO enhancement. For DL MIMO, 3GPP completed the study and published the technical report, TR 36.871. However, due to the Rel-11 timeline, the DL MIMO Work Item is now part of Rel-12 and will be described in section 4.

LTE systems, up to Rel-10, contain three control channels in the downlink: Physical Control Format Indicator Channel (PCFICH), Physical Downlink Control Channel (PDCCH) and Physical Hybrid ARQ Indicator Channel (PHICH), which make up the downlink control region of a subframe. They provide functionalities of indicating the size of the downlink control region, assigning downlink and uplink data resources, and providing acknowledgment for uplink transmission, respectively to enable the UEs to work effectively and efficiently in the network. The size of the legacy control region which occupies up to 3 OFDM symbols (or 4 if the system bandwidth is 1.4 MHz) significantly limits the control capacity. This limited capacity and the lack of flexibility in control region configuration may lead to insufficient use of resources for data transmission with the introduction of advanced transmission techniques such as:

- Carrier Aggregation (CA): The cross carrier scheduling functionality requires increased control capacity since control signaling for multiple carriers is carried only in one carrier.
- Multi-User MIMO and Cooperative Multipoint Transmission and Reception (CoMP): Advanced transmission modes improve the spectral efficiency for data transmissions and support a larger number of users, which may require higher control channel capacity.
- Machine Type Communication (MTC): The deployment of a large number of terminals in the relatively small bandwidth requires higher control channel capacity and preferably higher spectral efficiency.
- Small Cell: Denser cells with greater adaptability create an increasingly complex interference environment that would benefit from control region configuration that possesses greater flexibility and allows better interference coordination.

To address these issues, discussion on the control channel enhancements was initiated at the beginning of LTE Rel-11 standardization. The Enhanced Physical Downlink Control Channel (EPDCCH) was approved and complete in Rel-11.

3.1.4.1 PRINCIPLE

To meet the challenges described above, the design of the EPDCCH contains the following features:

Improved Control Capacity

EPDCCH shares the same physical resource as PDSCH. Unlike PDCCH, EPDCCH is frequency division multiplexed with PDSCH as shown in Figure 3.5. EPDCCH is allowed to occupy as many PRB pairs as needed; therefore, it has larger control capacity than PDCCH. Furthermore, the resources for control and data can be balanced according to the number of served users, so a tradeoff can be achieved to maximize the throughput.

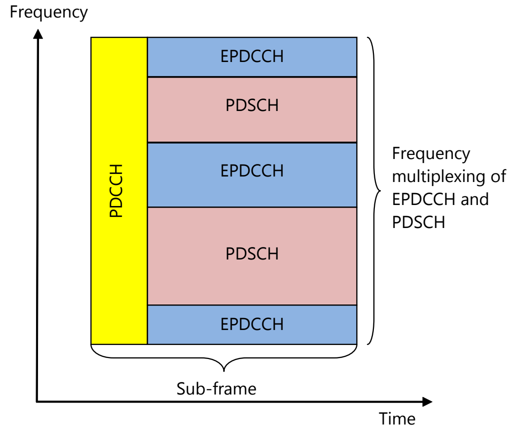

Figure 3.5. Frequency multiplexing of EPDCCH and PDSCH.

Flexible Resource Allocation

EPDCCH resource configuration is UE-specific. Similar to data transmission, the granularity for EPDCCH resource allocation can be as small as 1 PRB (Physical Resource Block) pair, providing greater flexibility than PDCCH whose resources are configured in terms of OFDM symbol. The most prominent benefit of this flexible resource allocation is the ability to support the frequency domain inter-cell interference coordination, which has been proven to be an efficient way to mitigate the impact of interference in LTE system. Furthermore, the smaller granularity can reduce the resource wastage when the number of users to be served simultaneously is small. To further improve the resource utilization, the EPDCCHs for different UEs are allowed to be multiplexed in the same PRB pairs in a UE-transparent manner.

Increased Spectral Efficiency

The legacy PDCCH transmission is spread across the system bandwidth and supports transmit diversity. It is recognized that, similar to the data channels, high spectral efficiency can be achieved on the control channel by using advanced techniques such as MIMO, beamforming and frequency selective scheduling. These techniques, which are not available to PDCCH transmissions, are therefore introduced for EPDCCH as localized transmission.

Localized transmission is used when reliable CSI feedback is available. This allows EPDCCH transmission to benefit from frequency selective gain since the network is able to schedule EPDCCH onto a narrow bandwidth that has good radio conditions to a UE. With reliable CSI feedback, MU-MIMO and beamforming are feasible in localized transmission, which would further improve the spectral efficiency.

Robustness

Distributed transmission is introduced in EPDCCH in order to maintain the robustness of the control channel transmissions. It can be used when reliable CSI feedback is not available, for example, due to high UE mobility. In this transmission scheme, the EPDCCH resource is spread across a wide bandwidth to benefit from frequency diversity gain. In addition, spatial diversity is achieved by Resource Element (RE)-level precoder cycling using two antenna ports.

3.1.4.2 FEATURE DESCRIPTION

The building blocks for PDCCH are the REG and CCE. Similarly, the building blocks for an EPDCCH are the EREG (Enhanced Resource Element Group) and ECCE (Enhanced Control Channel Element). A PRB pair allocated for EPDCCH consists of 16 EREGs where each EREG typically consists of 9 Resource Elements. An ECCE consists of 4 or 8 EREGs. An EPDCCH is therefore built up with one or more ECCEs. Figure 3.6 shows an example of EREG and ECCE construction. Here a localized transmission is assumed where the ECCE is formed from 4 EREGs from the same PRB pair. Figure 3.6 also shows the formation of EREG from REs distributed across the PRB.

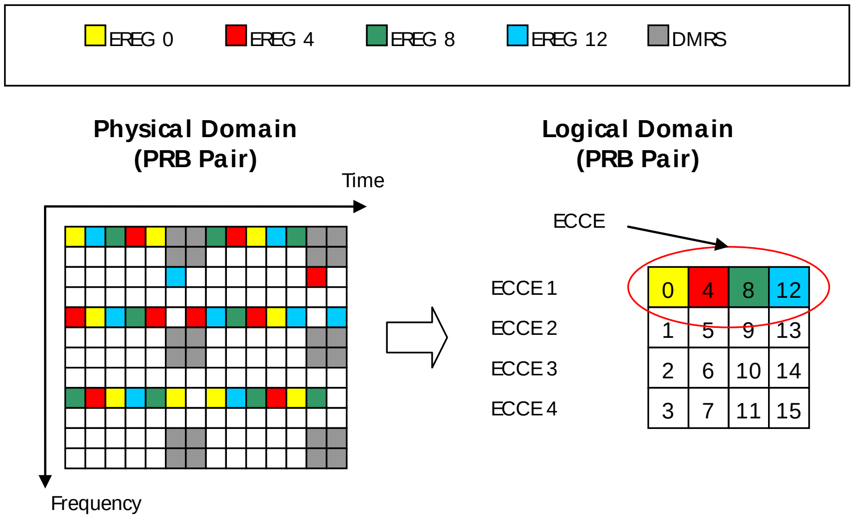

Figure 3.6. EREG and ECCE, where each ECCE consists of 4 EREGs for Localized transmission.

Up to two EPDCCH sets can be configured for a UE, with each set containing 2, 4, or 8 PRB pairs and being configured as localized or distributed. The UE would blind decode all the possible EPDCCH candidates within each EPDCCH set.

EPDCCH uses demodulation reference signals (DMRSs) and 4 DMRS antenna ports are defined for EPDCCH in a PRB pair. Each localized ECCE is mapped to one DMRS antenna port by specifications. For a localized EPDCCH, there is only one associated DMRS antenna port which is determined by the assigned ECCEs, and the UE ID when more than 1ECCE are used for an EPDCCH transmission. For distributed EPDCCH transmission where RE-level precoder cycling is applied to attain spatial diversity gain, 2 fixed antenna ports are allocated with fixed mapping between REs and the two antenna ports.

3.1.5 EVOLVED MULTIMEDIA BROADCAST MULTICAST SERVICE (EMBMS) SERVICE CONTINUITY AND LOCATION INFORMATION

In LTE Rel-11, E-UTRAN provides support for MBMS service continuity in a multi-carrier deployment of MBMS service. Rel-11 enhancements allow the network to signal assistance information to MBMS capable devices that includes information like carrier frequencies and service area identities where MBMS service is available. A MBMS capable device can also indicate information related to the MBMS services of interest to the network.

The MBMS interest indication by the device also allows the device to indicate the priority between MBMS service and unicast service. The network uses the MBMS interest indication provided by the device to ensure continuity of MBMS services. In idle mode, a MBMS capable device can prioritize a particular carrier frequency during cell reselections depending on the availability of MBMS service of interest in that carrier frequency.

3.1.6 FURTHER SELF-OPTIMIZING NETWORK (SON) ENHANCEMENTS

SON has been part of the LTE specifications since its introduction in Rel-8; there were enhancements and improvements to the various SON use cases throughout Rel-9, Rel-10 and Rel-11. This section outlines the main SON related enhancements introduced in Rel-11.

3.1.6.1 AUTOMATIC NEIGHBOR RELATIONS (ANR)

Prior to Rel-11, ANR focus was on the E-UTRAN (i.e., for LTE). Rel-11 ANR focuses on the management aspects of ANR for UTRAN and IRAT ANR. Rel-11 has identified the management aspects for the following SON use cases in the context of UTRAN Automatic Neighbor Relation (ANR), including:

- Intra-UTRAN ANR
- UTRAN IRAT ANR from UTRAN to GERAN
- UTRAN IRAT ANR from UTRAN to E-UTRAN

In addition to UTRAN ANR, Rel-11 has addressed management aspects for E-UTRAN IRAT ANR, including:

- ANR from E-UTRAN to GERAN
- ANR from E-UTRAN to UTRAN
- ANR from E-UTRAN to CDMA2000

3.1.6.2 LOAD BALANCING OPTIMIZATION

Load balancing optimization aims to address unnecessary traffic load distribution, beyond what is acceptable, and to minimize the number of handovers and redirections needed to achieve load balancing. 3GPP Rel-11 has defined the following targets or the combination of the following targets to use for load balancing: RRC connection establishment failure rate related to load, E-RAB setup failure rate related to load, RRC Connection Abnormal Release Rate related to load, E-RAB Abnormal Release Rate related to load and Rate of failures related to handover.

3GPP has defined additional specific load balancing related performance measurements for use in SON, including: the number of failed RRC connection establishments related to load, the total number of attempted RRC connection establishments, the number of E-RAB setup failures related to load, the total number of attempted E-RAB setups, the number of abnormal RRC connection releases related to load, the total number of RRC connection releases, the number of E-RAB abnormal releases related to load, the total number of E-RAB releases, the number of failure events related to handover and the total number of handover events.

3.1.6.3 HANDOVER OPTIMIZATION

Handover (HO) parameter optimization function aims at optimizing the HO parameters in such way to mitigate the problem scenarios, namely, too early handovers, too late handovers and inefficient use of network resources due to HOs. While the optimization algorithms are not specified, the exact set of HO parameters that may be adjusted by the algorithms is dictated by the choice of triggered HO measurements made by the Radio Resource Management (RRM) entity in an eNodeB.

Rel-11 has specified two options for the location of the SON algorithm for HO parameter optimization, namely, in the eNB(s), and in the element manager through which the parameter changes are executed in the eNBs.

3GPP Rel-11 has specified a HO Parameter Optimization Monitor Function to be used for monitoring the handover parameter optimization (for example, monitoring related performance counters or alarms), and a HO Parameter Optimization Policy Control Function to be used for configuring the handover parameter optimization policies.

3GPP Rel-11 has also specified the collection of the following HO-related performance measurements from the source and / or target eNB which can be useful in detecting HO-related issues on the cell level, namely: the number of RLF events within an interval after handover success; the number of unnecessary handovers to another RAT without Radio

Link Failure (RLF) and specific performance measurements related to handover failure (number of handover events, number of HO failures, number of too early HO failures, number of too late HO failures, number of HO failures to wrong cell, number of unnecessary HOs to another RAT). Problem scenarios are identified based on UE measurements, performance measurements, and event capture and analysis.

3.1.6.4 COVERAGE AND CAPACITY OPTIMIZATION (CCO)

The objective of Capacity and Coverage Optimization (CCO) is to provide optimal coverage and capacity for the radio network.

In Rel-11, symptoms of CCO problems, namely, coverage hole, weak coverage, pilot pollution, overshoot coverage and DL and UL channel coverage mismatch are addressed in detail. Capacity and coverage-related performance measurements collected at the source and/or target eNB can be useful in detecting capacity and coverage related issues on the cell level. Inputs for the identification of the problem scenarios, namely, UE measurements, performance measurements, alarms, and other monitoring information, for example trace data, are described.

UE measurements are sent within UE measurement reports and they may indicate the capacity and coverage problem. Rel-11 has specified that a tradeoff between capacity and coverage needs to be considered. Capacity and coverage-related performance measurements collected at the source and/or target eNB can be useful in detecting capacity and coverage related issues on the cell level. Minimizing Drive Tests (MDT), discussed more below, or HO-related performance measurements may be used also in detecting capacity and coverage related issues on the cell level. Alarms, other monitoring information, for example trace data, can be correlated to get an unambiguous indication of capacity and coverage problems. Parameters to be optimized to reach capacity and coverage optimization targets are defined, namely, downlink transmit power, antenna tilt, and antenna azimuth.

Logical Functions for CCO, namely CCO Monitor Function and CCO Policy Control Function, to be used for configuring the capacity and coverage optimization policies are defined in Rel-11. Options for the location of the centralized CCO SON algorithm are defined namely in the element management or in the network management layer. Performance measurements related with CCO are specified including maximum carrier transmit power and mean carrier transmit power.

3.1.6.5 RACH OPTIMIZATION FUNCTION

The objective of RACH Optimization is to automatically set several parameters related to the performance of RACH. 3GPP has defined specific target values on access probability and access delay probability to be configured by operators. The RACH optimization entity is specified to reside in the eNB. Performance measurements related with RACH optimization are the distribution of RACH preambles sent and distribution of RACH access delay.

3.1.6.6 ENERGY SAVINGS

3GPP Rel-11 has spelled out the importance of Energy Savings Management for Network Operators to look for means to reduce energy costs and protect the environment.

Operations, Administration and Maintenance (OAM) of mobile networks can contribute to energy savings by allowing the operator to set policies to minimize consumption of energy, while maintaining coverage, capacity and quality of service. The permitted impact on coverage, capacity and quality of service is determined by an operator's policy.

3GPP Rel-11 has defined two energy saving states for a cell with respect to energy saving: n*otEnergySaving* state and *energySaving* state.

Based on the above energy saving states, a full energy saving solution includes two elementary procedures: energy saving activation (change from *notEnergySaving* to *energySaving* state) and energy saving deactivation (change from *energySaving* to *notEnergySaving* state).

When a cell is in an energy saving state it may need neighboring cells to pick up the load. However, a cell in *energySaving* state cannot cause coverage holes or create undue load on the surrounding cells. All traffic on that cell is expected to be drained to other overlaid/umbrella cells before any cell moves to *energySaving* state.

A cell in *energySaving* state is not considered a cell outage or a fault condition. No alarms should be raised for any condition that is a consequence of a network element moving into *energySaving* state.

Criteria for the *energySaving* state is defined in 3GPP: degree of energy saving effect, controllability from the network and service availability.

The various Energy Savings Management (ESM) concepts can apply to different RATs, for example UMTS and LTE. However, 3GPP has specified that some of these ESM concepts may be limited to specific RATs and network elements, and specific solutions may be required for them.

In Rel-11, three general architectures that are candidates to offer energy savings functionalities are described: distributed, network management centralized and element management centralized. Energy savings management use cases, the cell overlay use case, and the capacity limited network use case, are described in detail. Requirements for element management centralized energy savings and distributed energy savings are specified. Coordination between energy saving and cell outage is addressed.

Switch-off/-on of 3GPP macro cells

Rel-11 addresses the impacts on signaling between the UE and core network when energy saving measures are applied to network entities. A primary energy saving mechanism is realized by switch-off of radio equipment on the network side. As a consequence, a UE currently being served by the radio equipment subject to switch-off will have to find an alternative, either in the same RAT (if possible by coverage, this would naturally be preferred), or in another RAT. These cases are called "intra-RAT energy saving" and "inter-RAT energy saving", respectively. The fundamental assumption is that, due to overlapping radio coverage, in practically all relevant cases, an alternative radio access can indeed be found. These two cases are summarized in Figure 3.7.

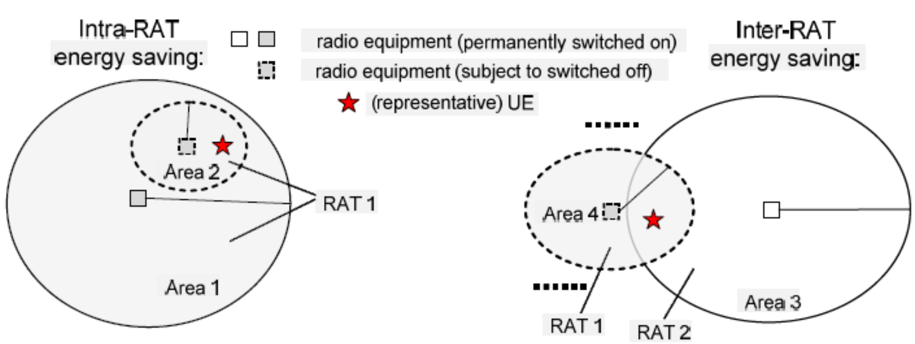

Figure 3.7. Two base coverage scenarios for energy saving by switch-off of radio equipment.

Overlaid intra-RAT

A capacity enhancing cell, subject to switch-off for energy saving, is placed into the (full) coverage realized by other cells (see figure 3.8). Such a cell can be either totally within the range of one cell or it can intersect with multiple cells of the base coverage. The relative position of a capacity-enhancing cell, regarding registration area boundaries, determines whether signaling between the UE and core network is to be expected as a result of switching the cell off/on.

Non-overlaid intra-RAT

The cell that is subject to switch-off has no alternative coverage, thus some cell adaption has to take place in order to not disrupt service for the UEs due to a coverage "hole" of this RAT (and e.g., with no capability for an alternative RAT). As shown in figure 3.8, registration area boundaries will be distorted with switch-off

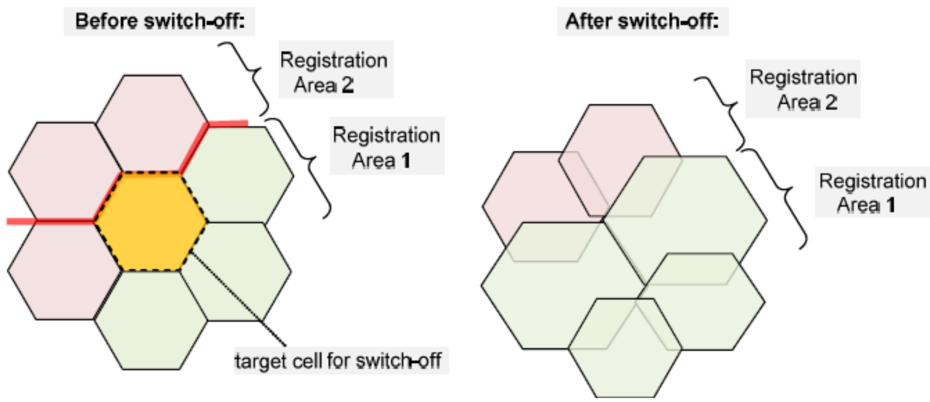

Figure 3.8. Coverage and registration areas for non-overlaid intra-RAT energy saving with 3GPP macro cells.

Inter-RAT

This case is illustrated in Figure 3.9.

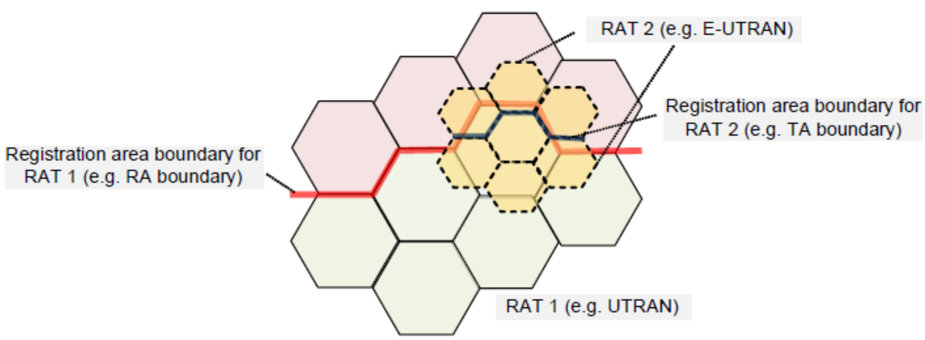

Figure 3.9. Coverage and registration areas for inter-RAT energy saving with 3GPP macro cells

3.1.6.7 COORDINATION BETWEEN VARIOUS SON FUNCTIONS

3GPP Rel-11 has identified and called out conflicts or dependencies between SON Functions. The mode of operation between the SON Coordination Function and the SON Function, as well as the role of the SON Coordination Function, in the detection and attempt to resolve the conflicts, are specified in Rel-11.

Conflict may happen when two or more SON functions try to change the same network configuration parameter. For example, there would be a conflict when one SON function tries to increase the value of one configuration parameter, while the other SON function tries to decrease the value of the same configuration parameter. Another typical conflict example is Ping-Pong modification of one configuration parameter between two or more SON functions.

Dependency means the behavior of one SON function may have influence on other SON functions. For example, CCO function may adjust the Neighbor Relation (NR) due to coverage optimization, and then the changed NR will have an influence on Handover Parameter Optimization function. SON Coordination means preventing or resolving conflicts or negative influences between SON functions to make SON functions comply with an operator’s policy.

For coordination of SON functions whose outputs are not standardized, 3GPP has defined how the Integration Reference Point (IRP) manager uses standardized capabilities to set the SON function(s) targets, and where their weights are needed. For coordination of SON functions whose outputs are standardized, the context of optimization coordination is FFS. 3GPP has addressed the coordination between SON functions below Itf-N and Configuration Management (CM) operations over Itf-N. Examples of conflict situations are specified in Rel-11.

3GPP Rel-11 has called out the fact that in a real network, it is possible that centrally managed operations via Itf-N and several SON Functions below Itf-N are running at the same time, and they may try to change the same parameters during a short time period. So coordination is needed to prevent this kind of conflict. If coordination between multiple SON Functions is necessary, 3GPP has identified a function referred to as a SON Coordination Function that will be responsible for preventing or resolving conflicts. The SON Coordination Function may be responsible for conflict prevention, conflict resolution, or both in parallel.

To prevent conflicts between the SON Functions, 3GPP has specified that the SON Functions may ask the SON Coordination Function for permission before changing some specific configuration parameters.

As a basis for decisions, the SON Coordination Function will typically use the following inputs received from the SON Function(s), such as: which SON Functions are modifying configuration parameters (including information about vendor, release etc.), the time duration for how long the configuration parameter should *not* be interfered with ("impact time"), the state of SON Functions, the SON targets which are the justification for the configuration change, and possible impact of a parameter change on other objects ("impact area"). Additional information, such as the state of certain managed objects, possible impact of the parameter change on Key Performance Indicators, priority of SON functions, and SON Coordination policies, is also specified.

The mode of operation between the SON Coordination Function and the SON Function, as well as the role of the SON Coordination Function in the detection and attempts to resolve the conflicts have been specified in Rel-11.

3.1.6.8 MINIMIZATION OF DRIVE TESTS (MDT)

Rel-11 has described the general principles and requirements guiding the definition of functions for Minimization of Drive Tests as follows:

1. **MDT mode.** There are two modes for the MDT measurements: Logged MDT and Immediate MDT.

2. **UE measurement configuration**. It is possible to configure MDT measurements for the UE logging purpose independently from the network configurations for normal RRM purposes. However, in most cases, the availability of measurement results is dependent on the UE RRM configuration.

3. **UE measurement collection and reporting.** UE MDT measurement logs consist of multiple events and measurements taken over time. The time interval for measurement collection and reporting is decoupled in order to limit the impact on the UE battery consumption and network signaling load.

4. **Geographical scope of measurement logging**. It is possible to configure the geographical area where the defined set of measurements shall be collected.

5. **Location information.** The measurements can be linked to available location information and/or other information or measurements that can be used to derive location information.

6. **Time information.** The measurements in measurement logs should be linked to a time stamp.

7. **UE capability information.** The network may use UE capabilities to select terminals for MDT measurements.

8. **Dependency on SON.** MDT solutions should be able to work independently from SON support in the network. Relationships between measurements/solution for MDT and UE-side SON Functions should be established in a way that re-use of functions is achieved where possible.

9. **Dependency on trace.** The subscriber/cell trace functionality is reused and extended to support MDT. If the MDT is initiated toward to a specific UE (for example, based on International Mobile Subscriber Identity (IMSI), International Mobile Equipment Identity (IMEI-SV), etc.), the signaling-based trace procedure is used, otherwise, the management-based trace procedure (or cell traffic trace procedure) is used. Network signaling and overall control of MDT is described in Rel-11.

The solutions for MDT should take into account the following constraints:

1. **UE measurements.** The UE measurement logging mechanism is an optional feature. In order to limit the impact on UE power consumption and processing, the UE measurement logging should rely as much as possible on the measurements that are available in the UE according to radio resource management enforced by the access network.

2. **Location information.** The availability of location information is subject to UE capability and/or UE implementation. Solutions requiring location information should take into account power consumption of the UE due to the need to run its positioning components.

Rel-11 has defined detailed mechanisms for Management Based Activation, Trace Parameter Propagation, and Trace Record Collection in the case of signaling-based activation.

Rel-11 has included Quality of Service (QoS) verification use cases beyond the coverage use cases addressed in Rel-10. The MDT data reported from UEs and the RAN may be used to verify QoS, assess user experience from the RAN perspective and to assist network capacity extension.

3.1.7 SIGNALING AND PROCEDURE FOR INTERFERENCE AVOIDANCE FOR IN-DEVICE COEXISTENCE

The latest UEs generally support multiple radio transceivers in order to support various technologies in the device. For example, many UEs today support LTE, Wi-Fi, Global Positioning System (GPS), Bluetooth, etc., which poses many challenges to prevent coexistence interference between the radio transceivers of the different technologies that are co-located on the device. This issue is demonstrated in Figure 3.10[109].

[109] 3GPP TR 36.816, “Study on signaling and procedure for interference avoidance for in-device coexistence (Release 11)”, V11.2.0 (2011-2012).

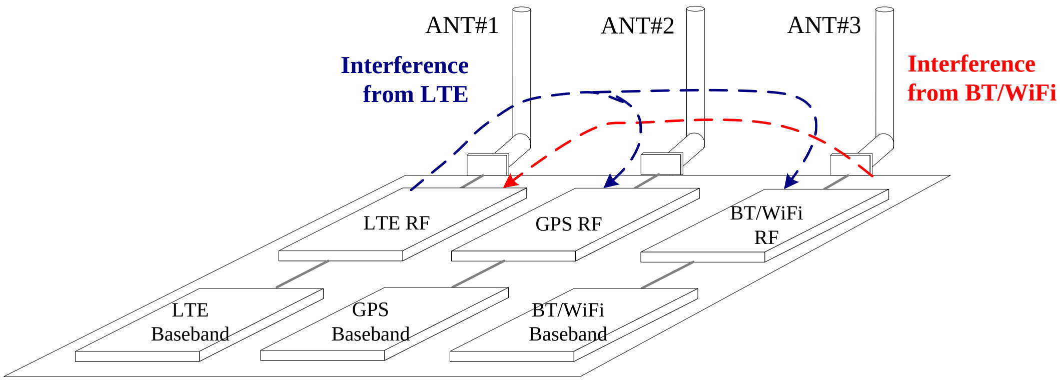

Figure 3.10. Example of coexistence interference in a UE that supports LTE, GPS and BT/Wi-Fi.

In cases where the frequency separation between the different technology transceivers is sufficient, filtering technologies can be used to prevent in-device interference between the technologies. However, this is not always possible in cases where the different technology transceivers are operating in adjacent frequencies or sub-harmonic frequencies. Therefore, 3GPP has been investigated alternative mechanisms to mitigate such co-existence interference within the UE. Two solutions are introduced and their basic concepts are as follow:

- The basic concept of a Frequency Division Multiplex (FDM) solution is to move the LTE signal away from the Industrial, Scientific and Medical (ISM) band by (e.g., performing inter-frequency handover within E-UTRAN or removing SCells from the set of serving cells).

- The basic concept of a Time Division Multiplexing (TDM) solution is to ensure that transmission of a radio signal does not coincide with reception of another radio signal. LTE Discontinuous Reception (DRX) mechanism is used to provide TDM patterns (e.g., periods during which the LTE UE may be scheduled or is not scheduled) to resolve the In-Device Coexistence (IDC) issues. DRX based TDM solution should be used in a predictable way (e.g., the eNB should ensure a predictable pattern of unscheduled periods by means of DRX mechanism).

In addition, the UE can autonomously deny LTE UL transmission (if configured by the network) to protect ISM in rare signaling cases if other solutions cannot be used. Also, the UE can autonomously deny ISM transmission in order to protect essential LTE signaling (e.g., RRC connection reconfiguration and paging reception, etc).

3.1.8 MACHINE TYPE COMMUNICATIONS (MTC)

The outcome of the Rel-11 Study Item, ‘Study on RAN improvements for Machine-Type Communications’, introduced one standard MTC enhancement which targets a better control of signaling congestion and overloading of RAN due to MTC devices. Extended Access Barring (EAB) is an extension of the legacy Access Control Barring (ACB) mechanism, enabling the RAN (eNB) to bar the access of one or several classes of UEs configured for EAB via new system information (dedicated for “EAB devices”).

Rel-11 EAB is defined for both E-UTRA and UTRA, and reuses most of the functionalities defined in Rel-10 for GSM EDGE Radio Access Network (GERAN). The way Rel-11 EAB achieves a better MTC congestion control (in E-UTRAN) is summarized, at high level, below.

The eNB can broadcast a new System Information Block (SIB) type (i.e. SIB 14), including:

- An *EAB Barring Bitmap*, which is a 10-bit string enabling the indication of which Access Class (AC), numbered as 0-9 and stored in the SIM) is barred. If a bit is set, the corresponding AC is barred, for example “1010000000” means AC0 and AC2 are barred.

- A *EAB Category*, which provides a further differentiation based on PLMN:
    - Category *a:* all UEs
    - Category *b:* UEs that are neither in their Home Public Land Mobile Network (HPLMN) nor in a Equivalent Public Land Mobile Network (EPLMN) of HPLMN
    - Category *c:* UEs that are neither in the PLMN listed as 'most preferred' Public Land Mobile Network (PLMN) (in the country where the UEs are roaming in the operator-defined PLMN selector list on the USIM), nor in their HPLMN nor in a EPLMN of HPLMN.

A UE configured for EAB in EPS Connection Management IDLE (ECM-IDLE) mode shall maintain valid SIB14 (SIB 14 change is notified by paging). When paging with *EAB-ParamModification* is received by a UE, it shall:

- Re-acquire SIB1 without waiting for the next modification boundary
- Re-acquire SIB14 if SIB14 is included in scheduling Info-List of SIB1, otherwise discard locally stored SIB14

UE Non Access Stratum (NAS) determines that an access attempt is subject to EAB if:

- UE is configured for "Extended Access Barring" (EAB as defined in TS 24.368)
- Access purpose (cause of RRC establishment) is not "Emergency call" or "MT Access" or "High Priority Access AC 11-15"
- UE is not configured to allow overriding EAB or upper layer doesn't request overriding EAB

In such cases, UE NAS will notify UE Access Stratum (AS) that the access attempt is subject to EAB. UE AS determines whether such access attempt is barred if (by checking SIB14):

- UE selected PLMN belongs to the category defined by "EAB-Category"
- The bit corresponding to the UE's AC for this access in "barring Bitmap" is set to 1

UE AS notifies NAS if the access is barred. If not barred by EAB, the access attempt is still subject to the legacy ACB check.

In shared (multi-PLMNs) LTE network, EAB control can be performed for each PLMN independently. In fact, SIB14 contains per-PLMN EAB parameters (barringBitmap and Category) in sequence for each sharing PLMN (as listed in SIB1). UE performs EAB check based on the EAB parameters of its selected PLMN.

3.1.9 FURTHER HOME NODEB AND ENODEB ENHANCEMENTS

Further enhancements for Home NodeB and eNodeB for UMTS and LTE were defined in Rel-11.

3.1.9.1 UMTS HNB

In UMTS Rel-8, only handover from Home NodeB (HNB) to macro mobility was defined. In UMTS Rel-9, solutions for inbound handover to HNB and HNB to HNB Hard handover were defined. In UMTS Rel-10, support for Soft Handover without Core Network (CN) involvement to a new interface (Iurh) was introduced, which was a Iurh-like interface between HNBs. This allowed the addition of two new mobility features:

- Hard handover HNB <> HNB using enhanced Serving Radio Network Subsystem (SRNS) relocation, with no CN involvement

- Soft Handover HNB <> HNB with no CN involvement

Both these scenarios were intra-Closed Subscriber Group (CSG).

In UMTS Rel-11, the use of Iurh was extended via the HNB gateway to use an Iurh link between the HNB gateway and a macro RNC. This enabled soft and hard handover (using enhanced SRNS relocation) to the macro network. These mobility features were added:

- Hard Handover macro RNC <> HNB (open/hybrid) using enhanced SRNS relocation
- Soft Handover macro RNC <> HNB (open/hybrid)

Also introduced at UMTS Rel-11 was an implementation-only solution for handling legacy UEs.

3.1.9.2 LTE HENB

In LTE Rel-10, X2 handover involving HeNBs was only possible between two HeNBs and when either the two HeNBs were operating in closed/hybrid access mode with the same CSG ID, or the target HeNB was operating in open access mode.

In LTE Rel-11, the following two aspects of mobility involving HeNBs were added:

- X2 handover from/to HeNB to/from macro eNB
- inter-CSG X2 handover towards hybrid HeNBs

The resulting scope of X2 mobility scenarios involving HeNBs allowed in Rel-11 can thus be summarized in Table 3.1:

Table 3.1. X2 Mobility Scenarios Involving HeNBs.

Source	Target	Notes
eNB or any HeNB	Open access HeNB	
eNB, or any HeNB	Hybrid access HeNB	
Hybrid access HeNB or closed access HeNB	Closed access HeNB	Only applies for same CSG ID and PLMN, and if the UE is a member of the CSG cell.
Any HeNB	eNB	

In Rel-11, the support of inter-CSG X2 handover towards hybrid HeNBs newly involved the MME to perform the access control according to the call flow in Fig. 3.11:

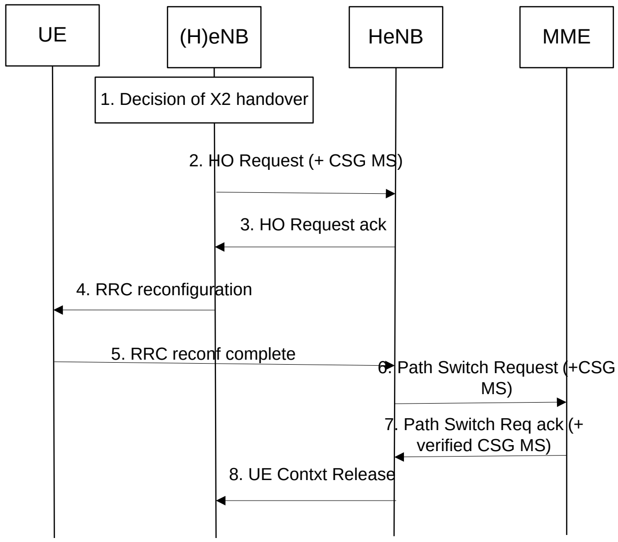

Figure 3.11. Inter-CSG X2 handover towards hybrid HeNBs.

- In step 2, the source (H)eNB includes the CSG membership status reported by the UE and the target HeNB uses it for admission control.
- In step 6, the target HeNB provides that CSG membership status to the MME during the path switch procedure.
- In step 7, the MME verifies the membership of the UE and includes back the verified membership to the target HeNB.

3.2 HSPA+ ENHANCEMENTS

New HSPA features in Rel-11 include 8-Carrier HSDPA, Downlink Multiflow Transmission, Downlink 4-branch MIMO, Uplink dual antenna beamforming and MIMO together with 64QAM and a number of small enhancements to the Cell_FACH state. These enhancements are described in more detail in a 4G Americas white paper specifically dedicated to HSPA+[110].

3.2.1 DOWNLINK (DL)ENHANCEMENTS

Downlink enhancements in Rel-11 included 8-carrier HSDPA, Multiflow transmission and 4-branch MIMO which are explained in the following sections.

3.2.1.1 8-CARRIER HSDPA

The 8-carrier HSDPA (8C-HSDPA) extends the HSDPA carrier aggregation up to 40 MHz aggregate bandwidth by enabling transmission simultaneously on up to eight carriers towards a single UE (see example in Figure 3.12). The

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110 The Evolution of HSPA: The 3GPP Standards Progress for Fast Mobile Broadband Using HSPA+. 4G Americas. October 2011.

carriers do not necessarily need to reside adjacent to each other on a contiguous frequency block, as it is possible to aggregate carriers together from more than one frequency band.

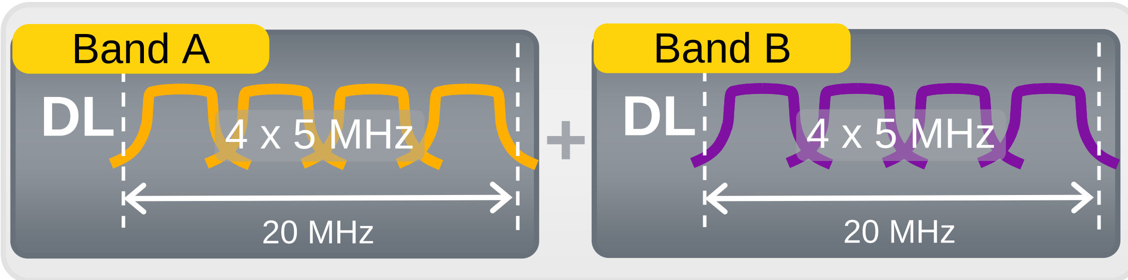

Figure 3.12. 8-Carrier HSDPA Aggregates up to 8X5 MHz Carriers from Different Frequency Bands

8-carrier HSDPA is increasing the peak HSDPA data rate by a factor of 2 compared to 4-carrier HSDPA. The benefits of aggregating multiple carriers are significant for the end user, since a diversity gain can be achieved from scheduling on the best carrier(s) and especially due to the fact that free resources in the other carriers can be flexibly used. Due to the bursty nature of the user data, in a network deploying multiple carriers, free resources are often available in some carriers while others are fully loaded. The gains can be seen in Figure 3.13 which shows the cumulative distribution of the average user throughput and the mean packet call delay for the macro cells scenario with an average cell load of 1 Mbps.

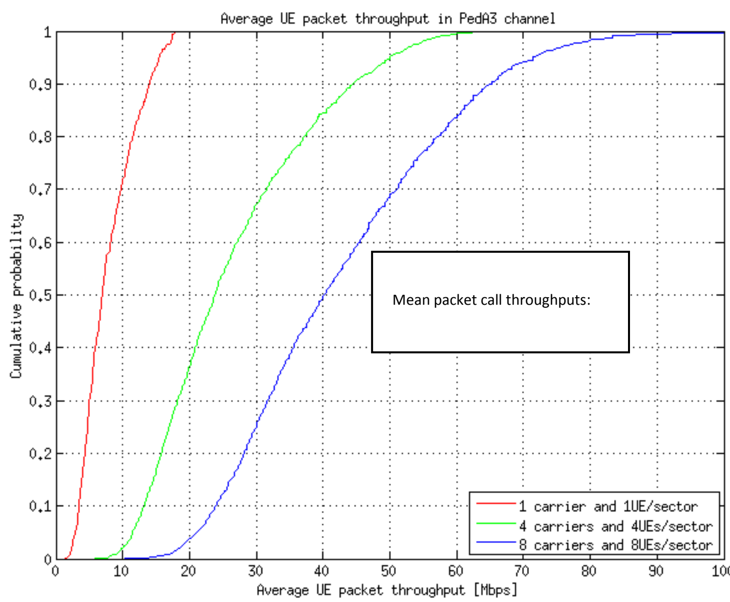

Figure 3.13: Cumulative distribution probability of the average UE packet throughput for 1, 4 and 8 carriers at low offered load.

The gains depend significantly on the load in the system. If the load is high, then there will be fewer free resources on the other carriers, which results in lower gains, and it can be expected to bring similar gains as the other multi-carrier features standardized in Rel-8 to Rel-10. As a potential additional evolution step, 4X4 MIMO can be envisioned, with the potential to yet again double the peak rate over 2X2 MIMO.

8-Carrier HSDPA is part of 3GPP Rel-11. The first band combination for 8C-HSDPA to be introduced in 3GPP is 8 adjacent carriers on Band I (2100 MHz). The activation/deactivation of the secondary carriers is done by the serving NodeB through physical layer signaling, and the uplink signaling is carried over a single carrier.[111]

3.2.1.2 DOWNLINK MULTIFLOW TRANSMISSION

The downlink Multiflow Transmission concept shown in Figure 3.14 is improving the achievable HSDPA cell edge data rates by both reducing the inter-cell interference and increasing the energy of the desired signal. By transmitting independent data streams to the UE, the achievable cell edge peak and average data rate can be increased. This gain stems from spatial multiplexing and exploits advanced interference suppression receivers that are able to suppress the cross-interference of the two data streams from each other.

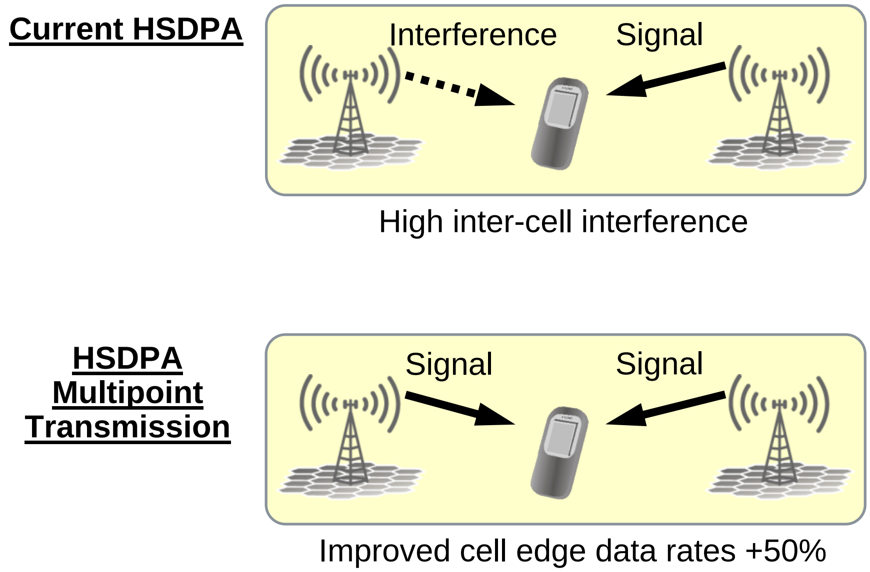

Figure 3.14. Downlink Multipoint Transmission.[112]

Each of the data flows in Multiflow can be scheduled independently thus simplifying the concept and enabling simple inter-site deployment without the need for tight network synchronization. The presence of two HSDPA flows from two cells leads to a doubling of the power available for the desired signal at the UE, which is used to increase the overall user throughput. In order to eliminate the inter-stream interference, the terminal should have two receive antennas and interference-aware receiver chains. For 3GPP Rel-11, Multiflow is considered for up to four different flows over two different frequencies; one can send data from up to four different cells to a UE.

[111] The Evolution of HSPA: The 3GPP Standards Progress for Fast Mobile Broadband Using HSPA+, 4G Americas, October 2011.
[112] The Evolution of HSPA: The 3GPP Standards Progress for Fast Mobile Broadband Using HSPA+, 4G Americas, October 2011

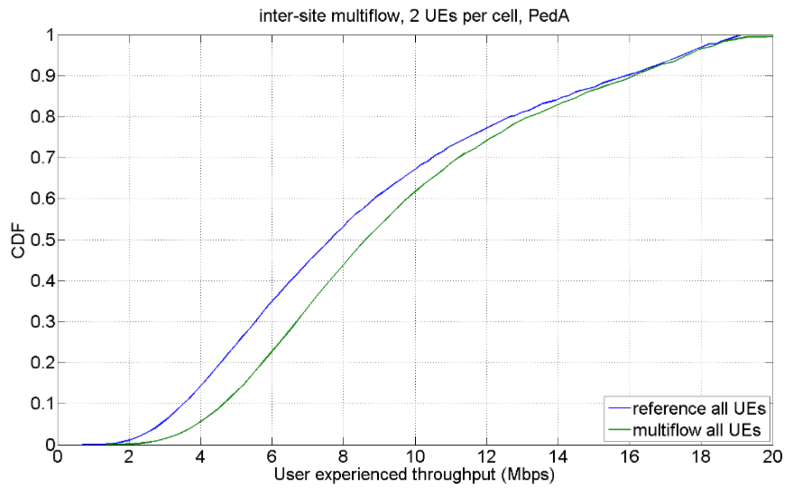

Figure 3.15. Cumulative probability distribution of user throughputs with and without Multiflow.

Figure 3.15 shows the cumulative distribution of the throughput experienced by the user with and without Multiflow (including both intra-site and inter-site Multiflow UEs). At the low values of the cumulative distribution, users at the cell edge gain particular benefit from Multiflow, since they are the most likely to receive transmissions from multiple cells with adequate signal quality.

Downlink Multiflow Transmission is part of 3GPP Rel-11 and can be configured together with Dual-Cell HSDPA for transmitting to the UE from 4 cells (two in each carrier) at the same time. Multiflow is also compatible with 2X2 MIMO allowing for each cell in the Multiflow set to transmit two data streams to the UE.

3.2.1.3 4-BRANCH MIMO

Downlink 4-branch MIMO as shown in Figure 3.16 introduces a higher order MIMO mode to HSDPA. With 4 receive antennas in the UE; the downlink peak rate can be doubled from that possible with 2X2 MIMO to 84 Mbps for a 5 MHz carrier. The capacity gain of 4-branch MIMO comes mostly from supporting 4-way Recieve (Rx) diversity. The peak data rate gain on the other hand is enabled by extending the HSDPA MIMO layers from two in 2X2 MIMO to 4 in 4X4 MIMO.

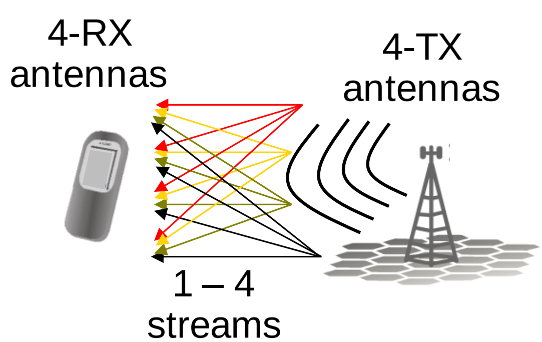

Figure 3.16. Downlink 4-branch MIMO.[113]

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The performance gain can be seen in Figure 3.17, where the average cell throughput is seen under the assumption of ideal channel estimation. It can be seen that adding Rx antennas gives more benefits than adding Transmit (Tx) antennas, while the maximum gain is achieved by using 4 transmit and 4 receive antennas. In that case, the system will automatically switch between beamforming with 4 antennas and using the antennas to send up to 4 parallel streams.

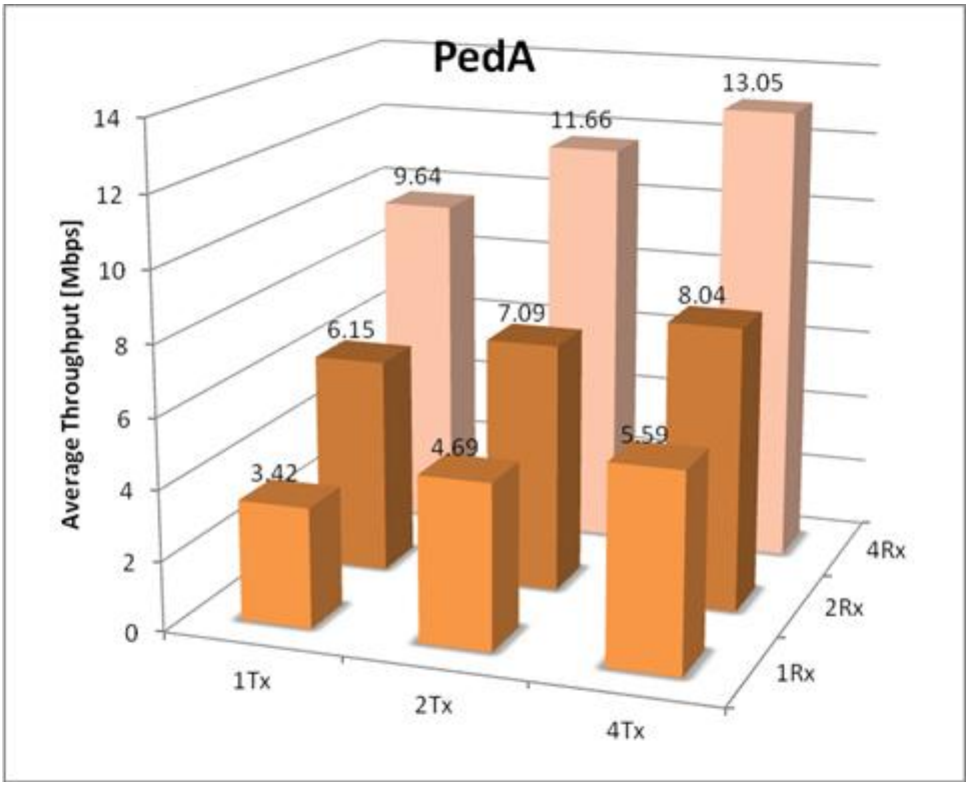

Figure 3.17: Average cell throughput with different number of Rx and Tx antennas.

In Rel-11, the 4-branch MIMO is supported with up to 4 carriers (20 MHz) leading to a peak downlink data rate of 336 Mbps. Future releases could weld the 4-branch MIMO and 8-carrier HSDPA together and reach 672 Mbps peak data rates for HSPA with 40 MHz bandwidth and 4 MIMO layers.

3.2.2 UPLINK (UL) ENHANCEMENTS

Uplink enhancements in Rel-11 include dual antenna beamforming and MIMO with 64 QAM which is explained in the following section.

3.2.2.1 DUAL ANTENNA BEAMFORMING AND MIMO WITH 64 QAM

Uplink dual antenna beamforming and 2X2 MIMO as shown in Figure 3.18 allows for the HSUPA transmissions to originate from two transmit antennas. Both rank 1 (single stream beamforming) and rank 2 (dual-stream MIMO) transmission modes are introduced. The rank 1 beamforming gains allow for better uplink data rate coverage and the rank 2 MIMO doubles the achievable peak data rate on the carrier. In addition, 2X4 antenna configurations with 4 Node B Rx antennas have been considered in the 3GPP evaluation work, even though additional receive antennas are more of a deployment option and do not impact the standards. Four-way Rx is expected to roughly double the capacity and significantly improve the probability for rank 2 transmission.

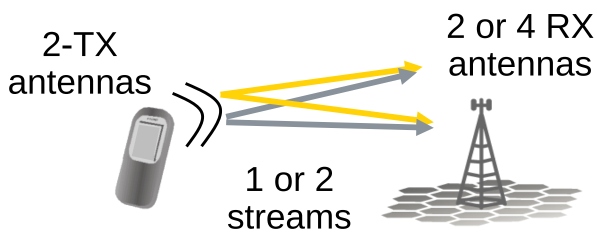

Figure 3.18. Uplink Dual Antenna Beamforming and MIMO.[114]

With uplink 2X2 (and 2X4) MIMO the uplink peak rate reaches 23 Mbps per 5 MHz carrier with 16 QAM modulation. As an additional evolutionary step, 64QAM modulation is also introduced, bringing the uplink peak rate with MIMO to 35 Mbps per 5 MHz carrier.

In order to be able to reach received signal-to-noise ratios that are high enough to make dual stream transmission with 64 QAM possible, clear dominance areas, four or even eight receiver antennas, or a combination of both will be required. Yet again, this is analogous to what happens in the downlink. Dual antenna transmission in the uplink should be viewed as two separate features. The first feature is the uplink beamforming, which is possible and beneficial in most environments and provides better uplink data rate coverage. The second feature is the uplink dual stream MIMO, which is possible only in more limited scenarios and doubles the uplink peak rate. Introducing 64 QAM modulation is a feature that does not require two transmit antennas, but when reaching for the highest peak rates, it needs to be coupled with uplink MIMO.

Figures. 3.19 and 3.20 show the gains of beamforming on the average and cell edge throughput. It can be seen that gains of up to 20 percent and 80 percent can be achieved respectively.

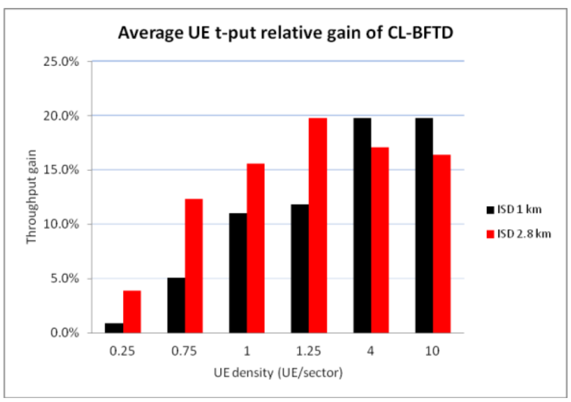

Figure 3.19. Average gain from Closed Loop Transmit Diversity in the uplink.

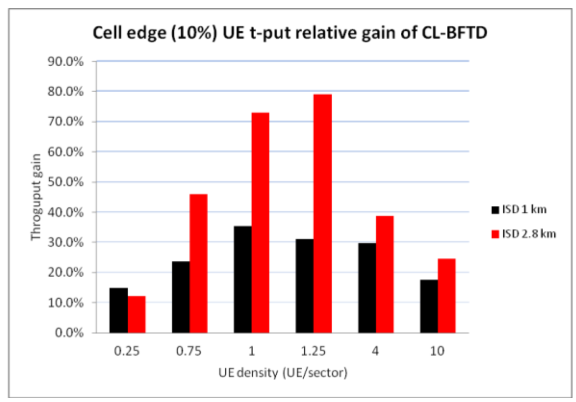

Figure 3.20. Cell edge gain from Closed Loop Transmit Diversity in the uplink.

Uplink beamforming, uplink 2X2 MIMO and uplink 64QAM (together with 2X2 MIMO) are supported by 3GPP Rel-11.

3.2.3 CELL_FACH IMPROVEMENTS

The Cell_FACH improvement features of Rel-11 are building on top of the high-speed Forward Access Channel (FACH) and RACH concepts introduced in 3GPP Rel-7 and Rel-8 respectively. The set of small improvements can be split into categories: improvements in downlink, uplink, UE battery life and mobility.

114 The Evolution of HSPA: The 3GPP Standards Progress for Fast Mobile Broadband Using HSPA+, 4G Americas, October 2011.

3.2.4 MACHINE TYPE COMMUNICATIONS (MTC)

Similarly to E-UTRA (see section 3.1.7), EAB has also been defined for Rel-11 UTRA. EAB enables the RAN (in this case UTRAN) to bar the access of one or several classes of UEs configured for EAB via new system information (dedicated for "EAB devices"). This allows a better control of signaling congestion and/or overloading in RAN due to MTC devices.

At a high level, the mechanism is similar to that defined in LTE. UTRAN can broadcast a new (EAB specific) SIB (i.e., SIB type 21), carrying a *EAB Class Barred List* (10 bits, corresponding to AC 0-9, where each bit indicates if access is allowed (0) or barred (1), and a *EAB Subcategory* (corresponding to PLMN categories). A UE configured for EAB shall use its allocated Access Class and PLMN sub-category when evaluating the EAB information that is broadcast by the network, in order to determine if its access (subject to EAB as per NAS request) is barred or not. Network sharing flexibility (EAB parameters per sharing PLMN) is supported also for UTRAN.

Few specific/additional UTRAN EAB aspects/requirements are:

- SIB 21 updates are notified to the UEs by means of legacy mechanisms (e.g., "value tag" change)
- UMTS EAB can be applied per CN domain (CS domain, Packet Switched (PS) domain, or both)

UMTS EAB is applicable to both Idle and Connected RRC states/modes, in particular EAB check is performed before sending a RRC connection request in idle mode and/or an Initial Direct Transfer (like Domain Specific Access Control (DSAC)) in connected mode.

3.3 NETWORK AND SERVICES RELATED ENHANCEMENTS

3.3.1 MACHINE TYPE COMMUNICATIONS (MTC)

Most important features and requirements such as device triggering, PS-only subscription and E.164 number shortage were addressed under the Work Item "System Improvements for Machine Type Communication (SIMTC)" in 3GPP Rel-11. Considering the number of MTC features in the set of service requirements, the feature work was prioritized.

Following are the main features introduced as part of this work and documented in TS 23.682[115]:

- Enhanced architecture including new functional entities called MTC Interworking Function (MTC-IWF) and MTC Authentication, Authorization and Accounting (MTC-AAA)
- Identifiers (Mobile Subscriber Integrated Services Digital Network Number-less (MSISDN-less)) – Usage of Internet-like identifiers at the external interface between Public Land Mobile Network (PLMN) and service provider domain to replace MSISDN
- Addressing – IPv6 was recommended for usage with MTC devices
- Device Triggering – Mobile Terminated-Short Message Service (MT-SMS) with a standardized interface to the SMSC
- Optimizations for devices with PS-only subscription

[115] 3GPP TS 23.682, "Technical Specifications Group Services and System Aspects; Architecture Aspects to Facilitate Communications with Packet Data Networks and Applications (Release 11)", V11.1.0 (2012-06).

- Dual-priority devices – certain applications can override low access priority configuration
- EAB for E-UTRAN and UTRAN
- SMS in MME configuration (architecture option for networks with no UTRAN or GERAN CS domain where a direct interface from Short Message Service Center (SMSC) to MME for SMS delivery is deployed).

3.3.1.1 MTC ARCHITECTURE

3GPP mainly introduced a new interworking function MTC-IWF in the architecture (shown in Figure 3.21) for service providers to interconnect with the mobile operator network to enable control plane device triggering, identifier translation and other features in the future. The end-to-end communication between the MTC application in the UE and the MTC application in the service domain may use services provided by the 3GPP system, and optionally services provided by a Services Capability Server (SCS). The MTC Application in the external network is typically hosted by an Application Server (AS). The SCS can be located in the service provider domain (as shown in the figure below), or it can also be hosted by the Mobile Network Operator (MNO) as a kind of Service Delivery Platform. In the latter scenario the SCS can implement charging and security functions. The SCS can be located in the service provider domain (as shown in the figure below) or by the MNO as a kind of Service Delivery Platform. In the latter scenario the SCS can implement charging and security functions.

While the MTC-IWF serves as first contact point for requests coming from the SCS and provides security, charging and identifier translation (external to internal identifier) at the ingress of the PLMN, the newly introduced MTC-AAA function translates the internal identifier (IMSI) at the network egress to the external identifier(s) before forwarding AAA requests to an AAA server in the service domain (thus avoid exposing IMSI outside the MNO domain). MTC-IWF receives a device trigger request from the SCS over the Tsp interface and forwards it to the SMSC via T4. It receives subscription data including the IMSI from the HSS via S6m and provides charging events via the existing interfaces Rf/Ga to the Charging Data Function (CDF)/Charging Gateway Function (CGF).

MTC-AAA can work in server or proxy mode and has interfaces to the P-GW/GGSN (Gi/SGi) (where AAA requests originate from), HSS (S6n) (to retrieve external identifier(s) for a given IMSI and vice versa) and external AAA servers. MTC-IWF receives a device trigger request from the SCS over the Tsp interface and forwards it to the SMSC via T4. It receives subscription data including the IMSI from the HSS via S6m and provides charging data via the existing interfaces Rf/Ga to the charging gateway.

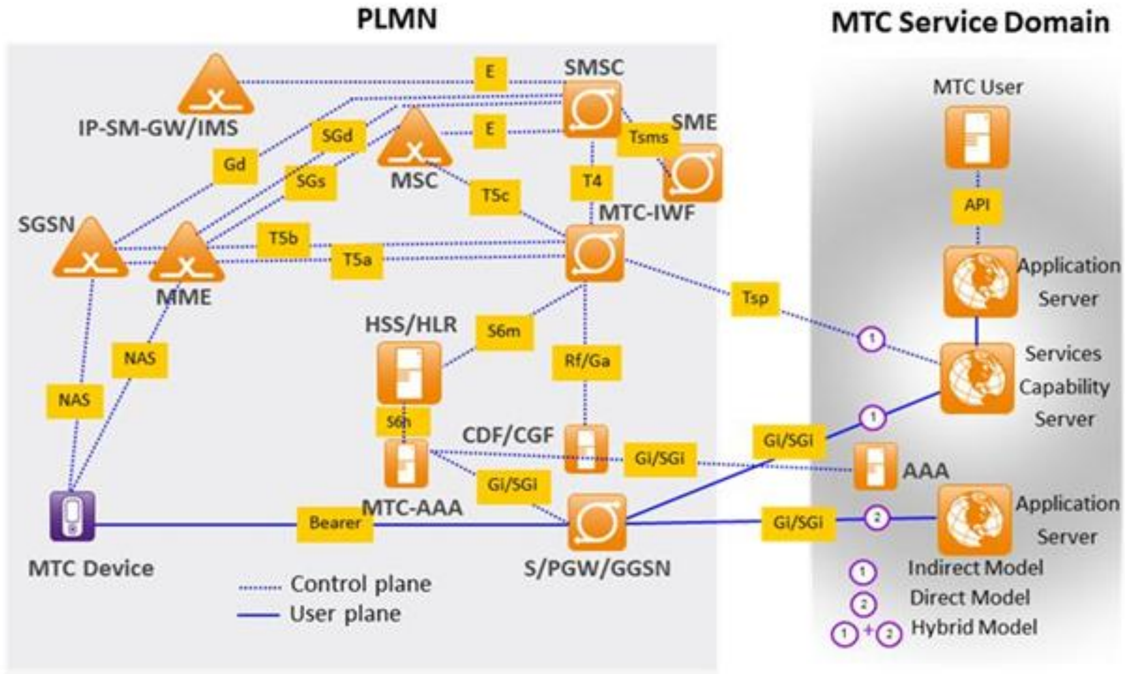

Figure 3.21. MTC Architecture.[116]

Different deployment models are possible for Machine Type Communication that allows support for different service level agreements between MNO and service provider:

- Direct Model: The AS connects directly to the operator network in order to perform direct user plane communication with the UE without the use of any SCS, this allows for simple implementation of Over-the-Top (OTT) applications, OTT deployments are transparent to the PLMN.
- Indirect Model: The AS connects indirectly to the operator network through the services of a SCS in order to perform indirect user plane communication with the UE and to utilize additional value added services (for example, control plane device triggering). The SCS is either:
  - MTC Service Provider controlled: The SCS is an entity outside of the operator domain and Tsp is an external interface (therefore, to a third party MTC Service Provider), or;
  - 3GPP network operator controlled: The SCS is an entity inside the operator domain and Tsp is an internal interface to the PLMN.
- Hybrid Model: The AS uses the direct and indirect models simultaneously in order to connect directly to the operator's network to perform direct user plane communication with the UE while also using SCS-based services. From the 3GPP network perspective, the direct user plane communication from the AS and any value-added control plane-related communication from the SCS are independent and have no correlation to each other even though they may be servicing the same MTC Application hosted by the AS.

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Since different models are not mutually exclusive, but just complementary, it is possible for a 3GPP operator to combine them for different applications. This may include a combination of both MTC service provider and 3GPP network operator controlled SCSs communicating with the same PLMN.

3.3.1.2 IDENTIFIERS

As mentioned earlier, shortage of E.164 numbers is an additional driver for optimizations and improvements in mobile networks. This urged the need to define Internet-like identifiers such as Fully Qualified Domain Names (FQDN), Uniform Resource Names (URN) or Uniform Resource Identifiers (URI) for subscriptions without MSISDN. Such identifiers are referred to as external identifiers.

One IMSI may have one or more external identifier(s) that are stored in the HSS. Rationale behind one to many mapping is twofold. A single device may have several applications running on the device and each application may use its own external identifier. Alternatively, a single device may have subscriptions with several service providers for different applications and each service provider may assign its own external identifier. Although this approach provides more flexibility for deployments, it comes with some drawbacks. At the border between PLMN and the service domain, external identifiers are used and the PLMN translates them to one internal identifier (like the IMSI) for usage within the core network. Reverse mapping (for example, for Mobile Originated Short Message Service (MO-SMS), at Gi/SGi interface) from internal to external identifiers may then cause issues in terms of the uniqueness of the reverse translation. Choosing the correct external identifier in such scenarios has not been resolved in the Rel-11 timeframe thus caution needs to be taken when assigning multiple external identifiers to a single subscription identified by IMSI.

The External Identifier shall be globally unique and has the following components:

- Domain Identifier: identifies a domain that is under the control of the Mobile Network Operator, therefore the SCS/AS use domain identifier to determine the correct MTC-IWF.
- Local Identifier: used to derive and obtain the IMSI. It shall be unique within the applicable domain and is managed by the Mobile Network Operator.

The External Identifier will have the form of a Network Access Identifier (NAI), therefore, username@realm, as specified in clause 2.1 of Internet Engineering Task Force Request for Comments (IETF RFC) 4282[117]. The username part format of the External Identifier shall contain a Local Identifier. The realm part format of the External Identifier shall contain a Domain Identifier. As a result, External Identifier will have the form "<Local Identifier>@<Domain Identifier>". This will mainly be used at Tsp, S6m, S6n, T4, Rf/Ga interfaces. External Identifier is not visible in the MME/SGSN/P-GW/GGSN mainly to avoid impacts to GTP signaling messages.

3.3.1.3 ADDRESSING

To cope with the expected huge number of machines connecting to the network IPv6 is recommended as a preferred addressing format for devices subscribed for machine type communication. For details on IP addressing principles and solutions for different scenarios, refer to Technical Specification (TS) 23.221[118].

[117] RFC 4282, "The Network Access Identifier", December 2005.
[118] 3GPP TS 23.221, "Technical Specification Group Services and Systems Aspects; Architectural Requirements (Release 11)", V11.0.0 (2011-2012).

3.3.1.4 DEVICE TRIGGERING

Device Triggering is a feature meant to trigger MTC devices in the attached state, with and without an existing Packet Data Protocol (PDP)/PDN connection. In current deployments, SMS is used to trigger attached devices but this requires a MSISDN allocated to each MTC subscription. As MSISDN ranges are limited in some regions (for example, in the U.S. and China), it is required to look for solutions that do not need a unique MSISDN per MTC user. In addition, solutions that are using Internet-like identifiers like NAI are more flexible as Mobile Network Operators and MTC service providers can allocate such identifiers freely on a per needed basis. It has to be noted that devices with an established PDP/PDN connection (for example, all devices attached to SAE/LTE) can register their IP address over-the-top at the Application Server by application layer means. Thus, the server can trigger the device by sending an application layer trigger request over the user plane without the need to use 3GPP network capabilities. However, when the SCS requests the 3GPP network to trigger a MTC device, it can provide the appropriate identifier in the request and the network has to translate this external identifier into an internal one (for example, the IMSI) that can be used to trigger the device. The device could be triggered by different means such as SMS, Cell Broadcast messages, Session Initiated Protocol (SIP) messages (Instant Messaging or SMS over IP), or via some new path traversing the MME/SGSN and/or HSS/Home Location Register (HLR) (for example, using Hyper Text Transfer Protocol (HTTP), DIAMETER/MAP and NAS as transport means). However, in Rel-11 SMS is the only standardized mechanism that has been adopted for device triggering. Cell broadcast messages are used by some operators for triggering groups of devices, but this is a proprietary solution. The External Identifier has to be stored in the HSS/HLR in order to allow the 3GPP network to translate the external request coming from the SCS into an internal trigger request using the proper Internal Identifier. One device may be assigned multiple External Identifiers thus the HSS/HLR needs to store one IMSI with many External Identifiers. Figure 6.8 shows the MTC architecture for device triggering with the interface Tsp (sp = service provider) between SCS and 3GPP network. Tsp is used by the SCS to send a trigger request to the PLMN using the External Identifier to identify the target device. Tsp is based on DIAMETER and terminates at the MTC Interworking Function (MTC-IWF) within the PLMN. The MTC-IWF sends the trigger request to the SMSC using the new T4 interface, which is also based on DIAMETER and described in TS 29.337[119]. Device triggering over Tsp/T4 is the only standardized method for triggering in Rel-11. Alternative solutions for triggering may be specified in the Rel-12 time frame. Optionally, the SCS/AS can also send device trigger SMS via the Tsms interface to the SMSC. Tsms is the existing legacy interface between a Short Message Entity (SME), for example, the SCS/AS and the Short Message Service Center (SMSC) to send and receive short messages.

3.3.1.5 PS-ONLY SERVICE PROVISION

PS-only service provision is providing a UE with all subscribed services via PS domain. PS-only service provision implies a subscription that allows only for services exclusively provided by the PS domain, therefore, packet bearer services and SMS. Support of SMS, via PS domain NAS, is a network deployment option and may depend also on roaming agreements. Therefore, a subscription intended for PS-only service provision may allow also for SMS services via CS domain to provide a UE with SMS services in situations when serving node or network does not support SMS via the PS domain. The functionality that enables PS-only service provision is described in TS 23.060[120] and TS 23.272[121].

3.3.1.6 DUAL PRIORITY DEVICES

As mentioned above, low priority access configuration was introduced in Rel-10 to aid with congestion and overload control when millions of M2M devices are trying to connect to the network. There may, however, be circumstances when such devices need to access the network for higher priority services. Following are some example scenarios:

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119 3GPP TS 29.337, "Technical Specification Group Core Network and Terminals; Diameter Based T4 Interface for Communications with Packet Data Network and Applications (Release 11)", V0.1.0 (2012-06).
120 *Ibid.*
121 *Ibid.*

- Electricity meters sending a daily report (of the per hour usage) can send this as 'low priority', but, may want to send an alarm without "low priority," if the meter is being tampered with or is being vandalized

- A road temperature sensor could send daily "I'm still working" reports using "low priority," but, when the temperature falls to sub-zero, immediately send a warning to the control center without "low priority"

- A M2M module which hosts multiple hybrid applications; the room temperature application always requires data transmission using "low priority" and video streaming application requires data transmission without using "low priority"

As a result, it is possible that an application overrides the "default low priority" setting on rare occasions for establishing normal connections. To accomplish this, a new configuration parameter called "override low priority access" was introduced. Devices with both low priority access and override low priority access configurations are considered to be dual priority devices. Override low priority access indicates to the UE that an application is allowed to connect to the network without setting the low priority indicator (for example, in PDN connection request messages). PDN connections marked as low priority and not marked as low priority may co-exist. When the UE has PDN connections established with low priority and without low priority, it is allowed to establish mobility management procedure and RRC connections without low priority / delay tolerant indicator.

3.3.1.7 ENHANCED ACCESS BARRING

Enhanced Access Barring (EAB) is a mechanism to restrict network access for low priority devices. This is activated by the Radio Access Network. A network operator can restrict network access for UE(s) configured for EAB in addition to the common access control and domain specific access control when network is congested. The UE can be configured for EAB in the USIM or in the ME. When EAB is activated in the radio base station (for example, via OA&M) and UE is configured for EAB, it is not allowed to access the network. When the UE is accessing the network with a special access class (AC 11 – 15) and that special access class is not barred, the UE can ignore EAB. Also, if it is initiating an emergency call and an emergency call is allowed in the cell, it can ignore EAB. UE is also allowed to respond to paging when barring is active and this is under the assumption that the network will initiate paging only when there is no more congestion.

Dual priority devices may also be configured with override EAB configuration. If the UE is configured to override EAB, then it indicates to the UE that it is allowed to override EAB when normal priority PDN connections are active.

3.3.1.8 SHORT MESSAGE SERVICE IN MME

SMS in MME was introduced for both MT and MO-SMS services mainly to address requirements from operators who do not deploy a 3GPP MSC (thus no SGs interface is available) and do not want to support MAP in their network. SMS over IP (i.e. SMS over IMS) could be one solution to address this, however the concern with this solution was the need for an IMS/SIP client in the devices and that not all devices (for example, machine type device, dongles) will have an IMS/SIP client implemented. Furthermore, inbound roamers whose home operators may not support IMS cannot be offered SMS over IMS thus will need support for SMS over NAS. These factors resulted in the need to introduce a new architecture for supporting SMS services in EPC defined in TS 23.272[122] (see Figure 3.22). The required protocol enhancements can be found in TS 29.338. This feature can be enabled or disabled in the MME via configuration.

[122] 3GPP TS 23.272, "Technical Specification Group Services and System Aspects; Circuit Switched Fallback in Evolved Packet System (EPS); Stage 2 (Release 11)", V11.1.0 (2012-06).

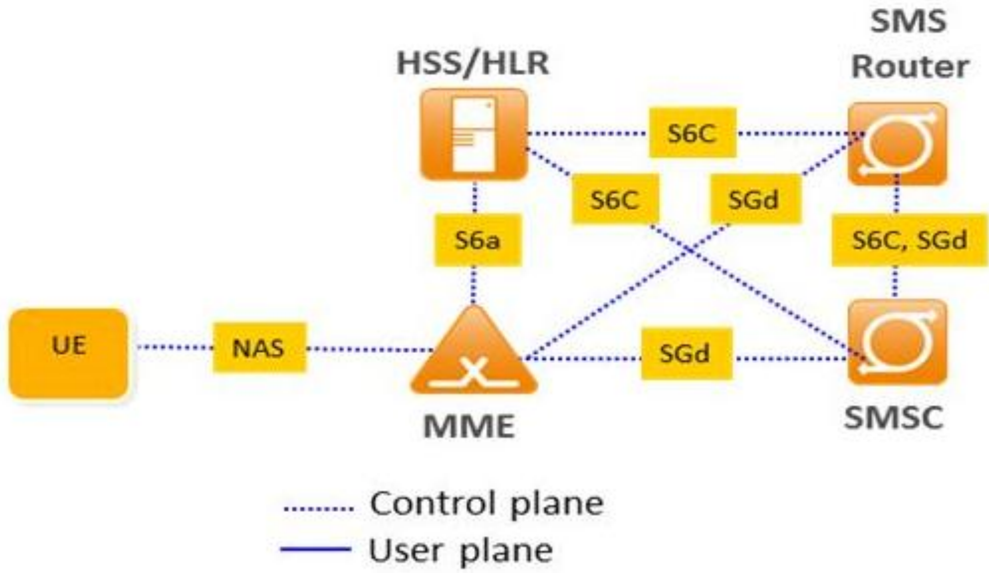

Figure 3.22. SMS in MME Architecture.

From the UE perspective, it remains transparent whether SMS in MME or SMS over SGs is offered by the network. The UE will perform combined EPS/IMSI attach (or combined TAU) in order to obtain SMS services. The network can decide to offer SMS over SGs or SMS in MME depending on various factors such as the user's subscription (PS-only, PS+CS), the user's requested service (SMS-only or SMS+voice), support for the feature in general, and local policies. If the UE is performing "combined attach" to request for SMS services only and the network supports SMS in MME, the network need not establish a SGs association between MME and MSC. The network will then indicate "SMS-only" in the accept message to inform the UE that it has been attached only for SMS services. To keep it transparent to the UE, MME will include a non-broadcast Location Area Identification (LAI) ("dummy LAI") and a Temporary Mobile Subscriber Identity (TMSI) value which cannot cause any ambiguity with assigned TMSI values in the combined attach accept or combined Target Acquisition and Tracking Unit (TAU) accept. This ensures backward compatibility so that the legacy UE considers the attach procedure to be successful. Between the UE and the MME, SMS is tunneled within NAS messages similar to the SMS over SGs architecture. SMS messages as defined in 3GPP TS 23.040[123] are encapsulated and transferred within NAS messages.

3.3.2 NETWORK PROVIDED LOCATION INFORMATION FOR IMS (NETLOC)

Network Provided Location Information for IMS Services is a core network enhancement.

Location Service (LCS) for EPS has been defined in Rel-9. Normally the LCS information is provided in the geographical information format, which is not suitable for charging purposes as it lacks access network information.

In the circuit switched network when a UE initiates a CS call or sends an SMS message, the MSC can get the current cell-ID information provided by RNC/Base Station Controller (BSC), which can be used for charging purposes and/or for recording the location of a subscriber for whom the government authority requests communication history. In the IMS, cell-ID information is provided currently by the UE. As the cell-ID information provided by the UE cannot be trusted, it is required that the network provides the cell-ID for scenarios like: lawful interception; IMS session charging records;

[123] 3GPP TS 23.040, "Technical Specification Group Core Network and Terminals; Technical Realization of Short Message Service (SMS) (Release 11)", V11.2.0 (2012-06).

destination for IMS emergency call selection; and IMS services that may need cell-ID information to trigger localized services.

Stage 2 worked on specifying the architecture solutions for making the cell-ID / PLMN ID and local time that the UE is camped-on, available to the IMS nodes when the mobile operator needs to record this information, either to fulfill legal obligations or for charging purposes. TR. 23842 recorded proposed solution alternatives and conclusions. Multiple Stage 2 specifications are updated, including 23.401, 23.060, 23.228 and 23.203, with regard to:

- EUTRAN, UTRAN and core network procedures are defined in 23.401, 23.060 for providing User Location Information (ULI) to Policy and Charging Rules Function (PCRF);
- The User Location Information is in the form of E-UTRAN Cell Global Identifier (ECGI)/Tracking Area Identity (TAI) or cell/ Service Area Identifier (SAI) and/or Local Time /time zone as part of bearer handling procedures in the enhancement to PS domain;
- Policy and Charging Control (PCC) procedures and event trigger ANI (Access Network Information) are defined (in TS 23.203) for IMS Application Function (AF) to subscribe ANI trigger to PCRF for ULI retrieval related to a user session creation, modification and termination;
- In TS 23.228 and 23.401, two mechanisms are defined for an AF to retrieve ULI:
    - The Proxy Call Session Control Function (P-CSCF) can retrieve the user location and/or UE Time Zone information using PCC mechanisms as specified in TS 23.203 and in TS 29.214. Operator policy determines whether to provide the the user location and/or UE Time Zone information from the access network in the INVITE request or within a subsequent message of the dialog.
    - When the user location and/or UE Time Zone information is required from the access network but not already available (e.g. when required in an INVITE request, when it is needed prior to session delivery, or when call is broken out to a Media Gateway Control Function (MGCF)), an IMS AS can trigger the retrieval of the user location and/or UE Time Zone information from the SGSN/MME via the HSS as specified in TS 29.328 and as described in clause 4.2.4a in TS 23.228.

Number of Core Network and Terminals (CT) and RAN specifications are updated for protocols and procedures to provide above features.

The SA5 specifications update was completed in September 2012, for charging architecture and principles with the addition of network-provided location information to IMS charging, Call Detail Record (CDR) definitions and corresponding diameter Attribute Value Pair (AVP) definition.

After R11 NetLoc work is closed, there are several corrections and alignment on TS 23.203, 23.401, and 23.060 to align the PCC frame work for ULI reporting. These changes include:

- At PCC rule activation, modification and deactivation the Event Reporting Function (ERF) shall send, as specified in the PCC/QoS rule, the User Location Report and/or UE Timezone Report to the PCRF.
- User last known location information: if requested by PCRF, in the Detach and Bearer Deactivation procedures, the MME and Serving/Public Data Network Gateway (S/P-GW) shall inform PCRF of the last known location of the UE, and with the information to enable the determination of the time at which the UE was in that location.
- At PCC rule deactivation, user last known location shall be reported by PCRF to AF upon receiving an Access Network Information report corresponding to the AF session from the ERF,

- If the Access Network Information report parameter for the User Location Report is set and the user location (i.e., cell) is not available to the ERF, the ERF shall provide the serving PLMN identifier to the PCRF which shall forward it to the AF.

- In alignment with Stage 3 Rel-11 work, report of geographical identifier described in geospatial manner within a country or territory or as civic ULI (postal code, area code, etc.) is moved to Rel-12.

3.3.3 SINGLE RADIO VOICE CALL CONTINUITY (SRVCC)

Voice over LTE (or VoLTE) with Single Radio Voice Call Continuity (SRVCC) to improve voice coverage by handing over the voice session from LTE to 2/3G CS domain has been standardized since Rel-8. The architecture enhancement for SRVCC (called eSRVCC) in Rel-10 can improve the handover performance overall. In Rel-11, SRVCC feature has been further enhanced with the priority handover (eMPS aspect of SRVCC), SRVCC from 2/3G CS to LTE/HSPA (rSRVCC), and video SRVCC from LTE to UMTS (vSRVCC).

3.3.3.1 EMPS ASPECT OF SRVCC

Enhancements for Multimedia Priority Service (eMPS) is a feature in Rel-10 for IMS sessions and EPS bearer sessions. The SRVCC with priority treatment is deferred to Rel-11. Depending on regulatory requirements in a region, it is useful to forward priority indication of an IMS-based voice call over LTE with priority to Circuit Switch of GERAN/UTRAN so that the call can be handled in a prioritized way, compared to other normal IMS-based voice calls when SRVCC is performed. In Rel-11, SRVCC has also been standardized for IMS voice+video session to UMTS CS video; hence, eMPS SRVCC can also apply to video SRVCC.

The mechanism to handle SRVCC for an IMS-based priority voice or voice+video session established in LTE in GERAN/UTRAN is to reuse the priority handling mechanisms that were already defined for GERAN/UTRAN in TS 25.413[124] for UMTS, and defined in TS 48.008[125] for GSM/EDGE. Figure 3.23. shows the overall call flow for SRVCC with eMPS handling.

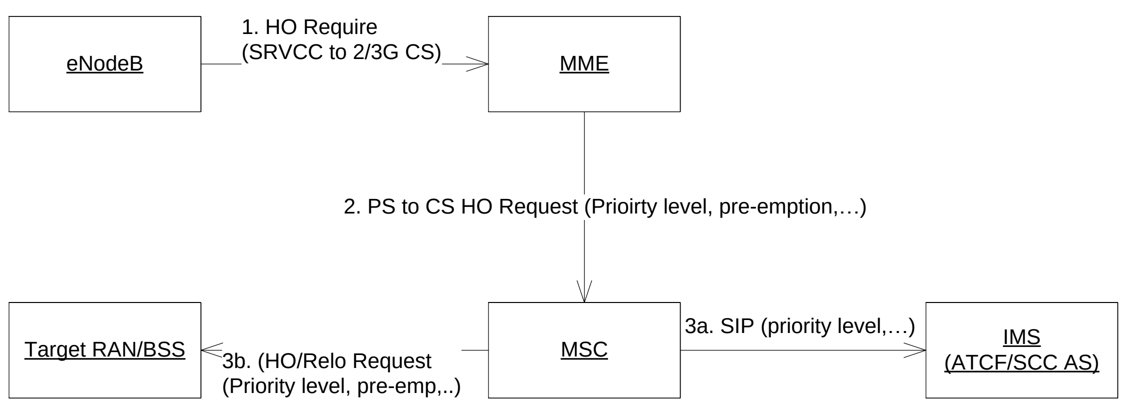

Figure 3.23. eMPS Aspect of SRVCC Session Handling.[126]

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124 3GPP TS 25.413, "Technical Specifications Group Radio Access Network; UTRAN Iu Interface Radio Access Network Application Part (RANAP) Signaling (Release 11)", V11.0.0 (2012-06).
125 3GPP TS 48.008, "Technical Specification Group GSM/EDGE Radio Access Network; Mobile Switching Centre – Base Station System (MSC-BSS) Interface; Layer 3 Specification (Release 11)", V11.2.0 (2012-05).
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1. eNodeB determines that SRVCC (voice or voice+video) needs to be performed and indicates to MME via S1_AP signaling.

2. MME determines to invoke eMPS SRVCC based on the Allocation and Retention Priority (ARP) value associated with the EPS bearer used for IMS signaling bearer (therefore, QCI-5). Based on MME configuration, certain ARP values are reserved for eMPS session. For eMPS SRVCC, MME forwards the ARP to the MSC Server in PS to CS HO Request message. The ARP also contains whether this request allows pre-emption of other existing in-use bearers in order to make resources for this Handover request.

3. MSC Servers uses the ARP value and pre-emption indication to determine its local priority level for requesting radio resources from target RAN/Base Station Subsystem (BSS) via the A / Iu-cs and from IMS nodes via SIP. The target RAN/BSS may put in queue the handover request or pre-empt an ongoing resource depending on the setting on the A/Iu-cs from MSS. The IMS nodes handle this session transfer request with priority.

Please note that the eMPS SRVCC to 1xCS is not defined in 3GPP.

3.3.3.2 SRVCC FROM 2/3G CS TO LTE/HSPA

In Rel-11, 3GPP has developed a feature to allow a CS voice call to be handed over to LTE/HSPA as an IMS voice session. Specially, CS call from 2/3G to LTE or from 2G to HSPA is supported (i.e., 3G to HSPA is not supported). This feature is sometimes called rSRVCC where “r” stands for reverse. The solution is biased toward enhancing user experiences (therefore, for higher data throughput as much as possible) versus the traditional view for coverage scenario. Hence, the handover solution requires more network preparation before the UE can perform the RAT changes.

There are certain pre-conditions that the network and UE must meet prior to rSRVCC. The UE must first have an active EPS bearer or PDP context, the UE must perform a successful IMS registration via Gm and indicate all the necessary rSRVCC related parameters to the IMS, the subscription profiles in HSS must allow rSRVCC, the serving MSC Server must perform the I2 IMS registration and must receive the needed rSRVCC parameters from IMS, and the IMS registration (the one via Gm) must not be expired.

When all of the above conditions are met, the 2/3G CS RAN/BSS and MSC server can start the rSRVCC procedure with the target LTE/HSPA. Figure 3.24. shows the overall call flow for rSRVCC to LTE/HSPA.

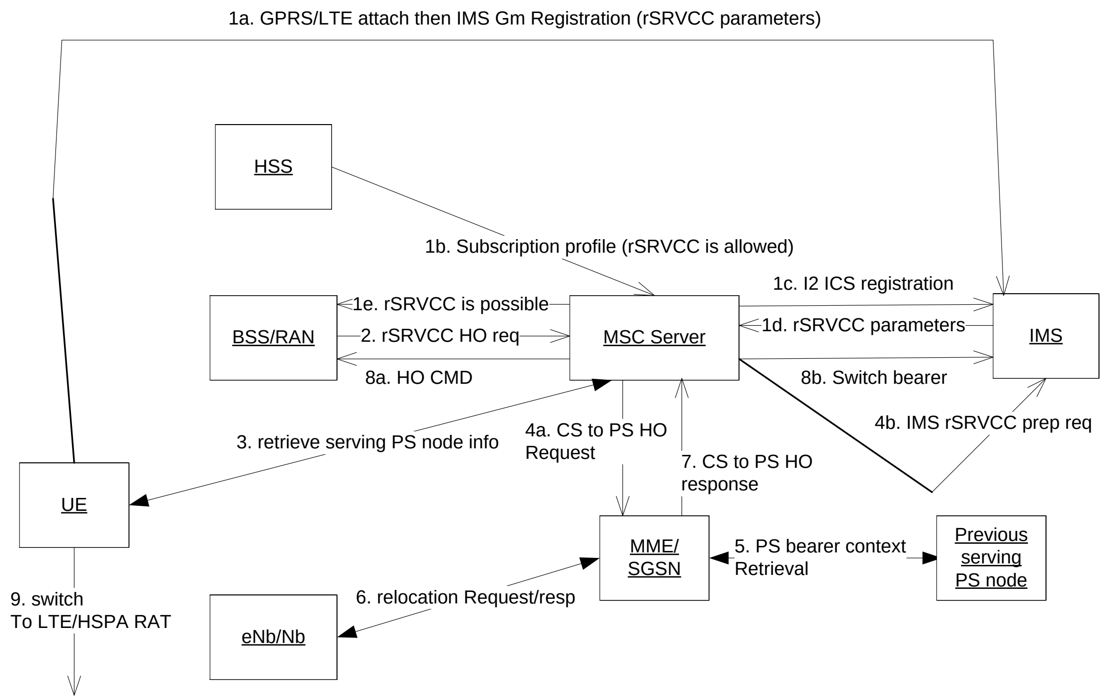

Figure 3.24. Call handling with rSRVCC.[127]

As described in the paragraph above, the pre-conditions for rSRVCC are shown as in step 1a to 1e. The rSRVCC capable UE indicates to IMS in step 1a of its supported voice codecs and the DL port number to be used for IMS voice media. This information is stored in IMS (ATCF) and the Access Transfer Control Function (ATCF) address is given to MSC Server is step 1d as the result of the ICS I2 IMS registration. When all the pre-conditions are met, the MSC Server indicates to BSS/RAN during the CS call setup procedure that rSRVCC is possible. MSC Server then retrieves the serving PS node information from UE as shown in step 3 when rSRVCC HO request is triggered (step 2). PS node information is the current serving SGSN or MME that has the UE PS context (for example, IP address, which PS bearer is active or in suspend). MSC Server then requests IMS (therefore, ATCF address received in step 1d) to start preparing for the media transfer in step 4b and to retrieve the PS media information transport address and codec information. The PS media information includes the Uplink IP address and port number, and the codec that the UE needs to be used when it is transmitting PS voice to the network over LTE after rSRVCC has performed.

In step 4a, the MSC server requests the target SGSN/MME to reserve the PS resources for rSRVCC by using CS to PS HO request message and indicates the current PS serving node information in this message. SGSN/MME uses the PS node information to retrieve the UE PS contexts (step 5), and then requests the target eNb/Nb to reserve the PS bearers according to the PS contexts (step 6). The radio resources are reserved, the related Handover command is returned back to MSC Server in CS to PS HO response in step 7.

In step 8 a/b, the MSC Server coordinates the IMS media switching with the sending of the handover command to UE. This causes the UE to change the RAT to LTE/HSPA (step 9) while the IMS begins to forward the DL media toward the Internet Protocol Connectivity Access Network (IP-CAN). The UE also sends the UL media to the IMS base after the RAT changes. However, these media (UL/DL) are sent over the non-dedicated bearer at this point, which does not have guaranteed QoS. The UE then requests the IMS to setup a dedicated EPS bearer (therefore, Quality of Service Class Index (QCI-1)) or

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conversational PDP context (HSPA) and transfer the voice media over to the bearer with proper QoS Support. It is expected that the voice session transfer from default bearer to dedicated voice bearer is relatively fast and any voice disruption is minimal to the user.

Please note that emergency rSRVCC is not supported in Rel-11.

3.3.3.3 VIDEO SRVCC FROM LTE TO UMTS

In Rel-11, 3GPP has developed a feature to allow an IMS voice+video session over LTE to be handed over to 3G CS video with 64 kbit CS data bearer. The overall concept follows the voice SRVCC as defined earlier. The main difference is that the MME is aware that a video component is being involved (therefore, indicated by PCC) and it requests the MSC Server to initiate the video SRVCC handling.

For video CS resource handling, MSC Server requests 64 kbit CS data from RAN. It also requests the IMS to perform the media switching from IP-CAN toward CS Domain. Both the UE and network will use a defined default CS video codec initially. UE can then re-negotiate another CS video codec, if needed afterward.

3.3.4 QOS CONTROL BASED ON SUBSCRIBER SPENDING LIMITS (QOS_SSL)

Policy Control Framework has been enhanced with TDF (Traffic Detection Function) for application detection and control features, which comprise the request to detect the specified application traffic, report to the PCRF on the start/stop of application traffic and to apply the specified enforcement actions. The supported enforcement actions are: bandwidth limitation, gating, redirection. Additionally, usage monitoring report to the PCRF is supported per session and per detected application.

PCC architecture is enhanced with a new interface Sd between the TDF and the PCRF, as shown in Figure 3.25.

The Sd reference point enables the signaling of ADC decision, which governs the Application Detection and Control (ADC) behavior, and it supports the following functions:

1. Establishment of Sd session between the PCRF and the TDF;
2. Termination of Sd session between the PCRF and the TDF;
3. Provision of ADC decision from the PCRF for the purpose of application's traffic detection, enforcement and charging at the TDF;
4. Request for ADC decision from the TDF to the PCRF;
5. Reporting of the start and the stop of a detected applications and transfer of service data flow descriptions and application instance identifiers for detected applications from the TDF to the PCRF;
6. Reporting of the accumulated usage of network resources on a per TDF session basis from the TDF to the PCRF;
7. Request and delivery of IP-CAN session specific parameters between the PCRF and the TDF

Two models may be applied, depending on operator requirements: solicited and unsolicited application reporting.

Solicited application reporting: The TDF is instructed by PCRF on which applications to detect, report to the PCRF and the actions to be enforced for the detected application traffic. The detection is applied only if user profile configuration allows this.

Unsolicited application reporting: The TDF is pre-configured on which applications to detect and report. The enforcement is done in the Policy and Charging Enforcement Function (PCEF).

The application detection and control can be implemented either by the standalone TDF or by PCEF enhanced with ADC capabilities (therefore, TDF is encompassed in PCEF).

Refer to the following 3GPP specifications for detailed SAPP (Service Awareness and Privacy Policies) functional, architecture and call flow information:

- TS 23.203 Policy and Charging Control Architecture
- TS 29.212 Policy and Charging Control (PCC); Reference points
- TS 29.213 Policy and charging control signaling flows and Quality of Service (QoS) parameter mapping
- TS 29.215 Policy and Charging Control (PCC) over S9 reference point; Stage 3

To allow mobile operators a much finer granularity of control of the subscribers' usage of the network resources, by linking the subscribers' session QoS with a spending limit, 3GPP work groups completed QoS_SSL work as one of the PCC architecture enhancements. QoS Subscriber Spending Limits (QoS_SSL) gives the operator the ability to deny a subscriber access to particular services if the subscriber has reached his allocated spending limit within a certain time period. It is also possible that the QoS of a subscriber's session could be modified when this spending level is reached. This allows the operator to have an additional means of shaping the subscriber's traffic in order to avoid subscribers monopolizing the network resource at any one time. Support for roaming subscribers without impact on the visited network is also provided. Also, using triggers based on the operator's charging models, the subscriber could be given the opportunity to purchase additional credit that increases the spending limit.

In order to support this functionality, PCC architecture is enhanced with a new interface Sy between PCRF and OCS (Online Charging System), as also shown in Figure 3.25 below:

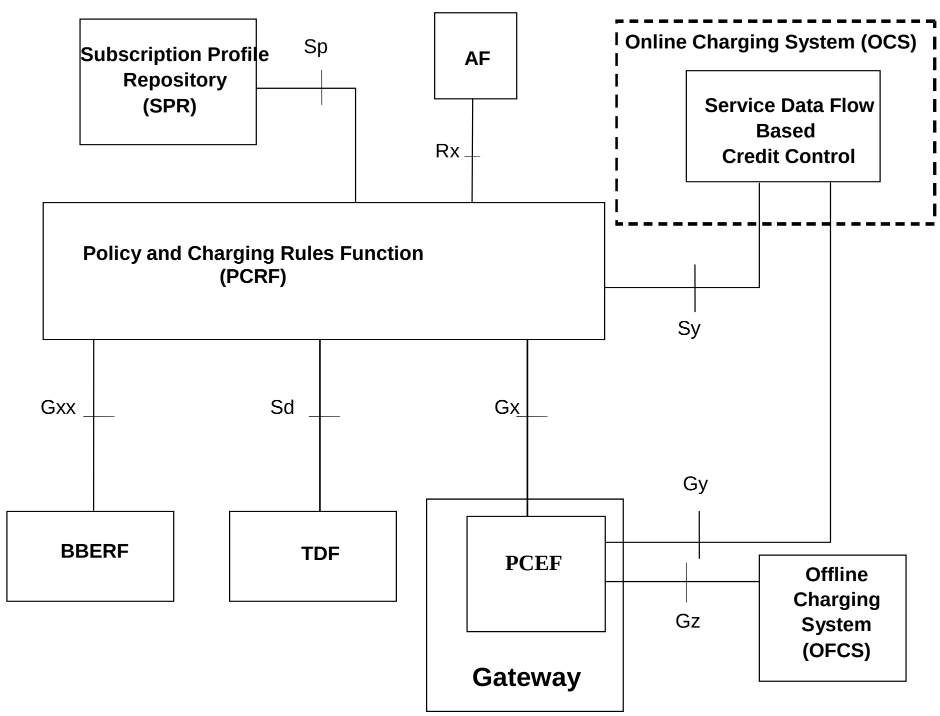

Figure 3.25. Overall PCC logical architecture (non-roaming) when SPR is used.[128]

128 TS 23.203 vb60 Fig. 5.1-1.

BBERF	Bearer Binding and Event Reporting Function
TDF	Traffic Detection Function
SPR	Subscription Profile Repository
PCEF	Policy and Charging Enforcement Function

The Sy reference point enables transfer of information relating to subscriber spending from OCS to PCRF and supports the following functions:

- Request of charging status reporting from PCRF to OCS
- Notification of policy counter status change from OCS to PCRF
- Cancellation of charging status reporting from PCRF to OCS.

"Policy Counter" is a mechanism defined within the OCS to track applicable spending for a subscriber. There is an indication in a subscriber's spending limits profile that policy decisions depend on policy counters available at the OCS that have an associated spending limit and optionally the list of relevant policy counters.

The identifiers of the policy counters that are relevant for a policy decision in the PCRF are stored in the PCRF or possibly in SPR. The PCRF is configured with the actions associated with the policy counter status that is received from OCS.

The PCRF requests the status of policy counters in the OCS at any time using the Initial or Intermediate Spending Limit Report Request Procedure. The OCS provides the status to the PCRF of the requested policy counters.

The PCRF may request spending limit reporting for policy counters from the OCS using the Initial or Intermediate Spending Limit Report Request procedure. If spending limit reporting is enabled, the OCS will notify the PCRF of changes in status of the policy counters (for example, daily spending limit of 2$ reached). The PCRF may cancel spending limit reporting for specific policy counter(s) using the Intermediate Spending Limit Report Request procedure, or for all policy counter(s) using the Final Spending Limit Report Request procedure.

The PCRF may use the status of each relevant policy counter as input to its policy decision to apply operator defined actions, for example, downgrade the QoS (therefore, APN- Aggregate Maximum Bit Rate (AMBR)), modify the PCC/QoS Rules, provide this as policy decisions to the PCEF and to the BBERF (if applicable) or modify the ADC Rules then provide them to the TDF.

Refer to the following 3GPP specifications for detailed QoS_SSL functional, architecture and call flow information:

- TS 23.203 Policy and Charging Control Architecture
- TS 29.219 Policy and Charging Control: Spending Limit Reporting over Sy reference point

SA5 and CT specifications regarding OCS architecture and logical function definition for spending limit control, diameter interface impact, Sy interface related procedures and message flows are also updated.

The additional PCC related features which are part of Rel-11:

- Usage Monitoring congestion handling. This feature helps operators to prevent signaling storm in case of (e.g., happy hour, busy hour etc.), when policy changes simultaneously for many subscribers and usage needs to be reported to the PCRF. In order to prevent it, counters before/after the time threshold are kept internally and being sent by the TDF or by the PCEF to the PCRF after within the next report. The relevant changes are implemented for Sd and for Gx interface.

- A new Annex P is added in TS 23.203 for Fixed Broadband Access Interworking with EPC, which specifies the enhancement to PCC framework for supporting dynamic QoS interworking with Policy Framework defined by Broadband Forum. The functionalities supported are:
  - perform resource reservation (e.g., admission control request to the Fixed Broadband Network) based on the bandwidth requirements and the QoS attributes of a service request for EPC-routed traffic in the Fixed Broadband network. Note: no UE initiated resource reservation procedures are supported for EPC-based Fixed Broadband Access
  - provide information to identify a 3GPP UE in the Fixed Broadband Network
  - perform resource reservation (e.g. admission control request to the Fixed Broadband Network) based on the bandwidth requirements and the QoS attributes of a service request for non-seamless WLAN offloaded traffic in the Fixed Broadband network

Refer to the following 3GPP specifications for detailed information for these features:

- TS 23.203 Policy and Charging Control Architecture
- TS 29.212 Policy and Charging Control (PCC); Reference points
- TS 29.215 Policy and Charging Control (PCC) over S9 reference point; Stage 3

3.3.5 MULTIMEDIA EMERGENCY SERVICES (MMES)

Multimedia Emergency Services (MMES) are next generation emergency services utilizing real-time session based text and other multi-media, in addition to voice, that are based on trusted applications in support of non-voice communications between citizens and emergency authorities.

Support of IMS Emergency Sessions with other media on UTRAN and E-UTRAN is also called IMS MES (IMS Multimedia Emergency Session). The enhancement has been added in Stage 1 and Stage 2 specifications to support session based IMS emergency sessions that allow the UE to use other media and communication types than voice and Global Text Telephony (GTT) during an IMS emergency session. This occurs when the network supports IMS voice emergency calls and the UE also supports other media or communication types.

Besides voice and GTT, other media types include:

- Real time video (simplex, full duplex), synchronized with speech if present
- Session mode text-based instant messaging
- File transfer
- Video clip sharing, picture sharing, audio clip sharing

An IMS MES does not require voice and GTT. Also IMS MES doesn‘t include support for legacy store-forward messaging such as SMS.

Since MMES is based on IMS emergency service work that was completed in Rel-9, when a UE with an active IMS MES with voice and other media moves out of IMS voice coverage, voice call continuity is supported by the UE and network. The remaining media (therefore, voice call) then becomes a CS emergency call. Other media will be dropped when a UE with an active IMS MES moves out of IMS voice coverage, irrespective of whether or not there is an active voice session.

Requirements for UE and originating network support are specified in TS 22.101.

Several Stage 2 specifications (TS23.401, 23.060, 23.203) are updated for support of other media in IMS emergency session. TS 23.167 was also updated for Codecs and domain selection rules for IMSESOM with E-UTRAN and UTRAN access.

The deployment of MMES depends on local regulatory requirements.

3.3.6 INTERWORKING WITH WI-FI ENHANCEMENTS

Enhancements to the Interworking with Wi-Fi are introduced in Rel-11. The specifications support enhancements to EPC for multi-access PDN connectivity, IP Flow Mobility and seamless WLAN offloading. WLAN Access to EPC with IP address continuity was defined in Rel-8 and extended in Rel-10 with Internet Protocol Flow Mobility (IFOM) and Multi-Access PDN Connectivity (MAPCON). However, routing from the UE to the PDN-GW was not optimized prior to Rel-11 because it did not consider UE location. Rel-11 improves the ePDG and PDN-GW selections based on the location of the UE for the WLAN Access to EPC through an enhancement called LOcation Based Selection of gaTEways foR WLAN (LOBSTER). This results in impacts to the PDN GW selection function for S2c, and currently work is underway to identify charging aspects and security aspects related to this improvement.

An additional improvement is related to S2a (interface to Trusted non-3GPP networks). Some operators have requested to use S2a (on GTP or PMIP) for WLAN access to EPC. There are different reasons for this request, such as many terminals do not support 3GPP extensions Internet Key Exchange version 2/ Internet Protocol Security and Dual Stack-Mobile Internet Protocol version 6 (IKEv2/IPsec and DSMIPv6), or an operator may consider specific WLANs as Trusted thus leveraging S2a to access EPC. However, it was agreed that Rel-11 enhancements would not introduce any UE impacts. Therefore, Rel-11 is enabling S2a Mobility based on GPRS Tunneling Protocol version 2 (GTPv2) and Proxy Mobile IPv6 (PMIPv6) (SaMOG) to EPC through WLAN access, as well as the support of non-seamless offload, with unmodified UEs. Because the UEs are unmodified, the service is limited to a single connection (PDN connection or non-seamless offload) per UE and does not support handovers. These limitations will be removed in Rel-12 with modifications to both UE and network; this is still under study. Charging aspects for this improvement have been solved under the assumption that the Trusted WLAN operator is the same as the 3GPP HPLMN (in non-roaming case) and 3GPP Visiting Public Land Mobile Network (VPLMN) (in roaming case).

Network Management specifications are also being added in Rel-11 to support Management Information Objects and Performance Management data for the new network elements and respective interfaces (for example, s2a, s2b, s2c).

3.3.7 UNIVERSAL INTEGRATED CIRCUIT CARD (UICC) ENHANCEMENTS

In Rel-11, enhancements to the UICC that were studied include HPSIM which are described in the following section.

3.3.7.1 UICC INSIDE FEMTOCELLS PROVIDING FEMTOCELLS HOSTING PARTY AUTHENTICATION

As a reminder, the 3GPP name for femtocell is the Home (e)NodeB also written H(e)NB.

Although the H(e)NB Hosting Party authentication mechanism has been defined since Release 9, a specific and optimized UICC (see acronym list) Application called HP Systems Insight Manager (HPSIM) is defined in Release 11. This HPSIM application is optimized for H(e)NB devices. It is backward compatible with what has been defined and used in previous releases, but also allows faster initialization and storage of multiple H(e)NB initialization profiles depending on location of the H(e)NB.

The HPSIM provides mutual authentication with Extensible Authentication Protocol Method - Authentication and Key Agreement (EAP-AKA) and secure access to the core network. The HPSIM allows the re-use of existing infrastructure (AKA authentication) implemented by 3GPP operators in the HLR. Furthermore, this allows the operator to use their existing billing system for charging for the service. This HPSIM application (in a UICC) is used inside the H(e)NB to increase the security level of the H(e)NB deployment while optimizing operators operational costs.

3.3.8 UICC INSIDE HANDSETS ENABLING FEMTOCELL

The role of Universal SIM (USIM) has increased in provisioning information for Home (e)NodeB. USIMs inside handsets provide a simple and automatic access to femtocells based on operator and user-controlled Closed Subscriber Group list.

In addition to the files, the USIM has been also granted new USIM Application Toolkit (USAT) commands that will enable UICC applications to receive the notification when the UE attaches to the femtocells. Such a feature enables UICC application to automatically notify the primary UE user or other users of the attachment to a femtocell. Another USAT feature allows the UICC to discover surrounding femtocells. This allows MNO to localize the subscriber or help customer service to troubleshoot femtocell set up issues. The operator can now forbid access to user-preferred femtocells and restrict access to operator-preferred femtocells, thanks to UICC parameters.

3.3.8.1 PUBLIC WARNING SYSTEM (PWS)

Public warning notification is one of the key features that were added in the USIM application Rel-11.

After the recent natural disasters (tsunami, storm, earthquake…) that impacted life and people’s properties, it was recognized 3GPP system should provide a more efficient, resilient and reliable Public Warning System (PWS). Such system should enable the authority to broadcast Warning Notifications the 3GPP system users. The content of such warning notification should at least contain information for the user to have a description of the event, know when and where the event is taking place, which agency sent the notification and more importantly what action should be taken. The system allows multiple languages to be used for the warning message so that local and roaming users would be able to understand these notifications.

One of the key issues that were found life critical is the risk of panic and its consequences created by a compromised warning notification. Though the PWS verifies the authentication of a warning notification, it is not impossible for an ill-intention organization to broadcast fake warning messages. The USIM PWS feature allows the operator to instruct the device, whether to process or ignore notification messages in the HPLMN or in PLMNs equivalent to it. When a compromised Public Warning System was found by the home operator, whether in its own PLMN or in a VPLMN, the operator is able to disable the process of warning notifications in its users’ UE. This can be configured remotely over the air in the USIM.

3.3.8.2 UICC ENABLING OVER THE AIR (OTA) MANAGEMENT

As previously mentioned, for the PWS feature, the upcoming releases will develop and capitalize on UICC Remote Application Management (RAM) and Remote File Management (RFM) over Hypertext Transfer Protocol Secure (HTTPS). The network can also send a push message to UICC to initiate the communication.

3.3.8.3 NON-ACCESS STRATUM (NAS) CONFIGURATION

During the work of 3GPP on SIMTC (System Improvements to Machine Type Communication) Release 11, a required functionality for the device was identified. A device configured for NAS signaling low priority can hold dual-priority applications that will need 'normal' (default) priority access in order to send infrequent service alerts/alarms in addition to the ‘low priority/delay tolerant’ access that are used for the vast majority of their connection establishments. The USIM has been enhanced in order to allow the operator to configure the UE to allow overriding NAS signaling low priority and Extended access barring.

3.3.9 LAWFUL INTERCEPTION ENHANCEMENTS

3GPP SA Working Group 3 was chartered with the goal of studying all relevant functions and services of Rel-11 to fulfill the national requirements on lawful interception. The following areas were considered:

- CAT (Customer Alerting Tones) & CRS (Customized Ringing Signal),
- VCC (Voice Call Continuity) & Service Continuity
- IMS Media Security
- H(e)NB also with Local IP Access and Selected IP Traffic Offload
- eMBMS
- LCLS
- SIMTC
- IMS Enhancements
- EPS Enhancements
- Enhanced Location Reporting

This work led to some changes to TS 33.106, TS 33.107 and TS 33.108.

3.4 RELEASE INDEPENDENT FEATURES

As spectrum allocations in different countries evolve, the 3GPP standards body continuously updates and adds new frequency bands. While new frequency bands and carrier aggregation schemes are introduced in particular releases, they may be used in UEs which otherwise implement an earlier release. This speeds the use of new spectrum and allows terminal and base station manufacturers to introduce new frequency bands without having to otherwise upgrade all the terminal's features to the latest release level.

Rel-11 specifically added the following three new bands which can optionally be used in systems otherwise designed for Rel-10. To add a new band to a terminal or base station, certain band-specific hardware such as Radio Frequency (RF) filters, antennas frequency converters and RF Power Amplifiers must be added, as well as minor changes to the device's firmware to control the new or expanded components such as the ability to program the synthesizers to new frequencies. Even so, this effort is often less difficult and time consuming than producing a handset with entirely new features associated with an increment in the release level. Rel-11 added the following three new bands.

Table 3.2. New Frequency Bands Added in Rel-11.

Frequency Band Description	Band Number	Work item Description Document
Extended 850 MHz Upper Band (814-849 & 859-894 MHz)	**26**	**RP-090666 TR 37.806**
LTE E850 - Lower Band for Region 2	**27**	**RP-110439**
LTE Downlink only D&E blocks (716-728 MHz)	**29**	**RP-110710**

Aggregated over all releases through Rel-11, there are a total of 36 bands identified for UTRAN/EUTRA, as tabulated in Appendix A.

Carrier Aggregation (CA) was introduced in Rel-10 but only in two generic contiguous intra-band and one inter-band case. Like the band classes, the Carrier Aggregation scenarios are treated as a release independent feature. Rel-11 concentrated on band-specific issues related to RF performance, inter-modulation analysis and conformance testing for the most urgently needed carrier aggregation band combinations. For Rel-10 through Rel-11 the following intra-band and inter-band CA scenarios have been standardized.

Table 3.3. Intra-band Carrier Aggregation Band Combinations through Rel-11.

Intra-band Carrier Aggregation						
Case #	Band #	Common Names		Status	3GPP Descriptive Document	Carrier/ Rapporteur
1	7	intra-Band	"2600"	Complete R11	530028	Ericsson C.Unicom
2	38	intra-Band	MBS of 2.6 GHz	Complete R11	520015	CMCC Huawei
3	40	intra-Band	IMT 2K	Complete R10	460007	
4	41	intra-Band	2600 MHz BRS/EBS	Complete R11	520016	Clearwire

Table 3.4. Inter-band Carrier Aggregation Band Combinations through Rel-11.

Inter-band Carrier Aggregation						
Case #	Lower Band #	Higher Band #	Common Names	Status	3GPP Descriptive Document	Carrier/ Rapporteur
1	1 +	5	2100+cell	Complete R10	460007	
2	1 +	18	2100+ESMR	Complete R11	540021	KDDI
3	1 +	19	2100+880	Complete R11	540022	NTT Docomo
4	1 +	21	2100+1.5G	Complete R11	540023	NTT Docomo
5	2 +	17	PCS+B&C	Complete R11	510025	AT&T
6	3 +	5	1800+cell	Complete R11	530026	SK Telecom
7	3 +	7	1800+2.6	Complete R11	480023	TeliaSonera
8	3 +	8	1800+900	Complete R11	550018	KT
9	3 +	20	1800+Dig. Dividend	Complete R11	530023	Vodafone
10	4 +	5	AWS+Cellular	Complete R11	510026	AT&T
11	4 +	7	AWS+2.6	Complete R11	530027	Rogers Wireless
12	4 +	12	AWS+ABC	Complete R11	510022	Leap
13	4 +	13	AWS+upperC	Complete R11	500018	Ericsson VZW
14	4 +	17	AWS+B&C	Complete R11	500017	AT&T
15	5 +	12	cell+ABC	Complete R11	510023	US Cellular
16	5 +	17	cell+B&C	Complete R11	510027	AT&T
17	7 +	20	2.6+Dig. Dividend	Complete R11	510024	Orange Huawei
18	8 +	20	900+Dig. Dividend	Complete R11	530024	Vodafone
19	11 +	18	PDC+ESMR	Complete R11	540020	KDDI

The number of carrier aggregation schemes is growing from 3 in Rel-10 to the 24 listed in the two tables above in Rel-11, a clear indication of the great interest in developing this capability to enable greater downlink throughput for the user experience.

4 PROGRESS OF 3GPP RELEASE 12: LTE-ADVANCED AND HSPA+ ENHANCEMENTS

This section provides a detailed description of the ongoing Release 12 (Rel-12) features that are nearing finalization. Rel-12 continues to build on LTE-Advanced and HSPA+ with further focus on downlink enhancements, needed strengthening to various small cell features, expanded carrier aggregation features, the enabling of Machine Type Communications (MTC), Wi-Fi integration and further work on system capacity and stability.

4.1 LTE-ADVANCED ENHANCEMENTS

As mentioned, Rel-12 further defines multiple areas for the enhancement of LTE-Advanced. This section reviews the features on which standards work has been finalized for LTE-Advanced, as well as several open areas that are currently being developed. The areas include the downlink enhancements for active antenna systems and MIMO, as well as small cells, femtocells, MTC, proximity services, UE enhancements, SON, HetNet mobility, MBMS, LIPA/SIPTO, eIMTA and FDD-TDD CA.

4.1.1 DOWNLINK (DL) ENHANCEMENTS

In this section, two downlink enhancements: Active Antenna Systems and Enhanced Downlink MIMO are described.

4.1.1.1 ACTIVE ANTENNA SYSTEMS

Active Antenna Systems (AAS) introduces an alternative antenna system from the one installed in the conventional Base Station (BS). An AAS Base Station (BS) uses multiple transceivers on an antenna array to produce a radiation pattern that can be dynamically adjusted. Compared to the conventional BS with traditional antenna, an AAS BS can offer a host of benefits:

- System capacity and performance gains by employing flexible cell split (vertical or horizontal) and/or beamforming, and by the elimination of the cable loss
- Improved system optimization by meeting new traffic demands and network evolution through adaptive software reconfiguration which would lead to reduce operation expenses and simplified site engineering

These benefits have motivated companies in 3GPP to start studying the specification feasibility of AAS BS in Rel-11. The study was completed in early 2012 and a new Work Item for Rel-12 was approved. The main objective of the Work Item is to identify the RF requirements that may be needed for an AAS BS specifications and the necessary conformance testing derived from those RF requirements.

Both the transmitter and receiver RF properties are considered during the study and Work Item. Specifically for the transmitter requirements, the spatial selectivity of an AAS BS is compared to the conventional BS for the Adjacent Channel Leakage Ratio (ACLR) and the unwanted in-band/out-band emissions. In the receiver side, the AAS may experience different spatial selectivity compared to fixed beam antennas since the AAS system does not achieve full spatial selectivity until after digital baseband processing of the multiple elements in the array. In other words, the effective power level of the interferer UE is higher due to the lack of multi-element pattern and hence may impact the receiver in-band blocking requirements. Other requirements such as output power and receiver sensitivity are also being considered.

The interactions between the antenna array system and the transmitters and receivers within the AAS are different from the conventional BS and the conventional antenna system. An abstract logical representation of the AAS radio architecture is shown in Figure 4.1 below.

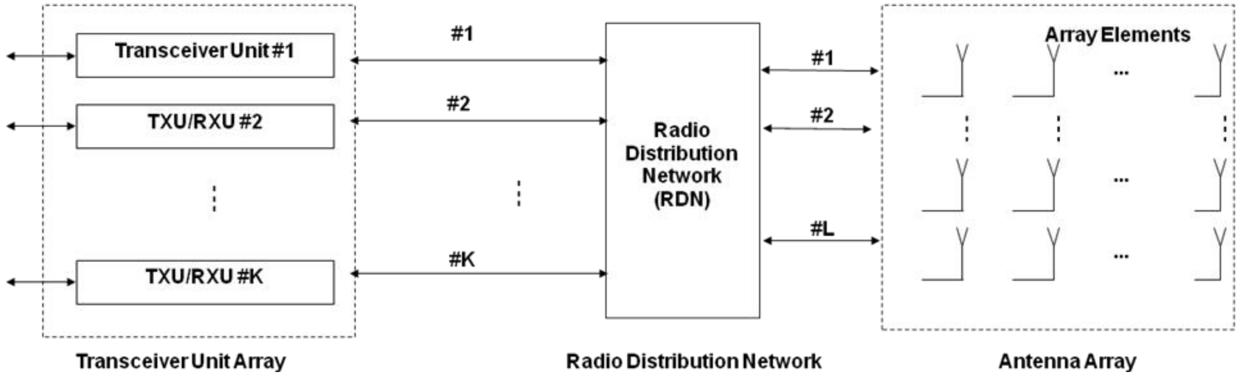

Figure 4.1. AAS Radio Architecture. The main components consist of the Transceiver Unit Array (TXRUA), Radio Distribution Network (RDN) and the Antenna Array (AA).

The radio architecture is represented by three main functional blocks, the Transceiver Unit Array (TXRUA), the Radio Distribution Network, (RDN), and the Antenna Array (AA). The Transceiver Units (TXRU) interfaces with the base band processing within the eNodeB.

The Transceiver Unit Array consists of multiple Transmitter Units (TXU) and Receiver Units (RXU). The Transmitter Unit takes the baseband input from the AAS Base Station and provides the RF TX outputs. The RF TX outputs may be distributed to the Antenna Array via a Radio Distribution Network. The Receiver Unit performs the reverse of the Transmitter Unit operations. The Radio Distribution Network, if present, performs the distribution of the TX outputs into the corresponding antenna paths and antenna elements and a distribution of RX inputs from antenna paths in the reverse direction. The transmitter and receiver unit can be separated and can have different mapping towards radiating elements.

Some of the central issues being considered in the specifications of AAS BS are briefly summarized below:

Requirement Reference Points

The requirement reference point is the point at which a core RF requirement is specified. Tests are defined at test requirement point(s); the test requirements are the criteria for passing the test which verify the core RF requirements. Two main approaches are currently being evaluated for the requirement reference points: Approach 1 is to define the requirements at the boundary of the transceiver and Approach 2 is to define the requirements at the far field. Approach 1 corresponds to conducted requirements as currently supported in legacy non-AAS Base Station at the antenna connector. For the case of AAS BS, the conducted requirements may be adapted and can be based on the output of a combiner that combines the outputs of all of the transceivers or may be at each transceiver individually. Approach 2 defines new requirements at the spatial domain in the far field. Details for both approaches are still being discussed in 3GPP.

Testing Methodologies

Multiple measurement setups capable of testing an AAS BS, such as Conducted Test, Over-the-Air Test, Coupling Test, Combined Test, etc. have been proposed and considered. Considerations have also been given to the scenario when an AAS BS design does not support access to the antenna connectors for conductive tests and radiated tests can be the alternative. Use of more than one measurement setup is therefore not precluded if the same level of measurement accuracy and compliance can be ensured. Analysis is still ongoing to support test requirements that are either at the transceiver array boundary or at the far field.

The Work Item is currently ongoing in Rel-12.

4.1.1.2 DOWNLINK MIMO ENHANCEMENTS

Downlink MIMO enhancements were studied in 3GPP and prioritized for the single point transmission scenario without cooperation. In order to improve the Single-User Multiple-Input Multiple-Output (SU-MIMO) spectral efficiency of the downlink, the LTE downlink spatial multiplexing was enhanced to support up to eight layers per component carrier in LTE Rel-10. Specifically, a new transmission mode (TM-9) was defined supporting SU-MIMO up to rank 8 and dynamic switching between SU and MU-MIMO.

In the Rel-11 Study Item “Study on Further Downlink MIMO Enhancements for LTE-Advanced”, the main topics studied were CSI feedback enhancements, issues from real life MIMO deployments and downlink control signaling enhancements.

Based on the evaluations carried out during the Study and Work Item phases, two CSI feedback enhancements were agreed to be included in Rel-12: 4Tx PMI feedback codebook enhancement and aperiodic feedback PUSCH mode 3-2. It was found in simulations that enhanced CSI feedback gives benefits in dynamic network traffic conditions (e.g., with non-full buffer traffic). This traffic model seems to benefit from improved accuracy of CSI feedback more than the full buffer traffic model since the effect of packet queue lengths are also taken into account. With enhanced CSI, the eNB can complete delivery of data packets earlier compared with legacy CSI feedback, resulting in improved average network spectral efficiency.

The Rel-12 4Tx codebook enhancement mainly targets cross-polarized antennas and thus reuse of the 8Tx dual codebook structure from Rel-10; $W=W_1W_2$. The precoding matrix W_1 is wideband (i.e. reported once per whole system bandwidth) and W_2 is reported per sub-band and 4 bits are used to select W_1 and 4 bits per sub-band is used to select W_2. Furthermore, the rank 3 and 4 of 4Tx enhanced codebook reuse the Rel-8 4Tx rank 3 and 4 codebooks per sub-band and use the identity matrix for $W_{1,}$ since the observed performance gain with dual codebook structure were insufficient compared to the Rel-8 codebook.

The major changes compared to 8Tx dual codebook design principles are that the beams in W_1 are evenly spread over the whole sector. Hence, by selection of W_2 the UE can select different beam directions per sub-band which implies robustness to time alignment errors and better performance in channels with large angular spread. Moreover, W_2 for rank 1 has an additional phase rotation between two polarizations which ensures 256 unique DFT-type rank 1 precoding vectors in case a co-polarized antenna is used. This is beneficial for a uniform linear antenna array and Multi-User (MU) MIMO transmission.

All aperiodic CSI reporting modes that are valid for transmission modes 8, 9 and 10 when PMI/ Rank Indicator (RI) reporting is configured, as well as periodic feedback modes PUCCH 1-1 and PUCCH 2-1, supports the enhanced 4Tx codebook. A configuration per CSI process determines whether a UE shall use the Rel-8 4Tx codebook or the Rel-12 4Tx enhanced codebook for PMI reporting. Codebook sub-sampling methods associated with the enhanced 4Tx codebook have been designed to fit with PUCCH payload sizes of 8Tx codebook in order to minimize standards changes and implementation complexity.

In addition to the enhanced codebook, a new aperiodic CSI feedback PUSCH mode 3-2 is introduced in Rel-12 with increased CSI accuracy since it provide both sub-band CQI and sub-band PMI. It can be configured for transmission modes 4, 6, 8, 9 and 10 when PMI/RI reporting is configured and with 2, 4 and 8 antennas at the eNB.

Further details can be found in the Technical Report[129] and the work Item has been completed in Rel-12.

4.1.2 SMALL CELL ENHANCEMENTS

Small cells have been supported by LTE since its inception with different enhancements introduced in Releases 9, 10 and 11. Small cells can be a key mechanism to enhance system capacity within the coverage area of an existing network and the increasing demand for higher speed has led to higher capacity demands and in the case of indoor scenarios, coverage challenges as well. A workshop on Rel-12 and onwards was held in June 2012 and there was strong interest in Small Cells for LTE[130]. Following that, 3GPP initiated two Study Items on Physical layer[131] and Higher layer[132] aspects, to determine whether there are aspects that would enhance the performance of small cells deployment. Given that this is a study, it may also conclude in one or several areas that there is no need for enhancements.

Similar to when the macro layer is densified, small cells can be deployed progressively to match the growth in demand for system capacity as the population of UEs increases and data applications become more demanding. Small cells would typically be deployed in areas of heavy traffic, known as hot zones, based on the statistics of the user distribution. This means that small cells will increasingly be deployed non-homogeneously resulting in non-uniformly distributed small cells coverage areas and the overlapped coverage areas between small cells may be large, medium, small or even without any overlapping. These new deployment scenarios motivated the objectives in the Physical layer Study Item.

The main aspects being studied in the Physical Layer Study Item include:

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129 TR36.871 v1.1.0, "Downlink MIMO Enhancement for LTE-Advanced," Alcatel-Lucent.

130 RP120838, "Summary of 3GPP TSG-RAN Workshop on Release 12 and Onward," RAN#56, June 2012.

131 RP-122032, "Small Cell enhancements for E-UTRA and E-UTRAN – Physical layer aspects," RAN#58, Dec. 2012.

132 *Ibid.*

- Potential enhancements to improve the spectral efficiency, such as the introduction of a higher order modulation scheme (e.g., 256 QAM) for the downlink or overhead reduction for UE-specific reference signals and control signaling

- Mechanisms to ensure efficient operation of a small cell layer composed of small cell clusters, including mechanisms for interference avoidance and coordination among small cells and mechanisms for efficient discovery of small cells and their configuration

- Synchronization mechanisms for small cells

The main aspects for the Higher Layer Study Item include evaluating the benefits of UEs having dual connectivity to macro and small cell layers served by different or same carrier, potential architecture and protocol enhancements, identify and evaluate the necessity of overall Radio Resource Management structure and mobility enhancements for small cell deployments.

In this section, the various proposals for enhancements and overview of their considerations are described. Since both Study Items are currently ongoing, the conclusions to the studies have not been included.

Physical Layer Considerations

The study into physical layer aspects has been preceded by a separate study into the small cell scenarios, where generic small cell deployment scenarios consisting of small cell clusters with or without an overlaid macro coverage layer have been identified and agreed. Both dense and sparse deployments of small cells are considered, with ideal backhaul and non-ideal backhaul.

A generic small cell deployment scenario is shown in Figure 4.2 below.

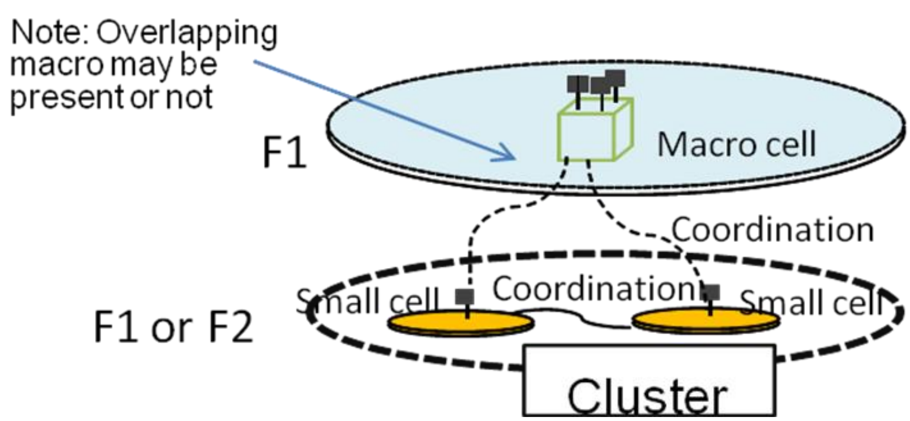

Figure 4.2. Generic small cell deployment scenarios. F1 and F2 denote two different carrier frequencies and the 4 different scenarios[133] are #1, #2a, #2b and #3. Depending on the scenario, overlapping macro coverage may be present or not.

133 TR36.872, "Small cell enhancements for E-UTRA and E-UTRAN – Physical layer aspects," v1.0.0.

Scenario 1 is when there is co-channel deployment of macro and small cell cluster, Scenario 2a and 2b are for non co-channel deployment of macro and small cells cluster, and Scenario 3 is for indoor small cells without the presence of macro cell. An overview of the various studies is provided in the following paragraphs.

Spectrum Efficiency Improvements

Two potential ways to improve the system spectrum efficiency are to increase the transmission efficiency and/or to reduce overhead. Following is a list of the evaluated schemes up to this date. No agreement has been reached on whether any of the schemes are beneficial to support.

- The high geometry experienced by UEs in some small cell deployments may provide a possibility for introducing a higher order modulation scheme such as 256 QAM for the downlink transmission. Studies into the potential gain of DL 256 QAM include consideration of the Error Vector Magnitute (EVM) and impairment modeling, the Rx IQ imbalance for the Rx impairments, as well as Tx EVM. From the results based on preliminary evaluations, the potential gains of 256 QAM are found when the Tx EVM is around 4 percent or less. However, it has also been found that these potential gains are more sensitive to the practical Rx impairments, especially IQ imbalance than to the Tx EVM.

- The channels of small cells typically have the characteristics of low frequency-selective fading with small delay spread and slow time-fading with low UE mobility. The low frequency-selective and slow time-varied fading may provide the possibility for overhead reduction of downlink and uplink UE-specific reference signals. These possible reductions of reference signal overhead is weighed against loss of demodulation performance.

- The traffic arrival pattern in dense small cell deployments is expected to exhibit a large variation of data to be scheduled at a given time interval. Multi-subframe and cross-subframe scheduling have been proposed as possible techniques for control signaling overhead reduction. If downlink control signaling can be eliminated from certain subframes, it allows PDSCH/EPDCCH transmissions to start from the first OFDM symbol in those subframes. These additional OFDM symbols that become available for PDSCH would improve the overall spectrum efficiency. Any possible reduction of control signaling overhead needs to be weighed against factors such as loss of scheduling flexibility.

Mechanisms for Efficient Operation of Small Cell Layer

Possible enhancements that are being evaluated for improving the efficiency of small cell operation include interference mitigation and cell discovery.

- Interference mitigation is critical to handle highly varied co-channel interference when small cells are deployed non-uniformly with intense bursty traffic arrival. Possible techniques under consideration for small cell deployments include small cell ON/OFF, enhancements to downlink and uplink power control, ICIC/eICIC, cell association and ICIC for EPDCCH.

    - Small cell ON/OFF – When a small cell has no or low traffic, the small cell could be turned off or dynamically blanked to reduce the interference to neighboring cells. Possible criteria for triggering this semi-static ON/OFF could be the increase or decrease in traffic load, UE arrival or departure (i.e., UE-cell association), and packet call arrival or completion. As an example, a turned-off small cell may be turned on if the traffic load in the vicinity of the cell increases to a certain level. In order to help determining the appropriate triggering conditions, signal strength measurements would be required, based on either DL or UL signals.

    - DL and UL power control – Adaptation of a small cell transmission power, including possibly both the common and data channel power are other candidate enhancements. There has not been any agreement that such schemes are beneficial.

- Enhancements of ICIC/eICIC for PDCSH and EPDCCH – In a dense small cell deployment, there may be more than one dominant interference source. Co-channel interference between small cells can be significant when the number of deployed small cells increases. The performance of the LTE frequency-domain and time-domain interference coordination schemes have been evaluated in the presence of multiple dominant interference sources in non-uniform small cell deployments. There have not been any agreements that such schemes are beneficial.

- Small Cells Discovery: For non-uniform dense small cell deployments, severe co-channel interference might hinder the UEs' detection of the synchronization signals and reference signals needed for cell identification. Currently the study is focused on how and if new discovery mechanisms are needed if the cell operates small cell ON/OFF.
  - Possible enhancements of small cell discovery over existing PSS/SSS/CRS detections include PSS/SSS IC, use of orthogonal RS (e.g., CSI-RS or PRS), and bursty transmission of a suitable signal. Bursty transmission of the discovery signal would be applicable to at least the eNB OFF state.

- Radio Based Synchronization: Synchronous LTE networks are essential for TDD systems and beneficial to existing features such as ICIC, (f)eICIC, eMBMS, CoMP and other potential techniques for small cell enhancements. The performance of Minimum MSE Interference Rejection Combining (MMSE-IRC) and IC receivers would also be improved in a synchronized network. Synchronization by Global Navigation Satellite System/ Global Positioning System (GNSS/GPS) might not be available for small cell deployments (e.g., indoor deployments or hotspots with high buildings around). Synchronization over backhaul might not always provide the required accuracy due to the timing reference being noisy in the existing backhaul infrastructure. Hence, radio interface-based synchronization solutions being considered for small cell deployments are network listening and UE assisted synchronization.
  - Network listening involves the target cell synchronizing with the source cell through decoding the timing information from reference signals (e.g., CRS, CSI-RS and PRS) of the source cell. The primary factor affecting network listening based synchronization performance is the hear-ability of source cell reference signals. The main question studied is whether there is any need for the physical layer to perform any enhancements to better support network listening. Currently, no such enhancement has been identified.
  - UE-assisted synchronization techniques are also considered, whereby the UEs measure and feed back the time difference between the source and the target cells. Currently however the focus is on network listening methods.

Higher Layer Considerations

In the Higher Layer Study Item, possible enhancements considered include mobility robustness, reduction of signaling load towards CN due to handover and improved per-user throughput and system capacity.

Dual connectivity refers to an operation where a given UE is capable of using radio resources provided by at least two different network points connected with non-ideal backhaul. Dual connectivity can be used to reach some of the enhancements listed above. For instance in Scenario #2, mobility robustness can be improved by keeping the control plane termination in a macro node, while allowing offloading of user plane traffic to pico nodes within the macro coverage. Thus, a robust signaling connection is maintained at all times to the macro layer, and potential handover issues for pico handovers can be avoided.

Another potential solution of dual connectivity is the inter-node radio resource aggregation[134] for Scenario #2 where radio resources from more than one eNB are aggregated for user plane data transmission. This is illustrated in Figure 4.3.

Depending on realization of this solution, signaling overhead towards the CN can potentially be saved by keeping the mobility anchor in the macro cell. Hence, dual connectivity consists of configuring a UE with one Macro Evolved NodeB (MeNB) and at least one Serving Evolved NodeB (SeNB).

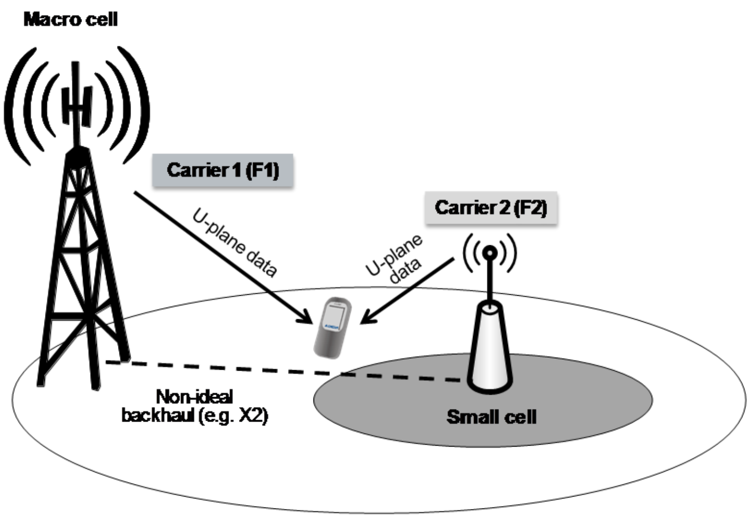

Figure 4.3. Inter-node radio resource aggregation for Scenario #2. F1 and F2 denote two different carrier frequencies and Macro and Small cells are connected using a non-ideal backhaul.

User Plane Architecture

3 options can be distinguished for splitting the U-Plane data between MeNB and SeNB:

- Option 1: S1-U also terminates in SeNB
- Option 2: S1-U terminates in MeNB; a bearer can be delivered via one eNB only
- Option 3: S1-U terminates in MeNB; a bearer can be split over multiple eNBs

These options are further illustrated in Figure 4.4 using the downlink as an example.

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134 TR36.842, “Study on Small cell enhancements for E-UTRA and E-UTRAN – Higher layer aspects”

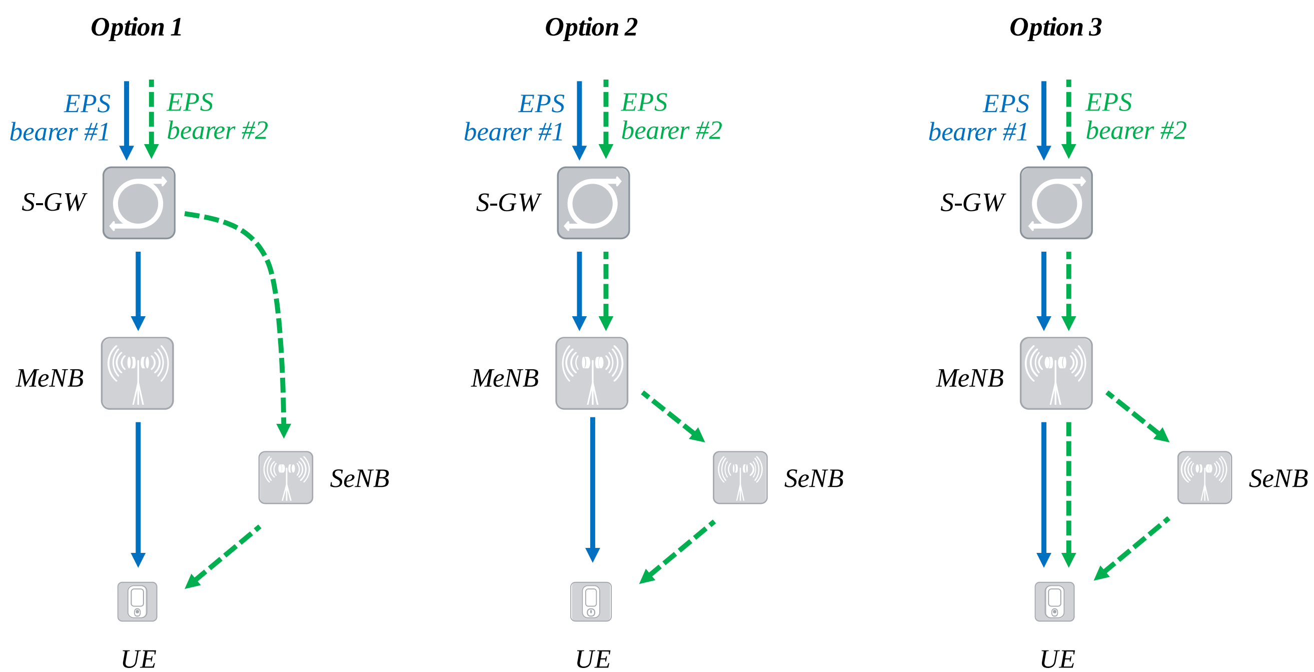

Figure 4.4. Bearer Split Options for the User Plane. 3 options can be distinguished for the splitting the U-plane data.

In terms of protocol architecture, when S1-U terminates at the MeNB, the protocol stack in the SeNB must at least support Radio Link Control Layer (RLC) (re-)segmentation. This is due to the fact that RLC (re-)segmentation is an operation that is tightly coupled to the physical interface, and when non-ideal backhaul is used, RLC (re-) segmentation must take place in the same node as the one performing radio link adaptation and transmitting the RLC Packet Data Units (PDUs). Based on this assumption, four families of U-plane alternatives emerge:

- Independent Packet Data Convergence Protocols (PDCPs): this option terminates the currently defined air-interface U-plane protocol stack completely per bearer at a given eNB, and is tailored to realize transmission of one EPS bearer by one node, but could also support splitting of a single EPS bearer for transmission by MeNB and SeNB with the help of an additional layer. The transmission of different bearers may still happen simultaneously from the MeNB and a SeNB.

- Independent RLCs: this option assumes that S1-U terminates in MeNB with the PDCP layer residing in the MeNB. In the case when a bearer is split over MeNB and SeNB, there is a separate and independent RLC bearer, also at UE side. Per eNB, the bearer is configured to deliver PDCP PDUs of the PDCP bearer, terminated at the MeNB.

- Master-Slave RLCs: this option assumes that S1-U terminates in MeNB with the PDCP layer and part of the RLC layer residing in the MeNB. While requiring only one RLC entity in the UE for the EPS bearer on the network side, the RLC functionality is distributed between the nodes involved, with a “slave RLC” operating in the SeNB. In downlink, the slave RLC takes care of the delay-critical RLC operation needed at the SeNB; it receives from the master RLC at the MeNB readily built RLC PDUs (with Sequence Number already assigned by the master) that the master has assigned for transmission by the slave, and transmits them to the UE. The custom-fitting of these PDUs into the grants from the MAC scheduler is achieved by re-using the currently defined re-segmentation mechanism.

Control Plane Architecture

In the C-plane protocols and architectures for dual connectivity, each eNB is assumed to be able to handle UEs autonomously, (i.e., act as MeNB to some UEs while acting as SeNB for other). It is assumed that there will be only one

S1-MME Connection per UE, and it is terminated in the MeNB. In dual connectivity operation, the SeNB owns its radio resources and is primarily responsible for allocating radio resources of its cells. Some coordination is still needed between MeNB and SeNB to enable this, such as:

- RRC protocol architecture

  At least the following RRC functions are relevant when considering adding a small cell layer to the UE for dual connectivity operation:

  - Small cell layer's common radio resource configurations
  - Small cell layer's dedicated radio resource configurations
  - Measurement and mobility control for small cell layer

In dual connectivity operation, a UE always stays in a single RRC state, (e.g., either RRC_CONNECTED or RRC_IDLE). Only the MeNB generates the final RRC messages to be sent towards the UE after the coordination of RRM functions between MeNB and SeNB. The UE RRC entity sees all messages coming only from one entity (in the MeNB) and the UE only replies back to that entity. L2 transport of these messages depends on the chosen User Plane (UP) architecture and the intended solution.

- RRC procedures

  Considering the initial SeNB radio resource configuration or the situation when the radio resource configuration of the SeNB needs to be changed, at least the following steps might be needed:

  - The MeNB provides input parameters (e.g., UE capabilities and the radio resource configuration of the UE) to the SeNB; this triggers when to provide these parameters as FFS
  - The SeNB decides on the relevant parameters (e.g., PUCCH configuration) and signals these to the MeNB
  - Based on input from the SeNB, the MeNB generates the final RRC message and signals this message to the UE. L2 transport of these messages depends on the chosen UP architecture and the intended solution.

In the above procedures, the first step can be skipped in cases when it can be guaranteed that RRCConnectionReconfiguration is valid and in line with the UE capabilities. Such cases could be when the SeNB already has the latest information of the UEs radio resource configuration in the MeNB or the parameters are not subject to the capabilities.

Both the Physical layer aspects and the Higher layer aspects Study Items were due for completion in December 2013.

4.1.3 FEMTO ENHANCEMENTS

There are several enhancements in Rel-12 for femtocells such as mobility to shared (H)NodeB, LTE X2 Gateway, low cost and enhanced UE MTC operation in LTE, and enhancements related to UE Power Consumptions Optimizations (UEPCOP) and Small Data and Device Triggering Enhancements (SDDTE).

4.1.3.1 MOBILITY TO SHARED HENB

The mobility to a target eNB which is shared by multiple operators relies on the principle that the PLMN that is going to be used at the target side is selected by the source (H)eNB. The mobility to a shared target HeNB poses specific challenges because the target PLMN selected must be compatible with the UE in terms of CSG membership when that HeNB is hybrid/closed. For example, if the target HeNB broadcasting a CSG is shared between PLMN1, PLMN2, the UE can be a member of that CSG for PLMN1 but not for PLMN2.

In 3GPP Rel-12, the mobility procedures for UEs are enhanced with a new capability of reading and reporting to the source eNB, prior to the handover decision, the list of PLMNs of the target cell which satisfy these two criteria:

- These PLMNs are either the serving PLMN or equivalent PLMNs
- The UE is a member of the target cell CSG for those PLMNs

In Rel-12, when receiving this new list and deciding to trigger the handover, the source eNB is also enhanced with the capability of selecting one of those PLMNs while verifying that it actually is an equivalent PLMN or the serving PLMN.

The new mobility procedure to shared closed HeNB is shown in the Figure 4.5. The MME will verify that the UE is 1) actually a member of the CSG for the PLMN eventually selected by the source eNB, and 2) allowed for this handover.

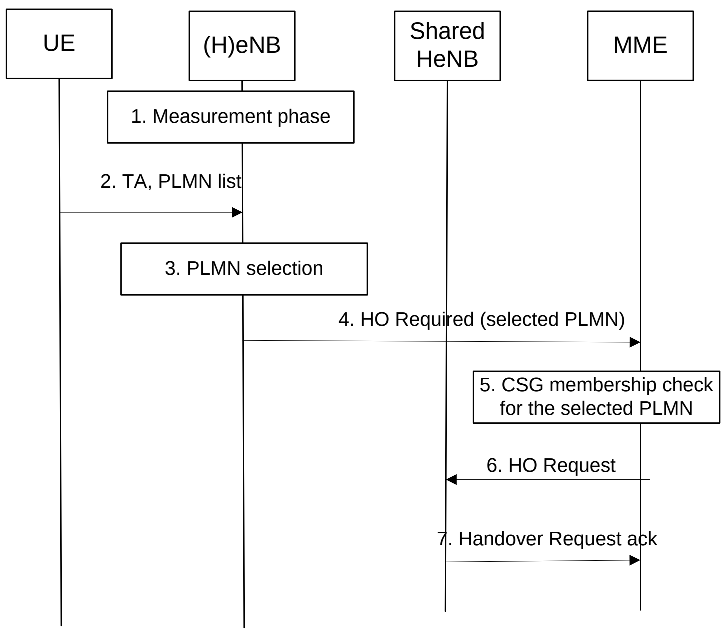

Figure 4.5. New mobility procedure to Shared closed HeNB.MME verifies the UE PLMN CSG membership.

Finally, it can be noted that in Rel-12, this procedure has been extended to also work when the target cell is operating in hybrid mode. If the UE detects that it is a member of the target cell's CSG for at least one of the target PLMNs, it will also report to the source eNB the same list and the same call flow as above will apply.

This Work Item on HeNB mobility enhancements was completed in Rel-12.

4.1.3.2 LTE X2GW (X2 GATEWAY)

The extraordinary explosion of mobile data traffic leads to the densification of LTE networks through the deployment of multiple small cells per macro sector, in particular numerous HeNBs under each macro sector. This creates a number of challenges for the scalability of X2 connections from an eNB to its neighbor HeNBs such as:

- Depending on the number of cells of a macro eNB and of the degree of densification by HeNBs, the number of HeNB neighbors could reach several dozens or even beyond

- A corresponding surge can be expected in the number of triggered “neighbor address discovery S1 procedures” and in the number of SCTP associations to be supported by an eNB

- Unlike eNBs, HeNBs under control of end users can experience frequent and/or unexpected switch off and also peaks of switch on signaling e.g. for residential case when in the evening a large number of HeNBs could power on at about the same time

- Impacts related to the change of IP address that can be associated with the switch on/off also need to be addressed

In order to meet all those challenges, in Rel-12, an eNB could connect to its neighbor HeNBs through one or more X2 Gateways (X2GWs). The X2GW may be optionally deployed over X2 interfaces independently of the HeNB GW which is deployed over S1 interfaces. This X2GW will help avoiding the issues previously listed while maintaining simple connectivity principles such as:

- a HeNB can connect to other (H)eNBs through a single X2GW

- X2 connections through more than one X2GW are not possible

The feature remains backwards compatible in the sense that a HeNB can connect to a peer (H)eNB using either direct X2 or via the X2GW. When the connection goes via the X2GW, the source (H)eNB includes a new target (H)eNB Radio Network Layer (RNL) identifier uniquely identifying the target (H)eNB in the X2 Setup Request message; this identifier can be mapped in the X2GW to derive a corresponding IP address to reach the relevant destination node.

This Work Item on X2GW support for LTE is currently ongoing with scheduled completion in Rel-12.

4.1.4 MACHINE TYPE COMMUNICATIONS (MTC)

With the increased availability of mobile broadband, cellular connectivity has become a realistic option for machine-type communication (MTC). In the long term, it is expected that the number of connected MTC devices will outnumber the human-centric communication devices.

In order to further optimize MTC communication and connectivity over LTE, the 3GPP standardization community has recently discussed radio access related technologies/mechanisms to:

- Further improve the support of low-cost and low-complexity device types to match low performance requirements (for example in peak data rates and delay) of certain MTC applications

- Provide extended coverage for MTC devices in challenging locations

- Enable for very low energy consumptions to ensure long battery life

- Serve very large numbers of devices per cell by optimizing signaling of small data transmission

The 3GPP activities addressing MTC enhancements, as previously described, have materialized in two main Study/Work areas:

- A RAN Work Item on low cost and extended coverage (following a Study Item which started during the Rel-11 time-frame)[135],[136]

- A RAN Study Item targeting the evaluation of a few solutions identified as part of a system-wide Work Item on Machine Type and other mobile data applications Communications Enhancements (MTCe)[137]. In particular, the two areas involving RAN study[138] are: UE Power Consumptions Optimizations (MTCe-UEPCOP) and Small Data and Device Triggering Enhancements (MTCe-SDDTE).

The following sections are intended to summarize the objectives of the RAN Study/Work and the current 3GPP status.

4.1.4.1 LOW COST AND ENHANCED COVERAGE MTC UE FOR LTE

The main goal of this work is to specify a new UE MTC operation in LTE that also allows for enhanced coverage compared to existing LTE networks, with two main objectives, as reported in the following content.

A first objective is to specify a new UE category/type for MTC operation in all LTE duplex modes supporting the following capabilities:

- 1 Rx antenna

- Downlink and uplink maximum Transport Block Size (TBS) size of 1000 bits

- Reduced downlink channel bandwidth of 1.4 MHz for data channel in baseband, while the control channels are still allowed to use the carrier bandwidth. Uplink channel bandwidth and bandwidth for uplink and downlink RF remains the same as that of normal LTE UE

A second goal is to provide a relative LTE coverage improvement – corresponding to 15dB for FDD – for the UE category/type defined above and other UEs operating delay tolerant MTC applications with respect to their respective nominal coverage. In particular, the following techniques (applicable for both FDD and TDD) should be targeted:

- Simplification of PHICH and PCFICH functionality or alternative mechanism to PHICH and PCFICH functionality so that coverage-limited UE is not constrained by PHICH and PCFICH physical channels

- A mechanism(s) to support scalability of spectral efficiency impact for coverage improvement by identifying UE requiring additional coverage improvement and informing eNB of the amount of coverage the UE requires

- Repetition/TTI bundling and extension to Power Spectral Density (PSD) boosting for applicable channels/signals identified during study phase

- A relaxed requirement for “probability of missed detection” for Physical Random Access Channel (PRACH).

A RAN work item was started in September 2013.

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135 TR 36.888: “Study on provision of low-cost MTC ues based on LTE” (Rel-11).
136 RP-130848: WID on Low cost & enhanced coverage MTC UE for LTE (Rel-12)
137 SP-120442; SP-120450: SA2 wids on UEPCOP and SDDTE
138 RP-130396: RAN SID on Machine-Type Communications (MTC) and other Mobile Data Applications Enhancements

4.1.4.2 RAN ASPECTS OF MACHINE TYPE (AND OTHER MOBILE DATA) APPLICATIONS COMMUNICATIONS ENHANCEMENTS

The Study Item performed in RAN was aimed mainly at investigating and evaluating the RAN-impacting solutions that have been proposed, at system level (see sec. 4.4.1), to address enhancements related to UE Power Consumptions Optimizations (UEPCOP) and Small Data and Device Triggering Enhancements (SDDTE).

In particular, enhancements have been studied in the context of MTC traffic involving small data transfers (with inter-arrival time from several seconds to many hours) and focused on the following solutions:

- UEPCOP: Power saving (or dormant) state and extended DRX cycle (Idle and connected)

- SDDTE: Data over NAS signaling over control plane, connectionless approaches over user plane and keeping UEs in connected mode for small data transmission

Details on the identified solutions can be found in Technical Report 23.887.[139] Note that both E-UTRAN and UTRAN related enhancements are part of the Study scope (both at system and RAN levels).

The RAN Study Item was closed at RAN#61 in September 2013. The RAN study outcome is captured in the Technical Report 37.869[140]. In December 2013, a Work Item has started, covering the following objectives:

- For UE Power Consumption Optimizations, RAN2 specification(s) will be enhanced to align the Access Stratum procedures with the (CT1) NAS solution on the agreed new “Power saving state”;

- For Signaling Overhead Reduction, RAN2 should evaluate the introduction of new assistance information/parameters from CN to RAN related to the UE and its traffic type/pattern, in line with the (SA2) agreed new CN-RAN signaling.

4.1.5 PROXIMITY SERVICES (PROSE)

Proximity Services (ProSe) is one of the main areas of focus in LTE Rel-12. The work in 3GPP is split up into proximate discovery and direct communication. Proximity Services (ProSe) communications involves user equipments (UEs) communicating with each other over a direct communication link rather than via the network elements in the cellular infrastructure.

The direct communication part is motivated by Public Safety scenarios. The scope of the work in Rel-12 is to support direct broadcast communication between Public Safety personnel in the absence of the network. Further details on the Public Safety aspects of ProSe are discussed in Section 4.3.2. The discovery portion of the work will be the focus of this section.

ProSe discovery identifies UEs that are in proximity of each other. The main motivation for the ProSe discovery work is the ability for operators to provide a highly power efficient, privacy sensitive, spectrally efficient and scalable proximate discovery platform. This allows the discovery to be “Always ON” and autonomous, with possible improvement in battery life time compared to over-the-top (OTT) solutions based on tracking the absolute location of the device and other device to device technologies such as Wi-Fi Direct and BTLE. The use of licensed spectrum for ProSe discovery may allow mobile operators to employ it to offer a range of differentiated applications and services to users. Examples of potential

139 TR 23.887: “Machine-Type and other Mobile Data Applications Communications Enhancements”.

140 TR 37.869: “Study on Enhancements to Machine-Type Communications (MTC) and other Mobile Data Applications; Radio Access Network (RAN) aspects”.

commercial use cases of ProSe discovery are social discovery, proximate advertising, consumer alerts of nearby events, gaming integrating physical-world elements, education home automation, and supervision of persons not supposed to leave or enter a specific area.

ProSe discovery can either be direct or EPC-level and is authorized by the operator. The authorization is either on a UE basis or on an application basis. The network also controls the use of resources that are used for discovery.

The topics being currently studied as part of the discovery design in RAN 1 are signal timing, discovery signal design, payload definition, resource allocation and resource selection. In addition to these topics, RAN 2 is also studying RRC State for discovery message transmission. These are all contained in 3GPP TR 36.843[141].

The discovery design topics currently being studied in SA2 are direct and EPC-level discovery procedures, access authorization, identities allocation and processing, and security (active involvement in SA3). These are contained in 3GPP TR 23.703[142]. The 3GPP SA1 feasibility study for proximity services is contained in 3GPP TR 22.803[143].

The service requirements for proximity services have been incorporated into the service requirements for the Evolved Packet System (EPS) in 3GPP TS 22.278[144].

As of December 2013, all the previously mentioned studies were ongoing.

4.1.6 USER EQUIPMENT (UE) ENHANCEMENTS

UE receiver enhancements are particularly well suited to mitigate the increased inter-cell interference that comes as a natural consequence of several trends:

- cell densification
- deployment of heterogeneous networks
- use of SU/MU-MIMO

This increased interference can either come from higher power cells when the terminal is being served by a small cell (in a co-channel deployment with macro- and pico-cells for example); from neighboring small cells in the case of a dense small cell deployment in either a dedicated carrier deployment or a co-channel deployment; or even from intra-cell as a result of SU/MU-MIMO operation.

It is in this context that advanced UE receivers with interference cancellation and/or suppression can increase system capacity and user experience. These advanced receivers have been defined in 3GPP in the course of a few releases starting from Rel-10 and described in previous 4G Americas whitepapers (in particular HetNet FeICIC to mitigate strong interference from common signals such as CRS, PSS, SSS, Primary Broadcast Channel (PBCH)).

Furthermore, in Rel-12, there is another on-going Study Item that focuses on interference cancellation and/or suppression of data and control channels with possible network coordination. Three categories of candidate receiver types have been defined; each operating under various degrees of knowledge of interferer parameters, and each receiver type may be applicable for dealing with inter-cell, intra-cell, and/or inter-stream interference. The types consist of:

141 3GPP TR 36.843, Feasibility Study on LTE Device to Device Proximity Services - Radio Aspects.
142 3GPP TS 23.703, Study on architecture enhancements to support Proximity Services (prose).
143 3GPP TR 22.803, Feasibility study for Proximity Services (prose)
144 3GPP TS 22.278, Service requirements for the Evolved Packet System (EPS).

- Interference suppression receivers – these receivers refer to receivers that apply linear filtering to the received signal to suppress the interference, as opposed to explicitly cancel the interference
- Maximum likelihood receivers
- Interference cancellation receivers

As of December 2013, this Study Item was ongoing.

4.1.7 SELF-OPTIMIZING NETWORK (SON) ENHANCEMENTS

Rel-12 SON enhancement studies focus on inter-operability aspects of existing features and also of new features in some areas.[145]

One part of the study concerns the automatic adjustment of cell borders for the purpose of load balancing, introduced in Rel-9, in light of release-dependent requirements linked to the UE's capability to be served by a cell that is not the strongest cell (cell range extension). The focus is on evaluating different opportunities with more UE specific handling, and whether there are needs for new standardization support. One example concerns possible ping-pong handovers in case of different treatment of different UE types with different UE capabilities in two eNBs involved in load balancing.

Another part of the study concerns network deployments based on active antennas and both the new needs for SON to manage the deployment as well as the impacts on existing SON features. Connection continuity and handover robustness in the case of cell splitting/merging are particularly identified areas, but also aspects of cell shaping and UE specific beamforming.

The Rel-11 SON work includes further improvements to the handover optimization mechanism (e.g., inter-eNB and inter-RAT transfer of RLF information using core network interfaces in areas with scattered LTE coverage) and also options to evaluate the situation after a completed handover.

This Study Item was ongoing in 3GPP in December 2013.

4.1.8 HETEROGENEOUS NETWORKS MOBILITY

Heterogeneous Networks (HetNets) can be deployed in single carrier or multicarrier environments (including non-CA and CA cases). Seamless and robust mobility of users from LTE macro to small BTS-layer, and vice versa, is needed to enable offload benefits. The Study Item on HetNet mobility enhancements[146] showed that HO performance in HetNet environments is not as good as the macro-only environment in terms of HO failure and ping-pongs (or short of time of stay in a cell). Higher HO failures were observed for pico to macro Handover.

Autonomous UE mobility state estimation is based purely on the number of experienced cell changes in a given time period, but without explicitly taking the cell-size into account, and the mobility state estimation may not be as accurate as in macro-only environment.

The Work Item on Mobility Enhancements aims to improve overall HO performance with regard to HO failure rate and ping-pong in HetNet environments. Optimal configuration of parameters and better speed estimation are seen as potential solutions to improve HO robustness while keeping the ping-pongs under control.

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145 TR 37.822 v1.0.0, “Study on next generation Self-Optimizing Network (SON) for UTRAN and E-UTRAN”.
146 TR36.8391 v2.0.0, “Mobility Enhancements in Heterogeneous Networks”.

Scenarios with more Base Transceiver Station (BTS)-layers and multiple carriers also means that there are more potential error cases as was seen during the Study Item, and therefore better recovery procedures could help improve the overall system robustness. Today, recovery after RLF is handled by re-establishment procedures which are triggered after a configurable delay. Faster re-establishments after a HO failure will reduce interruption time for the user and improve the user experience. Solutions under consideration include optimal setting of the delay timer.

Efficient small cell discovery is important to ensure efficient offload from macro to small cells while conserving UE battery, especially for cases where cells are on different carriers. Inter-freq measurements required for accurate discovery of a small cell in another carrier not only uses up battery power but also requires measurement gaps. The Work Item aims at reducing UE power consumption requirements without sacrificing offloading potential. Solutions under discussion include network based fingerprinting and background search with relaxed measurement requirements.

As of December 2013, this Work Item was ongoing.

4.1.9 MULTIMEDIA BROADCAST MULTICAST SERVICE (MBMS) ENHANCEMENTS

It is of paramount importance for an operator to rely on recovery schemes in case a node/interface failure event happens in order to maintain the delivery of services. Such recovery mechanisms had already been designed prior to 3GPP Rel-12 for EPC nodes and in Rel-12 they have been further extended to additionally cover all MBMS nodes, i.e., to enable recovery in case any of the Broadcast Multicast Service Center (BM-SC), MBMS GW, MME, Multi-cell/Multicast Coordination Entity (MCE) or eNB nodes fails or any interface between them fails.

Furthermore, although support of MBMS services has been introduced in 3GPP Rel-9, there have been no UE measurements defined that could be reported to the network in order to help monitor the signal quality at the UE. There are various measurements defined for the unicast signal, but due to the difference created by the lack of Single Frequency Network (SFN) signal combining, the same measurements have very limited usefulness in predicting the MBMS signal quality. In order to provide better tools for the network to monitor and adjust the MBMS operational parameters, new measurements targeting MBMS signals will be introduced in Rel-12.

In this section, both the recovery mechanisms and measurements enhancements are described.

4.1.9.1 RECOVERY MECHANISMS

MBMS Sessions Re-Establishment

The first cornerstone of MBMS recovery mechanisms consists of the re-establishment of the MBMS sessions over the M3 interface following an MCE failure or an M3 path failure. Upon receiving the Reset message or the M3 Setup Request message from the MCE, the MME will maintain the MBMS bearer contexts while locally deleting the MCE related information corresponding to the services indicated in the Reset message. The MME will then subsequently re-initiate the MBMS Session Start messages corresponding to those services.

These new Session Start messages will enable the MCE to restore M3 Application Protocol (M3AP) contexts related to the involved MBMS services and restart the MBMS services themselves if interrupted during the failure event. Hence, this automatic re-establishment of MBMS sessions makes the MBMS system reliable for the operator. For example if a subsequent MBMS Session Update or MBMS Session Stop comes in just after the failure, it can be safely delivered using the restored M3AP associations.

The feature can also similarly cover the re-establishment of MBMS sessions over the M2 interface following an eNB failure or an M2 path failure. In this case the MCE will re-initiate the MBMS Session Start messages towards the eNB to restore the services affected by the failure.

MME Take-Over Mechanism

The second cornerstone of MBMS recovery mechanisms consists of the MME takeover following a Sm path failure. For example, in case of a permanent Sm path failure, this feature enables the MBMS GW to select another MME of the pool to be used instead. This selection of an alternative MME can also be used for a non-permanent Sm path failure if an MBMS Session Stop message or an MBMS Session Update message is received from the BM-SC which needs to be delivered immediately during the failure duration.

Once the new MME2 has been selected, the MBMS GW generates MBMS Session Start messages corresponding to the services of the not reachable MME1 and including a "re-establishment" indication. The MME2 propagates each of these messages to the MCE which notices the special indication in them and infers from its presence that it must "replace" the ongoing service by the newly received one which has the same TMGI value.

In the meantime, as soon as the Sm path becomes available again, the MBMS GW sends an MBMS Session Stop message to the former MME1 with also a special indication to just remove the hanging corresponding M3AP contexts in the MME1. This feature has been extended to cover the case of the SGmb path failure for which the BM-SC can similarly select an alternative MBMS GW2. This case is particular since the new MBMS GW2 could perfectly happen to select the same MME (as used by former MBMS GW1) to deliver the new MBMS Session Start messages including the "re-establishment" indication. The MCE will then have to replace in this particular case the ongoing MBMS sessions by new sessions even though received from the same MME.

These MBMS enhancements are expected to be completed in Rel-12.

4.1.9.2 MBMS MEASUREMENTS

The MBMS measurement report is primarily intended to support network maintenance and optimization. The MBMS radio level metrics can be used for the following purposes:

- MBMS radio level metrics can indicate the existence of coverage holes
- MBSFN radio level metrics can assist in configuring appropriate MCS for each service. An MCS setting that is too aggressive may result in heavy application layer retransmission via file repair while an MCS setting that is too conservative leads into underutilization of the radio resource. In both scenarios, the network capacity cannot be fully exploited
- MBMS radio level metrics can assist in optimization of Forward Error Correcting (FEC) code parameters at the application level
- MBMS radio level metrics can assist in allocating the appropriate number of Multicast Broadcast Single Frequency Networks (MBSFN) subframes for the MBSFN area
- MBMS radio level metrics can potentially capture the loss due to excess delay spread. Even with relatively low cellular Tx power, there could be multipath beyond the cyclic prefix when the environment has lots of reflection

It follows from the targeted use cases that the measurement report is not particularly delay sensitive. It is not expected that a measurement report would trigger an immediate action in the network such as handover or reconfiguration. Therefore, the reporting delay requirements can be relaxed.

To avoid additional power consumption and measurement burden for the UE to collect MBMS radio level metric, the UE could start collecting the metric when it starts receiving MBMS service; it only collects such metric during the MBSFN subframes when it receives MBMS service.

The measurement collection should be separated corresponding to different MBSFN areas and the collection can be restricted to the MBSFN area(s) in which the UE actively receives MBMS service.

Examples of radio layer MBSFN metric can be the following:

- Signal strength related measurements:
  - MBSFN RSRP
  - MBSFN Reference Signal Received Quality (RSRQ)
- SNR related measurements:
  - MBSFN RS Signal-to-Interference plus Noise Ratio (SINR)
  - MBMS supportable MCS (MBMS CQI)
- Error rate related measurements:
  - MBMS error rate

Note that not all of the mentioned measurements need to be defined in order to make the measurement useful. This Work Item was approved in September 2014 and was ongoing in December 2013.

4.1.10 LOCAL INTERNET PROTOCOL ACCESS/SELECTED INTERNET PROTOCOL TRAFFIC OFFLOAD (LIPA/SIPTO) ENHANCEMENTS

The following sections describe Local Internet Protocol Access (LIPA) and Selected Internet Protocol Traffic Offload (SIPTO) enhancements.

4.1.10.1 COLLOCATED SIPTO AT LOCAL NETWORK

In a similar way as the Local Internet Protocol Access (LIPA) feature which was introduced in 3GPP Rel-10, the feature “Collocated SIPTO at local network” in 3GPP Rel-12 enables the offloading of the internet traffic from the RAN node itself through an embedded P-GW function.

However this new Rel-12 feature applies in a very different scope:

- The offloading happens in the private network
- The feature extends to a variety of RAN nodes ranging from eNB to HeNB and NodeB+ to HNB while the LIPA feature was restricted to HNB/HeNB

Despite the difference in scope, the feature operates in a similar way as LIPA. In LTE, the RAN node provides its embedded GW (Gateway) IP address at every idle-active transition over the S1-MME interface, so that the MME can reuse it for P-GW selection over S5. Conversely, the MME gets the relevant uplink TEID of the SIPTO bearer over S5 interface and sends it to the RAN node so that the latter one can establish an internal tunnel to flow the data directly between its radio part and the embedded P-GW part. Given that this feature is “co-localized” and may not be operated by the adjacent RAN node, the SIPTO bearer must therefore be deactivated as soon as the UE leaves the coverage corresponding to the cells of the served RAN node. To perform the deactivation, the radio part of the served RAN node will inform the P-GW part whenever a handover has been completed so that the P-GW can trigger the PDN deactivation procedure for the relevant EPS SIPTO bearer.

By directly offloading the internet traffic into the private network, this feature allows a significant release of the core network load, in particular for those UEs which are quite stable under the same eNB/HeNB or NodeB+/HNB such as stationary or nomadic UEs.

4.1.10.2 SIPTO AT LOCAL NETWORK WITH STAND-ALONE GTW

The 3GPP Rel-12 feature "SIPTO at Local Network with Stand-alone GTW" leverages the 3GPP Rel-10 feature "SIPTO above RAN". As the name indicates and in contrast to the previous "collocated SIPTO at local network", the P-GW function enabling the offloading of the internet traffic is located in a standalone gateway above the RAN node.

However the two main characteristics of the feature compared to Rel-10 are:

- The P-GW enabling the offloading is located in the private network
- The S-GW is necessarily collocated with the P-GW

These two architectural characteristics also bring some constraints: For example, if the SIPTO bearer is the first established, the S-GW can be selected together with the P-GW, but if there is already an existing connection when the SIPTO bearer is established then the S-GW must be relocated at the same time this bearer is setup. In contrast to the "collocated" case, the use of a stand-alone gateway above the RAN node makes the feature more flexible because the gateway can serve multiple RAN nodes and therefore the SIPTO bearer and the offloading function associated with it can be continued as the UE handovers from one RAN node to one of its neighbors provided that the latter neighbor is also served by the same gateway. The set of RAN nodes served by a same gateway thus make up what is called a "Local Home Network" (LHN). The feature then becomes attractive for UEs which are not necessarily stationary or nomadic (as in the previous case) because the SIPTO bearer could be continued until the UE goes out of the LHN where that bearer got started.

To allow this SIPTO mobility scheme to work, the RAN node must signal at every idle-active transition its pertaining local Home Network ID. The MME keeps this information in memory and at every handover compares it with the new Local Home Network ID provided by a target eNB in the handover message. If the MME sees no change of LHN, it maintains the SIPTO bearer; otherwise it triggers the deactivation of the associated PDN connection. In case of idle mode mobility, the same kind of detection is achieved by providing the LHN ID over S1 to the MME during the tracking area update procedure. Furthermore, in order to make the overall process more seamless, the MME can set the flag "reactivation required" in the "deactivation message" in order to enable quick re-establishment of the SIPTO bearer in the next LHN.

Hence, this feature allows operators to offer a seamless offloading function for UEs moving within an LHN, while avoiding the 'single point of failure' connectivity issue if they decide to deploy multiple stand-alone gateways to manage a same LHN.

This Work Item is expected to be completed in Rel-12.

4.1.11 ENHANCED IMT-ADVANCED (eIMTA)

In enhanced IMT-Advanced, LTE supports two different duplex modes, FDD and TDD. In FDD, uplink signals and downlink signals are separated in frequency. To protect the receiver from interference from transmission in the other direction, a guard band is needed. For TDD, the same carrier frequency is used and the systems instead rely on synchronization between nodes as well as a guard in time where all nodes are silent.

To better utilize spectrum in a TDD system, a TDD configuration that matches the traffic should be selected. Most networks see more downlink than uplink traffic and hence utilize a somewhat downlink heavy configuration. This is typically configured to be the same over the whole network to make sure as to not introduce strong base station-to-base station interference. This implicitly means that the TDD configuration seldom matches the instantaneous need of a cell, only a long term average of the network. To enable better utilization of TDD resources, dynamic adaptation of uplink-downlink ratios is introduced in LTE Rel-12.

Studies[147] have shown that significant gains can be seen in uplink and downlink user bitrate by adapting the TDD configuration to the instantaneous need of the cell. Due to packet-centric traffic, the variations in load for uplink and downlink may be very fast and hence adaptation on the smallest possible timescale results in the largest benefits.

If cells independently select subframes to use for uplink or downlink, they will cause interference; interference is normally not seen in TDD networks due to synchronization and alignment of TDD configurations. A base station using more downlink subframes will cause interference to the uplink reception in neighbor base stations, while the UE in that neighbor base station will cause interference to the downlink receiving UE in the first cell. This is practically troublesome in macro area networks where base stations have high elevated antennas and high output power. For these base stations, the base station-to-base station interference can be significantly stronger that the received signal strength. To begin with, this is the motivation to have synchronized and coordinated networks.

However, more and more networks are complimented by additional nodes, with significantly lower output power and antennas are placed below roof-tops or even indoors, to provide coverage and capacity to a small area. In the networks where the output power and the propagation between base stations and UEs are similar, little difference is seen between UE-to-base station and base station-to-base station interference, which makes traffic adaptation possible.

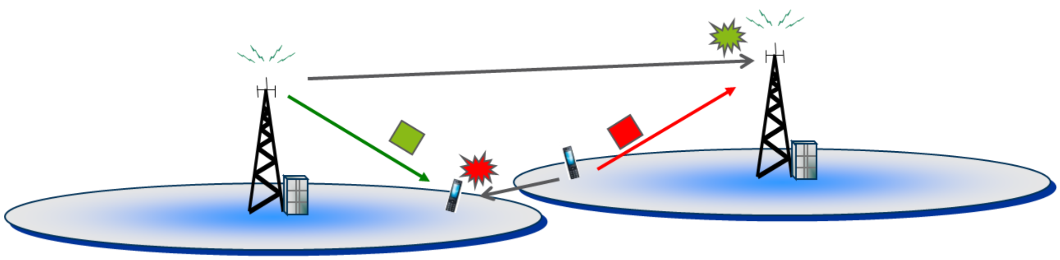


Figure 4.6. Inter-cell interference types in TD-LTE with dynamic uplink-downlink configuration. Shown is the possible interference between the UL of a UE into the DL of another UE.

The specification work for traffic adaptation for LTE TDD was being finalized in December 2013 by 3GPP. To enable traffic adaptation, a UE is configured with two different TDD configurations from the network. The UE then follows one configuration for uplink communication and a second configuration for downlink configuration. The subframes with different directions in the two configurations are dynamically controlled from the network for either uplink or downlink communication. To save UE power and enhance channel quality measurements in the UE, the base station may provide an indication of what subframes will be used for uplink and downlink respectively using a new physical layer signaling.

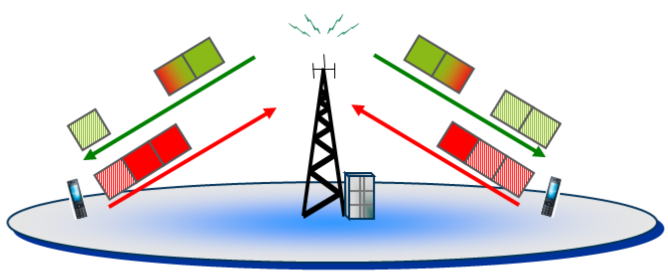


Figure 4.7. TD-LTE with dynamic uplink-downlink configuration with fixed and flexible subframes. Separate configurations for DL (green) and UL (red).

[147] TR 36.828, "Further Enhancements to LTE TDD for DL-UL Interference Management and Traffic Adaptation".

To enable the use of traffic adaptation in less isolated cells means that handling base station-to-base station interference is needed. With interference measures in the base station and the UE, it is possible to detect strong interference and adapt scheduling accordingly. Additionally, new uplink power control has been introduced such that the UE can adapt its output power differently whether or not strong interference is seen. Downlink power control can also be used to reduce the downlink output power in subframes where strong interference is caused to neighbor cells. For the cases where a cluster of low power nodes are placed close to each other, but isolated from other cells (e.g., within the same building), coordination is possible to adapt to the traffic within the cluster but independent from the outside network.

Side benefits seen from traffic adaptation are: reduced network energy consumption and reduced background interference. In LTE, cell specific reference symbols (CRS) are transmitted in all configured downlink subframes, independent of whether there is data to be transmitted or not. With traffic adaptation enabled, a smaller number of subframes will be configured as downlink and hence, a fewer number of subframes contain always-on signals. This will improve network performance even without selecting configuration based on instant traffic conditions and will also make the feature interesting for a macro deployed TDD system.

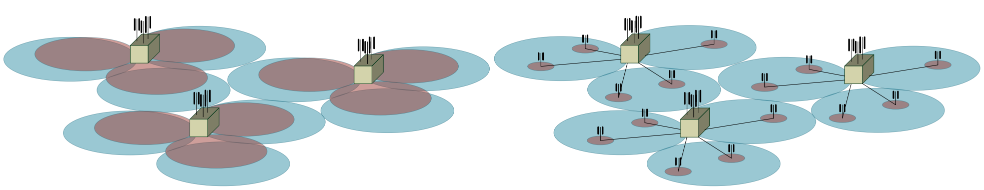
This Work Item was ongoing in December 2013 with scheduled completion in Rel-12.

4.1.12 FREQUENCY DIVISION DUPLEX-TIME DIVISION DUPLEX (FDD-TDD) CARRIER AGGREGATION

Within Rel-12, 3GPP is working on procedures for allowing UEs to aggregate both TDD and FDD spectrum jointly. The main solution to be specified is CA between a number of TDD and FDD carriers. CA between the FDD and TDD spectrum would allow user throughputs to be boosted (at least for DL CA) and it would allow a better way to divide the load in the network between TDD and FDD spectrum. Other uses cases, other than CA for joint TDD and FDD operation, are also studied. For example, introducing support for dual connectivity between TDD and FDD is studied. Dual connectivity[148] provides a tool to connect UEs to cells that are operating either TDD or FDD while the cells are connected with a backhaul of higher delay than that required for CA. The reason for operating in such a mode can, for example, be to enhance user throughputs, lower core network signaling or enhance the mobility performance. As this area is currently studied within 3GPP and the scenario/requirement and design is not settled the remaining part for this section relates to CA operation between TDD and FDD spectrum.

There are several examples of different operator scenarios wherein it can be beneficial to operate CA between FDD and TDD spectrum. Here two different examples are given; in a first example, an operator has already deployed FDD spectrum and owns additional TDD spectrum at a higher frequency which can be used to boost the network capacity in certain traffic hotspots. In a second example, the operator has already deployed LTE in TDD spectrum and is refarming FDD spectrum (e.g., GSM or CDMA2000). This is used to boost the overall network capacity; CA can, in such a deployment, allow increased user throughputs.

In 3GPP, the work to specify the support for CA between TDD and FDD is based on supporting the different CA scenarios outlined in TS 36.300[149]. The main two deployment cases for CA are the co-located scenario (scenario 1-3) and a non-co-located scenario (scenario 4). These scenarios are illustrated in Figure 4.8.



[148] TR36.842, “Study on Small cell enhancements for E-UTRA and E-UTRAN – Higher layer aspects”
[149] TS36.300, “Overall description (Stage 2)”

Figure 4.8. Collocated (left) and non-collocated (right) CA deployments.

Following the general framework for CA, it is assumed that the FDD and TDD network is synchronized with each other. This would allow reusing the general concepts and designs from Rel-10 and Rel-11 CA. It is further foreseen that a multitude of different UE capabilities needs to be supported depending on the target market and on which exact spectrum combinations are aggregated. The most common type of UEs would be a UE that supports DL CA with the addition that it may also support UL CA.

Most of the CA framework can be extended to support CA between TDD and FDD. The major changes that are foreseen are L1 control signaling handling and requirement work which allow mainly for UEs to function in an appropriate manner while receiving/transmitting in both TDD and FDD spectrum simultaneously. In the end, CA between TDD and FDD is a further step in the communality between the two flavors of LTE.

The RAN work started on this Work Item in November 2013.

4.2 HSPA+ ENHANCEMENTS

As mentioned, Rel-12 further defines multiple areas for the enhancement of HSPA+. This section reviews the features for which standards work has been finalized for HSPA+, as well as several open areas that are currently being developed. Areas detailed in this section include UMTS Heterogeneous Networks, scalable UMTS FDD bandwidth, EUL enhancements, emergency warning for UTRAN, HNB mobility, HNB positioning for UTRA, MTC and DCH enhancements.

4.2.1 UNIVERSAL MOBILE TELECOMMUNICATION SYSTEM (UMTS) HETEROGENEOUS NETWORKS

The rapid growth of 3G mobile devices and the exponential increase in data traffic requires a corresponding increase of cellular capacity. To meet these requirements, the deployment of small cells (micro, pico) is known to be a powerful tool to expand the network capacity in an efficient way. Such heterogeneous network deployments not only help improving overall traffic/data capacity, but can also mitigate poor macro coverage issues.

To optimize performance in 3G small cells deployments, 3GPP is studying enhancements for Heterogeneous Networks (HetNet) in UMTS, with a focus on capacity improvements.

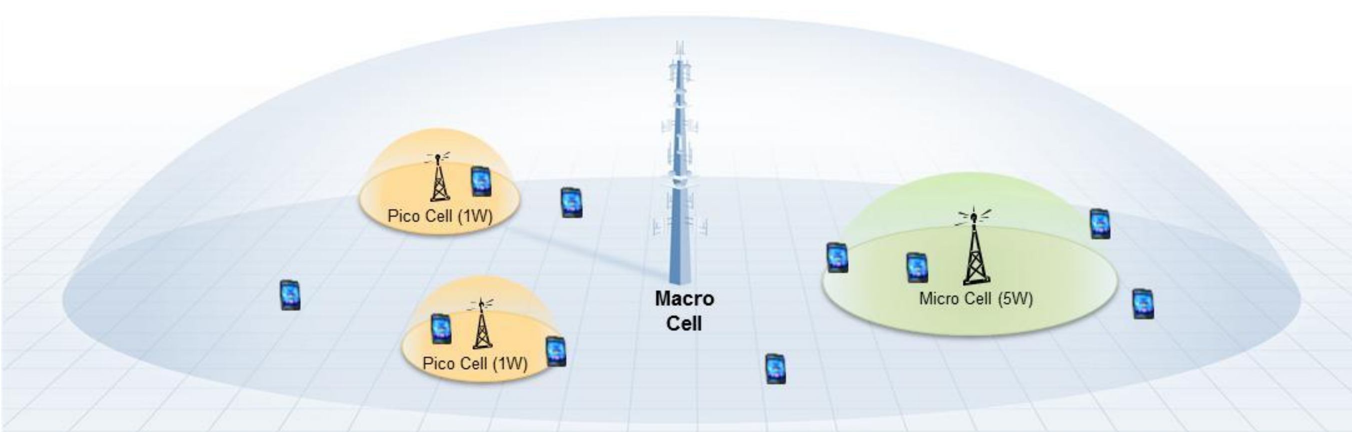


Figure 4.9. General HetNet Architecture, with Macro, Micro and Pico cells.

The following paragraphs summarize the main scenarios and solutions under investigation in Rel-12.[150] Terminology-wise, small cells are often referred to in standards as Low Power Nodes (LPN). Such convention is used also in the upcoming sections.

HetNet Deployment Scenarios

The following figures illustrate the main HetNet "carrier" related scenarios under study: Figure 4.10 illustrates the co-channel deployment scenario; Figure 4.11 illustrates a particular co-channel deployment scenario using combined cells; Figure 4.12 illustrates the dedicated frequency deployment scenario; and Figure 4.13 illustrates the multi-carrier scenario.

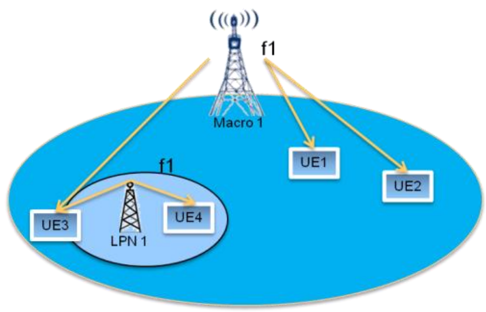


Figure 4.10: HetNet Co-channel deployment scenario. LPNs are deployed within the Macro cell coverage and uses the same frequency f1.

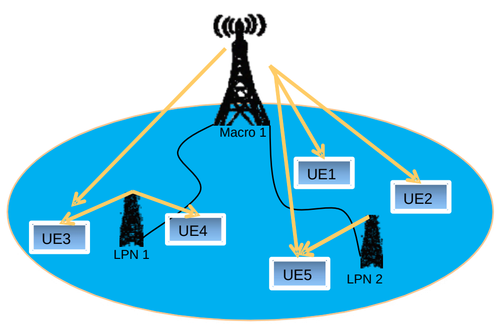


Figure 4.11. Combined cell deployment scenario. LPNs are deployed within the Macro cell coverage and uses the same frequency f1.

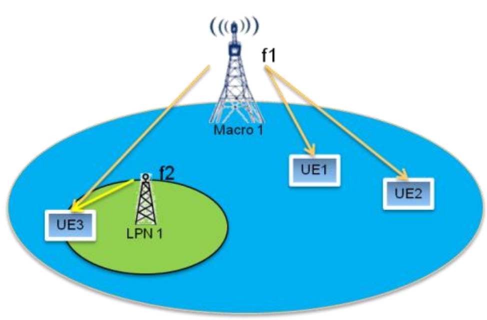


Figure 4.12. HetNet Dedicated frequency deployment scenario. Macro uses frequency f1 and LPN uses frequency f2.

150 RP-121436, SID on HSPA Hetnet.

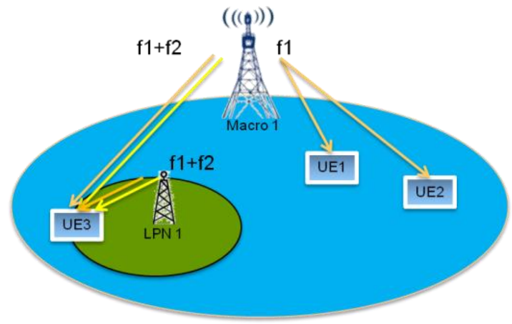


Figure 4.13. HetNet Multi-carrier deployment scenario. Both Macro and LPN use two frequencies, f1 and f2.

4.2.1.1 HETNET ENHANCEMENTS

Different issues and solutions are under investigation as part of the HetNet study, as summarized in the following content.

Uplink and downlink interference and link imbalance for HetNet co-channel deployments:

In heterogeneous networks, the difference in transmit power between the macro node and the LPN causes different coverage areas for the uplink (UL) and the downlink (DL). This is generally referred to as UL-DL imbalance. The UL boundary (equal path loss) and the DL boundary (equal downlink received power) between macro and LPN cells are different, and the region between such boundaries is referred to as the imbalance region or imbalance zone. Such aspects are illustrated in the Figure 4.14.

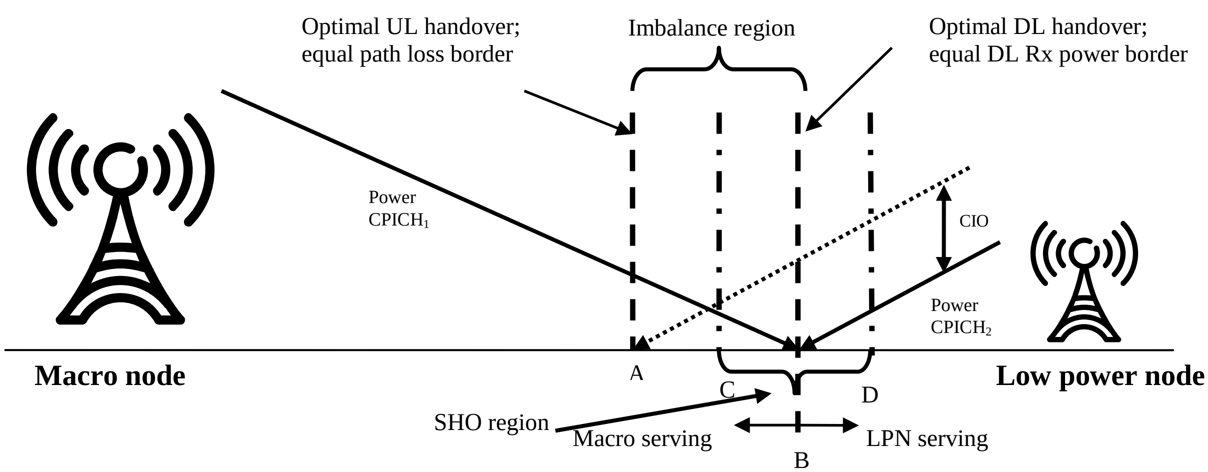


Figure 4.14. Heterogeneous network deployment, and general UL-DL imbalance.

Different performance issues and mitigation techniques are under study, aiming at optimizing specific HetNet interference and imbalance situations which can be categorized in two main areas:

- small cell coverage issues and potential solutions
- uplink and downlink interference between macro and small cell

A few of the initial identified solutions and observations from the Study Item are summarized:

- UL/DL imbalance in HetNet creates issues such as High Speed-Dedicated Physical Control Channel (HS-DPCCH) reliability and uplink interference, limiting the downlink and uplink performance. Applying cell individual offset Cell Individual Offset (CIO) to bias/offload more UEs towards the LPNs would improve throughput, but very large CIOs may generate further imbalance issues. To improve HS-DPCCH reliability a few techniques were previously detailed, e.g., HS-DPCCH boosting or tuning power control/Signal-to-Interference Ratio (SIR) for legacy networks and/or a new uplink pilot channel for enhanced HetNets

- There are also methods which may allow minimizing interference from UEs (not in Soft HO between macro and LPN) originating from UL/DL imbalance. Some identified mechanisms rely on limiting macro UL UE throughput, applying different values of CIO or receiver sensitivity level in LPN, using ICIC techniques (e.g., including enhanced network assistance) or playing with inter-frequency traffic steering for UEs in strong imbalance areas

Range expansion techniques with multi-flow

From an overall load and performance perspective, it would be desirable to evenly distribute the UEs among all cells in the system; this becomes especially important in Heterogeneous networks where small cells have the goal to offload capacity from the macro network.

One identified mechanism to achieve a simple and effective load balancing in HetNet deployments is to extend the coverage range of the LPNs (referred to as "Range Expansion"). The Rel-12 Study aims to evaluate system performance benefits of range expansion in combination with different multi-flow configurations (including co-channel and multi-carrier multi-flow configurations).

For Co-channel Range Expansion, the study mostly focuses on impacts and mitigations when using legacy CIO-based offloading. For Multi-Carrier Range Expansion, one solution under evaluation is called “Macro Power Reduction”, which can be used together with multi-flow operation. One example of offloading through macro power reduction (on one frequency), is shown in figure 4.15 (in the scenario of two shared frequencies for macro and pico cells).

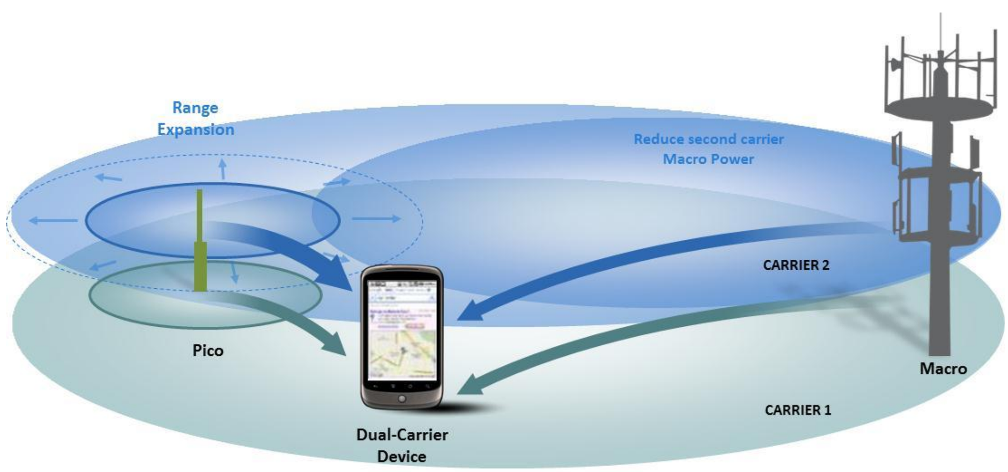


Figure 4.15. Macro power reduction as a range expansion technique.

The following multi-carrier multi-flow scenarios were analyzed as part of the HetNet study.

Table 4.1. Multi-carrier LPN range expansion scenarios and optimal multi-flow configurations.

Scenario	Macro cell	LPN (Low-Power Node)	Multiflow configuration
1	F1+F2	F2	SF-DC DF-DC DF-3C
2	F1+F2	F1+F2	SF-DC DF-DC DF-3C DF-4C

Combined cells

Another HetNet study area addresses those deployments where macro and LPN cells are combined. The term "combined" cell (also called shared cell) refers to one cell radiating over several transmission points (e.g. using spatially separated antennas).

Figure 4.15 illustrates an example of HetNet combined cell scenario, where the Macro cell is connected to the LPNs deployed within the Macro cell area, all sharing the same (macro) primary scrambling code and closely coupled to the macro clock (by high speed and low latency backhaul). In such a HetNet architecture, there would be a central unit, which may be a macro scheduling unit, connected to multiple LPN nodes. For example, these nodes can be Remote Radio Units (RRUs). The RNC connects to the central unit and is not aware of these different nodes.

In a HetNet co-channel deployment, scheduling is done per each cell while in a combined cell scheduling is performed per combined cell. Hence, the scheduler decides which nodes (LPNs) should transmit to a particular UE. Two main downlink transmission modes are under evaluation for combined cells deployments.

- *Single Frequency Network (SFN):* This mode combines signals over the air from all nodes by means of transmitting exactly the same pilot channel, downlink control channels and downlink data channels using the same carrier frequency, spreading and scrambling codes.

- *Node Selection with Spatial Reuse:* Similar to the SFN mode, the same pilot signal Primary Common Pilot Channel (P-CPICH) is transmitted from all the nodes (allowing it to serve the legacy users); instead, downlink control and traffic channels are scheduled to different UEs from different nodes using additional (demodulation) pilot channels (sent by the different nodes of the combined cells).

Mobility enhancements in HetNet

The study on HetNet has covered also potential optimizations to improve mobility performance in the presence of macro and small cells. In particular, the following four areas have been investigated:

- Improvements to UE discovery and identification of small cells

- Mobility performance for UEs at different speeds
- Mobility issues in dense small cell deployment
- Mobility enhancements in HetNet multi-flow scenarios

The main conclusions from the study are summarized below:[151]

- For dense small cell deployment, the focus should be on extending the Neighbor Cell List (NCL) requirements (e.g., allowing UE to measure and/or report more than 32 intra-frequency or inter-frequency cells), avoiding known issues such as Packet Scheduling (PSC) re-use/confusion
- For improving mobility reliability (e.g. reducing HO failures for high sped UEs moving between Macro and LPN cells), further enhancements can be considered. One example is the possibility to configure different mobility parameters for macro and LPNs, such as HO/SCC event time-to-trigger
- For small cell discovery and identification, the focus should be on proximity detection (UE based, NW based or NW assisted) for connected mode, and UE battery savings during "dormant" states, e.g. introducing some relaxed inter-frequency measurements for UEs in non-DCH state
- For range expansion, further mobility enhancements (e.g., intra-frequency event triggered reporting on the secondary carrier) can be considered
- For combined cell, performance benefits are expected due to the simplification of RRC signaling and mobility procedures (being macro and LPNs an extension of the same combined cell)

The preliminary study outcome supports the general conclusion that Heterogeneous networks offer substantial throughput gains for HSPA. The gains increase as the percentage of UE offloaded from Macro cell to LPN increases, (e.g., when increasing the number of LPNs per Macro area and/or increasing the transmit power of the LPNs).

Further study is ongoing on a few solutions and optimizations to address HetNet interference/imbalance mitigation, namely on *E-DCH decoupling* and *Network Assisted Interference Cancellation* (NAIC).

E-DCH decoupling is based on the idea that the uplink scheduling grants can be controlled by the LPN while the HSDPA data is transmitted by the macro cell. Aspects under investigation include the quality and cost (in terms of LPN power) of downlink control signaling transmitted by the LPN, and the delay in receiving the scheduling grants.

Few NAIC aspects and options were studied, e.g. for optimizing LPN range expansion scenarios, including post-decoding and pre-decoding IC, IC assistance signaling (explicit or implicit), and coordinated scheduling. Evaluation of NAIC solutions is still ongoing, (e.g., studying signaling overhead impacts on overall DL capacity and legacy UEs).

An additional area for study is the impact of combined cells, namely on performance of legacy terminals, and possible mitigation techniques. With regard to mobility enhancements in HetNet deployments, the initial study has been completed, and the work is progressing toward the standardization phase.

The Study Item on HetNet has been closed, and the following two Work Items are currently ongoing:

1. A Work Item on Hetnet Mobility aims at the following objectives:[152]

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[151] TR 25.800, "Technical Report on HSPA Hetnet"
[152] RP-131348, "WI on Hetnet Mobility enhancements"

- Consider solutions for small cell discovery and identification. The focus should be on proximity detection (UE based, NW based, UE based NW assisted) and the relaxed inter-frequency measurements for UE in non-DCH state
- Consider solutions to improve mobility for UEs with high speed
- Consider solutions to support mobility for dense small cell deployments focusing on extended NCL list
- Consider further mobility enhancements (e.g. intra-frequency event triggered reporting on the secondary carrier)

2. A Work Item on other Hetnet enhancements, covering the main solutions areas listed below:

- Co-channel interference management (to mitigate UL/DL imbalance)
- Range expansion for co-channel and multi-carrier
- New Iub signaling for dynamic CIO adaptation
- Network Assisted Interference Cancellation (NAIC)

4.2.2 SCALABLE UMTS FDD BANDWIDTH

Spectrum availability and flexible usage are among the basic traditional needs for cellular operators. For UMTS FDD, 5 MHz is the only channel bandwidth (BW) defined so far (for TDD there are smaller BW options). Today, such bandwidth limitation appears to restrict operators' flexibility in those 3G markets where 5 MHz for UMTS FDD may not be available or suitable, for example, when the frequency resources are coming from displaced/re-farmed legacy systems, or where spectrum cost is a significant burden.

To allow a more efficient spectrum allocation and usage for UMTS FDD, a feasibility standard study is ongoing to analyze suitable options to support scalable FDD bandwidths, smaller than 5MHz.

The Rel-12 ongoing study[153] aims at identifying relevant use cases (e.g. bandwidths, multi-carrier combos and/or service requirements for narrow FDD bandwidth operation), and analyzing performance aspects of candidate solutions (together with their implementation and specification impacts).

Deployment Scenarios

The study identified a few target deployment scenarios. In terms of bandwidth, two scaled (1/Nth) values are currently considered: 2.5MHz (corresponding to N=2) and 1.25MHz (corresponding to N=4), which are shown in Figure 4.16 below.

153 RP-130221, "SID on Scalable UMTS Bandwidth"

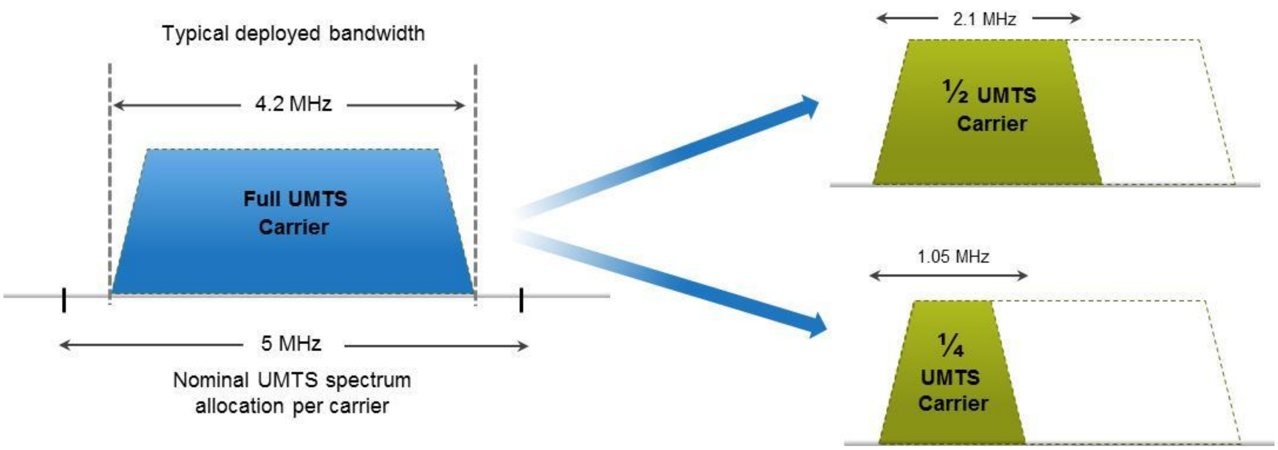


Figure 4.16. Scalable UMTS FDD Bandwidth scenarios (N=2 and N=4) with 2.5 MHz and 1.25 MHz respectively.

In terms of carriers' configuration, the Scalable UMTS carrier may operate as standalone or as supplemental downlink carrier (multi-carrier scenario). The latter case refers to the mode of operation where the 5 MHz carrier acts as the primary carrier, and the Scalable UMTS carrier is usable as the secondary HSDPA carrier in downlink. Table 4.2 lists the main Scalable UMTS scenarios initially identified within the Rel-12 study.

Table 4.2. The first deployment scenarios for Scalable UMTS.

Note: An additional multi-carrier scenario was also considered: three UMTS 5MHz carriers and one 2.5 MHz carrier in 15 MHz bandwidth.

Mode of Operation	Bandwidth	Comments	Bands
Standalone	2.5 MHz (corresponds to N=2)	Support for DCH shall be considered.	Band VIII (and Band I)
Standalone	1.25 MHz (corresponds to N=4)	HSPA data only	Band VIII (and Band I)
Multi-carrier	a) 5 MHz + 1.25 MHz (corresponds to N=4) b) 5 MHz+ 2.5 MHz (corresponds to N=2)	a) focuses on 6 MHz of contiguous band	Band VIII (and Band I)

Some potential solutions that have been studied are described in the following content.

4.2.2.1 SCALABLE UMTS TIME DILATION

Since the start of the study, there has been one main identified solution, called "time dilation" (or time dilated UMTS), aimed at re-using most of the legacy radio interface protocols structure. This solution is described in detail in the study's Technical Report 25.701[154] and briefly summarized in the following content.

The Scalable UMTS time dilation solution comprises increasing the UMTS chip period by a time dilation factor N, where N is equal to 2 or 4. Consequently, the Scalable UMTS chip period is increased to $N*T_c$, where T_c is the UMTS chip period

[154] TR 25.701, SI Technical Report on Scalable UMTS Bandwidth

(i.e., 0.26 μs). This results in the Scalable UMTS chip rate being reduced by a factor of 1/N relative to the UMTS chip rate of 3.84 Mcps and the Scalable UMTS spectrum bandwidth being reduced by a factor of 1/N relative to the UMTS spectrum bandwidth of 5 MHz.

Figure 4.17 illustrates the time dilation concept.

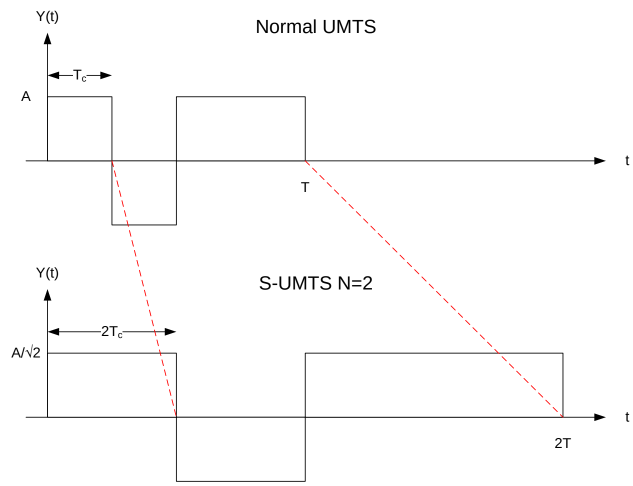
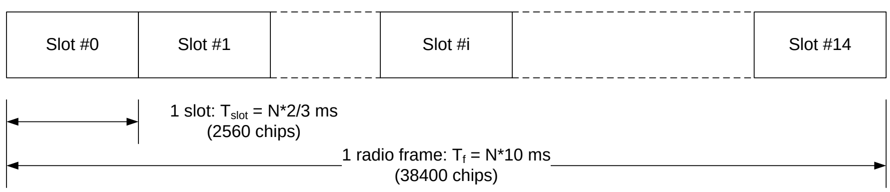


Figure 4.17. Time-dilated UMTS FDD waveform (time domain).

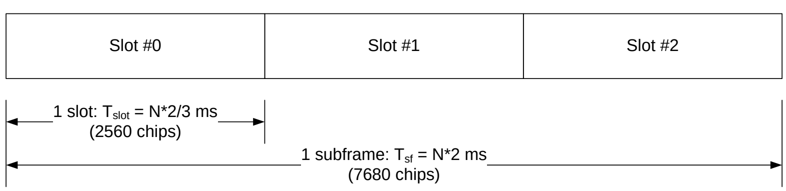
Time-dilated UMTS requires all time-related physical layer parameters to be scaled accordingly (i.e., dilated N times relative to UMTS). For example, in the case of time-dilated UMTS N=2, the radio frame duration increases from 10 ms to 20 ms, as shown in Figure 4.18.

Also, the High Speed Physical Downlink Shared Channel (HS-PDSCH) subframe duration increases from 2 ms to 4 ms as shown in Figure 4.19.



NOTE: N=1 corresponds to normal UMTS

Figure 4.18. Radio frame structure for Scalable UMTS time dilation solution.



NOTE: N=1 corresponds to normal UMTS

Figure 4.19. HS-PDSCH subframe structure for Scalable UMTS time dilation solution.

The power spectral density (PSD) of the Scalable UMTS time dilation solution in both the uplink and downlink can be either the same as normal UMTS or scaled by a factor of N relative to normal UMTS (where N=2 or 4). In the first case, the Scalable UMTS total transmit power is 1/N of normal UMTS. In the second case, the Scalable UMTS total transmit power is the same as normal UMTS. This is illustrated in Figure 4.18 and Figure 4.19.

In Figure 4.20, for the uplink, if the normal UMTS UE transmit power is 23 dBm, then the Scalable UMTS UE transmit power is 23 dBm – $10\log_{10}(N)$ (i.e., 20 dBm for Scalable UMTS N=2 and 17 dBm for Scalable UMTS N=4). For the downlink, if the normal UMTS Node B/cell transmit power is 43 dBm, then the Scalable UMTS Node B/cell transmit power is 43 dBm - $10\log_{10}(N)$ (i.e., 40 dBm for Scalable UMTS N=2 and 37 dBm for Scalable UMTS N=4).

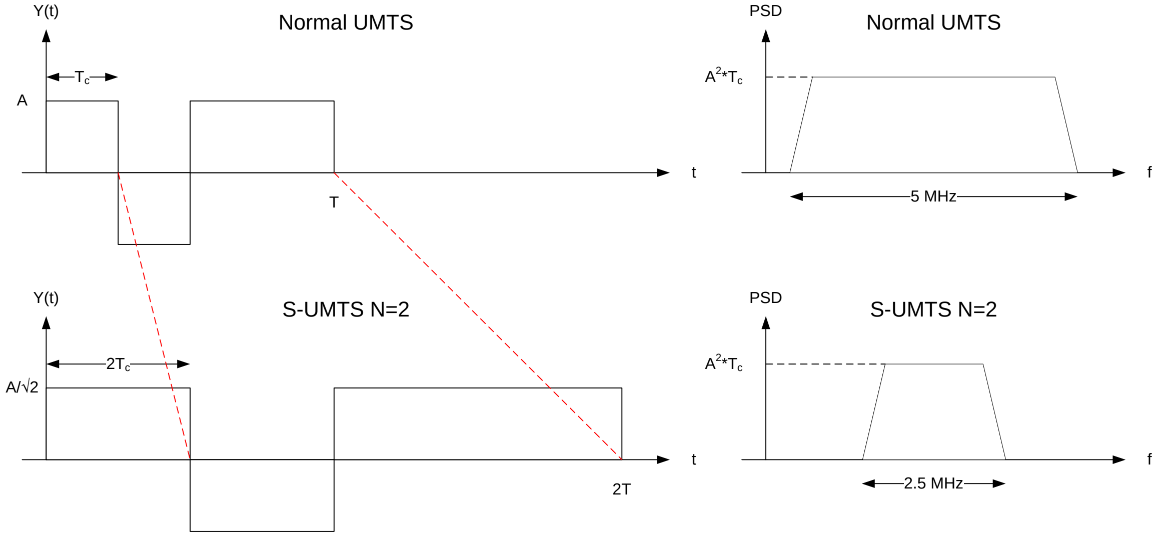


Figure 4.20. Scalable UMTS PSD same as normal UMTS.

In Figure 4.21, for the uplink, if the normal UMTS UE transmit power is 23 dBm, then the Scalable UMTS UE transmit power is also 23 dBm (for both Scalable UMTS N=2 and N=4). For the downlink, if the normal UMTS Node B/cell transmit power is 43 dBm, then the Scalable UMTS Node B/cell transmit power is also 43 dBm (for both Scalable UMTS N=2 and N=4).

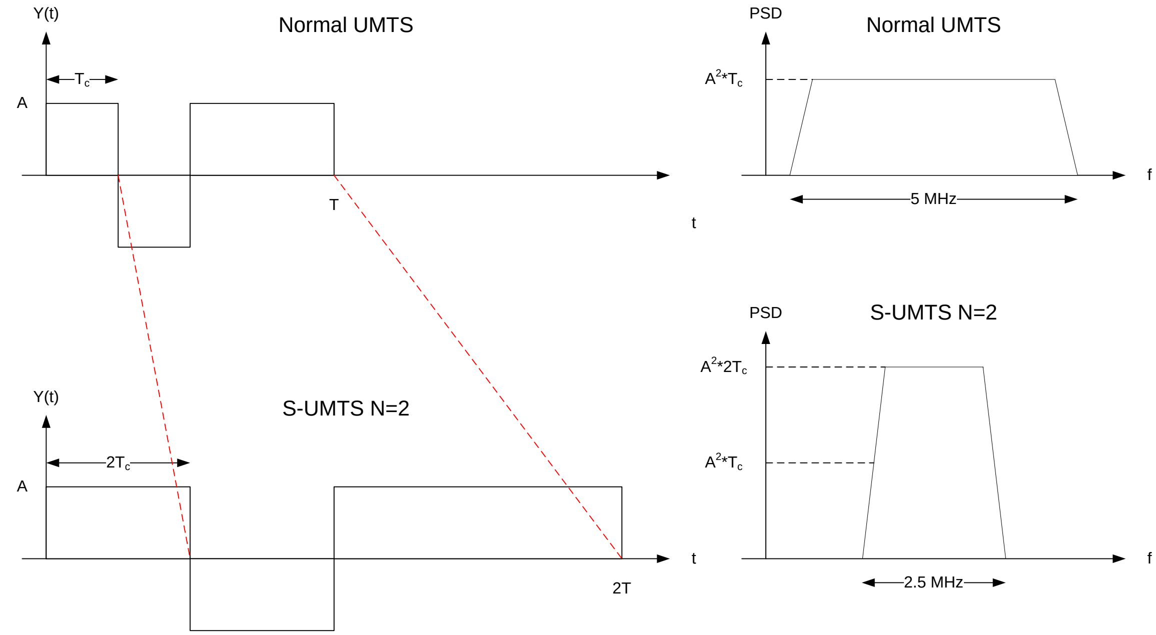


Figure 4.21. Scalable UMTS PSD scaled by N relative to normal UMTS.

4.2.2.2 SCALABLE UMTS BY FILTERING

Another solution proposed and under initial evaluation is called Scalable Bandwidth UMTS by Filtering.

The Scalable Bandwidth UMTS solution by filtering relies on using the same Baseband (BB) processing and the typical 3.84 Mcps chip rate used in UMTS FDD systems, and filtering the signal to fit to a channel bandwidth below 3.84 MHz. This solution is referred to as Scalable Bandwidth UMTS by Filtering.

Figure 4.22 illustrates this concept, where the filtered UMTS pass-bandwidth is narrower than the 3.84 Mcps signal, in particular 2.5 MHz (so far the only addressed use case).

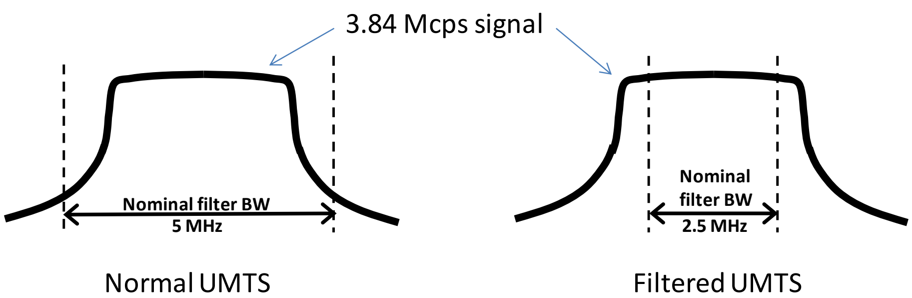


Figure 4.22. Normal and 2.5 MHz filtered UMTS waveforms.

This study item was ongoing in December 2013, thus conclusions on possible standard solutions were unavailable at the time of this writing.

4.2.3 FURTHER EUL ENHANCEMENTS

Between 2012 and 2013, a considerable increase in the number of users as well as in the offered traffic per user has been experienced in HSPA networks, both in the downlink and in the uplink. For example, one report measures total data traffic doubling in mobile networks year-on-year.

During this time, several features improving the performance of HSPA have been standardized in 3GPP, both for uplink and downlink. In Rel-11, there were a number of uplink improvements introduced including:

- The Enhanced Uplink (EUL) in CELL_FACH feature, first introduced in Rel-8, was further improved
- Uplink transmit diversity improved general performance and especially cell edge coverage
- 64 QAM and MIMO increased the uplink peak rate on EUL 2ms TTI to 34 Mbps per 5 MHz carrier

In early discussions on the Rel-12 study item, a number of companies agreed that there should be focus on both new enhancements that improve the performance of EUL, and to further enable those capabilities already available in the standard to be able reach more users in real networks.

At the RAN plenary in December 2012 the following text was agreed on the objectives of the further EUL study item 25.700.[155] *It should fulfill the objective of identifying potential technical solutions for increasing the uplink capacity, coverage and end user performance (e.g., latency, achievable rates, etc.).* The improvements are targeted towards the following scenarios:

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155 TR 25.700, "The study on Further EUL Enhancements"

- Improvements to uplink user plane cell capacity with high number of users (high priority)
- Improvements to uplink coverage and latency (lower priority)

In total, eight areas for studies were agreed, and a background and status summary follows:

- Enabling high user bitrates in a mixed-traffic scenario by means of a more efficient method of confining high-RoT operation to dedicated secondary carriers

  The maximum allowed uplink interference level in a cell, also known as the maximum Rise-Over-Thermal (ROT) is a highly important quantity in WCDMA based networks. The maximum allowed interference level in a cell is related to the peak rates that can be achieved in the cell.

  Typically, macro cells are dimensioned with an average ROT of around 7dB, which enables the UL data rates of 5.7 Mbps supported by most commercial smartphones, while also securing voice and data coverage for cell edge users. High data rates such as 11 Mbps (available since Rel-7) and 34 Mbps (available since Rel-11) require ROT levels greater than 10dB and 20dB respectively.

  The maximum uplink interference level that an operator can allow is determined by a number of factors such as the density of the network, the capability of the network to handle interference (for example with advanced interference suppression or cancellation techniques), and the capabilities of the devices in the network, including both smartphones and legacy feature phones.

  In Rel-12, the *Lean Carrier* solution has been proposed to further meet the needs of high data rate users. Lean carrier is a multi-carrier solution that is built on the Rel-9 HSUPA dual-carrier solution. Dual-carrier allows two carriers, a primary and a secondary to be assigned to a user. The user's traffic can be flexibly allocated between the carriers while doubling the peak rate achievable.

  The Lean Carrier solution optimizes the secondary carrier for fast and flexible handling of multiple high rate data users, through faster and more efficient granting and lower cost per bit. The lean carrier solution is designed to allow multiple bursty data users in a cell to transmit at the highest peak rates without causing any uplink interference to each other or to legacy users. For the greatest energy efficiency, it is proposed that the Lean Carrier solution shall cost nothing in resources from either the system or terminal on the secondary carrier until the user sends data.

  It must be possible for Lean Carrier to be flexibly deployed according to the needs of the operator's network. For example the maximum ROT on a user's secondary (lean) carrier can be configured to support any available uplink peak data rate, while the maximum ROT on a user's primary carrier can be configured to secure cell edge coverage for signaling, random access and legacy (voice) users.

- Rate Adaptation to support improved power and rate control for high rates

  High uplink data rates require more power. Maintaining a fixed data rate at the desired quality target in an environment where interference levels vary greatly can result in large fluctuations in received power.

  In WCDMA systems, inner loop power control adapts the UL Dedicated Physical Control Channel (DPCCH) power based on a quality target (e.g., a SIR target). The UL data power is offset from the control channel power by a fixed gain factor. ,At high uplink rates, a high power is required and the gain factor is large. Fluctuations in control channel power are multiplied by the data gain factor, giving large fluctuations in overall transmitted and received power. In addition, at high rates the data transmission is more susceptible to self-interference, and a saturation point can be reached where increasing the DPCCH power to meet the received SIR target does not increase the received SIR.

To avoid such problems, the concept of rate adaptation can be applied. High-rate users are assigned a fixed received-power budget, and as interference levels change, the bit rates are adapted to keep the desired quality target while not exceeding the allowed power budget. In short, the bit rate is adapted to received power, and not the power to the rate.

Limiting fluctuations in received power for high-rate users is beneficial for overall system capacity because these users can transmit more efficiently, and other users in the system, including low-rate ones such as voice users, consume less power when power levels are stable and predictable.

3GPP is studying and comparing three Rate Adaptation algorithms. One algorithm does not require standard changes, (i.e., the rate is adapted using the existing grant mechanism) and two algorithms do require standard changes to allow the granted rate and granted power to be decoupled from each other.

All of the proposed algorithms can keep the received power constant while adapting the rate to changing interference levels. Algorithms involving standard changes include extra control loops to allow more quantities to be controlled independently from each other, such as DPCCH SIR, Rate, and total received power. 3GPP is currently evaluating the pros and cons of the different alternatives.

- Improvements to handling of dynamic traffic on EuL, e.g. more efficient grant handling, improvements to the handling of scheduled and non-scheduled data and control transmissions during bursty traffic, etc.

  To achieve the highest rates that are possible (December 2013) in the uplink, a high bit-energy to interference ratio is required. When high rate users transmit one at a time (i.e. are Time Division (TD) scheduled), then there is no intra-cell interference from other high rate users, and the high Eb/No required can be achieved more easily. TD scheduling is used in the simulation assumptions in 3GPP discussions of the lean carrier and rate adaptation solutions.

  The original enhanced uplink standard was not designed specifically for TD scheduling even though it is possible to run in a TD mode, using for example per HARQ grants. When users are TD scheduled then the granting mechanism should be fast and efficient so that the scheduler can easily switch from one user to another without gaps where no user can transmit. A number of companies have submitted proposed schemes to make TD scheduling more efficient.

- Improvements to EUL coverage when using single RAB as well as various multi-Radio Access Bearer (RAB) combinations

  EUL 2ms TTI is generally preferred to 10ms TTI due to higher peak rates and low latency however 10ms TTI cell edge coverage is better due to the longer TTI. Proposed changes include both improvements to the coverage measurements that support a switch between 2ms and 10ms TTI, and mechanisms to perform faster switching.

- Improvements to current access control mechanism to provide efficient approach for UTRAN in case of uplink overload

  Smartphone users want to be able to rapidly access the network whenever they want. Maintaining a device in a connected-mode state, such as CELL_FACH, CELL_PCH or URA_PCH, for as long as possible, is one way of achieving this. Access from these states is much faster than from the IDLE state. In recent releases, connected-mode states have been made more efficient from a battery and resource point of view, and so it is feasible to maintain inactive devices in these states for longer.

  As the number of smartphone users increases, networks need flexible mechanisms to maintain high system throughput even during periods of extremely heavy load. Allowing the network to limit the number of concurrently active users as well as the number of random accesses is one such mechanism.

Improvements that enable high throughput under heavy load, and allow users to benefit from lower latency in connected mode, while enabling both admission decisions that are differentiated on traffic type, and control over the number of simultaneous users, have been proposed for Rel-12.

- Reduce UL control channel overhead for HSPA operation

  The more control channel overhead can be reduced, the greater capacity is available for data on the uplink. In Rel-7, CPC was introduced which allowed the DPCCH channel to stop transmitting when the user is not transmitting data. Further reduction of DPCCH overhead such as removal of DPCCH bursts is considered in the Lean Carrier item.

  In addition, a number of proposals have been made in Rel-12 to further reduce the overhead of the Enhanced Dedicated Physical Control Channel (E-DPCCH) and HS-DPCCH control channels, for example reduction of information bits on the E-DPCCH and CQI reduction on HS-DPCCH in cases where the user is inactive on DL.

- Mechanisms to perform UL data compression between the UE and the RAN

  The purpose of this item is to evaluate:

  - Compression gains and performance benefits for different types of smartphone traffic. At least UL capacity, signaling load, UE battery and latency should be considered.
  - Mechanisms to selectively enable/disable data compression when traffic is compressible/uncompressible.

  Application layer protocols (e.g., Http), allow process-to-process communication between the UE and entities across an IP network. For each process-to-process communication, different uplink packets may contain redundant information, and redundancy may also be found between different processes. For instance, different Http GET requests from the same UE often contain repeated information regarding the user agent, language, connection, etc. Compression mechanisms may be used to reduce this redundant information across packets.

  Compression of process-to-process protocol data may be performed either at the application or at lower layers. Lower layer compression, e.g. at the RNC, has the advantage of allowing the exploitation of redundancy across several IP flows for a single UE.

  A possible UL data compression mechanism proposed in Rel-12 is based on pattern-matching (LZ77 algorithm) and entropy coding (Huffman). The compressor in the UE, and de-compressor in the RNC maintain a fixed amount of memory so as to keep track of the contents of past data packets. This memory enables the pattern-matching algorithm to reference instances of repeated bytes across packets.

- Low-complexity uplink load balancing solutions, e.g. a fast uplink carrier switching in Cell Dedicated Channel (Cell_DCH) state, especially for configurations where the downlink is configured in multicarrier operation while the uplink is in single carrier.

  Some contributions on UE switching between carriers were presented and later withdrawn. As of December 2013, it is proposed that network controlled methods should be considered.

  The further EUL enhancements Study Item contains a number of technical proposals to further increase the uplink capacity, coverage and end user performance in HSPA networks.

This Study Item was completed in December 2013.

4.2.4 HNB EMERGENCY WARNING AREA FOR UNIVERSAL TERRESTRIAL RADIO ACCESS NETWORK (UTRAN)

UMTS Cell Broadcast does not support the concept of warning areas, so that for an emergency warning in an area, individual HNBs have to each be sent a message by the Cell Broadcast Center (CBC). This study will consider solutions for handling Emergency Warnings for HNBs, such as introduction of an Emergency Area ID list similar to LTE and consider the impact of the introduction of proposed solutions, including the impacts on transport links along both directions of the signaling chain.

As of December 2013, this Study Item was ongoing.

4.2.5 FURTHER ENHANCEMENTS FOR HNB MOBILITY

The further enhancements introduce CELL_FACH (and CELL_PCH and URA_PCH) support for HNBs. Because of the autonomous setup of HNBs, they allocate their User Radio Network Temporary Identifiers (URNTIs) independently, and so in CELL_FACH it is difficult to use the URNTI to determine the source cell of the mobility procedure. Introducing a method of managing the URNTIs, whereby the HNB-GW allocates blocks of U-RNTIs by specifying a U-RNTI prefix to each HNB under its control, allows these modes to be supported for Rel-12 HNBs.

At HNB registration the HNB-GW assigns a U-RNTI range to the HNB based on avoiding overlap in neighboring HNBs and also the capacity of the HNB. During CELL_FACH mobility the target HNB can request information on the U-RNTI from the HNB-GW and establish Iurh interface to the source as shown in Figure 4.23.

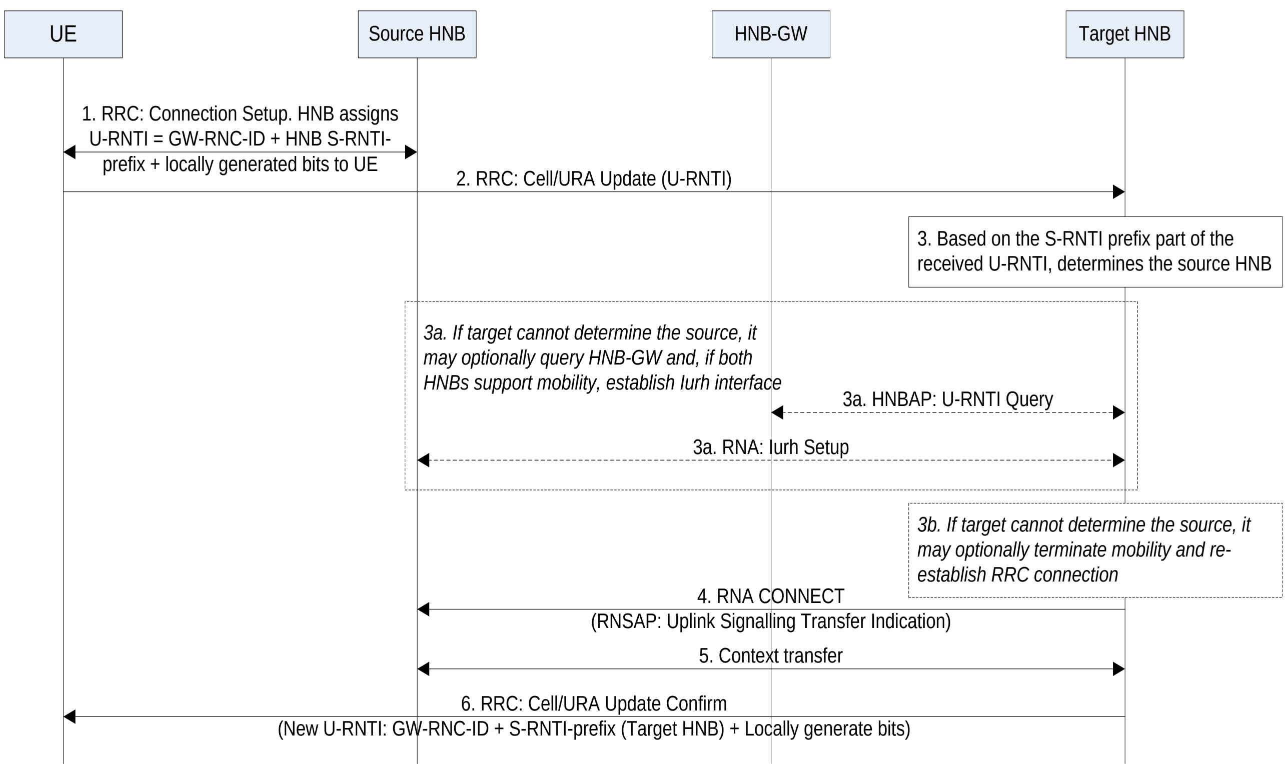

Figure 4.23. CELL_FACH mobility; the target HNB can request information on the U-RNTI from the HNB-GW and establish Iurh interface.

Similar operation occurs when handling HNB to macro RNC and macro RNC to HNB CELL_FACH mobility.

A further aspect is that the UE does not support autonomous search in CELL_FACH, so unless the HNB was in the neighbor list, cell reselection would not occur. Thus, some new UE behavior was defined to support autonomous search in CELL_FACH for reselection to non-serving frequencies and inter-RAT frequencies, this only needs to be performed when second DRX is used.

This completed the agreed mobility support modes for the HNB, and further enhancements for mobility are not envisioned.

In addition, RAN sharing was introduced for HNBs and HeNBs. A similar solution was used for both UMTS and LTE. If the target cell is a shared CSG/hybrid cell, then the measurement report also includes the subset of the broadcast PLMN identities that pass access check and for which the CSG whitelist of the UE includes an entry comprising the cell's CSG ID and the respective PLMN identity. The eNB/RNC verifies access check for the PLMNs indicated by the UE, and selects one, if multiple PLMNs pass the access check. Finally, the MME/SGSN verifies the CSG membership check for the PLMN selected by the source eNB/RNC. Changes for RRC UMTS include: adding a new PLMN list to measured results; and for LTE RRC, making suitable the use of PLMN list and the indicator for primary PLMN. These changes are effective for Rel-12 UEs.

This Work Item on HNB mobility enhancements has been completed in Rel-12.

4.2.6 HNB POSITIONING FOR UTRA

While HNBs generally have a small cell radius and therefore positioning based on cell-id may be adequate, in circumstances of dense urban or rural deployments enhanced positioning may be necessary using a Standalone Serving Mobile Location Center (SAS). To support this, the Packet Capture (PCAP) protocol can be used, as it is for macro network, however this is not supported across the HNB-HNB-GW interface Iuh, as it requires Signaling Connection Control Part (SCCP) and this is not included in the protocol stack. Introducing a User Adaption Layer to the Iuh stack will allow PCAP to be used and hence enable enhanced positioning to be used for HNBs, enabling the same UE positioning facilities as are available in the macro network.

In addition, the Work Item will also consider whether the new functionality may be applied to enhance positioning of the HNBs themselves.

The Work Item is currently ongoing in Release 12.

4.2.7 MACHINE TYPE COMMUNICATIONS (MTC)

Within Rel-12, MTC enhancements for UMTS (and LTE) are under work and/or study at the system and RAN level. The RAN Study focused on UE Power Consumptions Optimizations (MTCe-UEPCOP) and Small Data and Device Triggering Enhancements (MTCe-SDDTE),[156] targeting both UMTS and LTE[157] (see Section 4.1.4).

In particular, enhancements have been studied in the context of MTC traffic involving small data transfers (with inter-arrival time from several seconds to many hours), and focusing on the following solutions:

- UEPCOP: Power saving (or dormant) state and extended DRX cycle (Idle and connected)
- SDDTE: Data over NAS signaling for infrequent small data transmission over control plane, and assistance information (e.g., UE mobility behavior and traffic type/pattern provided to RAN) for frequent small data transmission

156 SP-120442; SP-120450: SA2 wids on UEPCOP and SDDTE
157 RP-130396, “RAN SID on Machine-Type Communications (MTC) and other Mobile Data Applications Enhancements”

The RAN study outcome is captured in the TR 37.869[158]; though some part of the analysis has been focusing on LTE aspects, most conclusions are expected to apply similarly to UTMS as well.

The RAN Study Item has been closed at RAN#61 in September 2013, and a Work Item started in December 2013, with the following goals:

- For UE Power Consumption Optimizations, RAN2 specification(s) will be enhanced to align the Access Stratum procedures with the (CT1) NAS solution on the agreed new “Power saving state”;
- For Signalling Overhead Reduction, RAN2 should evaluate the introduction of new assistance information/parameters from CN to RAN related to the UE and its traffic type/pattern, in line with the (SA2) agreed new CN-RAN signalling.

Further RAN work is on hold, waiting for further evaluation and decisions from System and Core Network related groups (SA2 and CT1).

4.2.8 DEDICATED CHANNEL (DCH) ENHANCEMENTS

As known by those familiar with UMTS and HSPA radio access protocols, there are two main types of transport channels to carry traffic over the UTRAN radio interface: DCH, used for transporting CS (and R’99 PS) traffic and the shared HSPA channels, used to carry high speed data (radio signaling can use both options). The Rel-12 work on “DCH enhancements for UMTS” refers to a series of optimizations to enhance the link efficiency of DCH traffic (e.g. for CS AMR voice).

A Study Item was recently concluded on DCH enhancements,[159] showing that optimizing DCH efficiency will provide benefits not only to CS traffic capacity, but also PS/data capacity. In fact, a few of the optimizations were shown to provide data throughput gains in scenarios involving a mix of voice and data transfer, when CS voice is carried over DCH. Furthermore, certain enhancements improve the UE battery life (or talk time) as well.

Based on the outcome of the study, 3GPP is in the process of specifying DCH enhancements in Rel-12.[160]

4.2.8.1 FEATURES AND ENHANCEMENTS

The ongoing Work Item on UMTS DCH enhancements focuses on the following main optimization techniques, enabling UL and DL Frame Early Termination and DTX/DRX operation for DCH:

- Frame Early Termination (FET) ACK Indicator
- DPCCH Slot Format Optimization

The high level design concepts are briefly summarized in the following paragraphs. Study details and performance aspects are captured in the corresponding Technical Report.[161]

DCH Frame Early Termination

158 TR 37.869, “Study on Enhancements to Machine-Type Communications (MTC) and other Mobile Data Applications; Radio Access Network (RAN) aspects”

159 RP-130216, “SID on UMTS DCH Enhancements”

160 RP-131357, “WID on UMTS DCH Enhancements”

161 TR 25.702, Technical Report on UMTS DCH Enhancements

A major enhancement to DCH is the introduction of Frame Early Termination (FET), both in UL and DL. Typically for Circuit Switched (CS) traffic, e.g. speech with a target Bit Error Rate (BLER) of e.g. 1 percent, it is not always necessary to receive all slots within the TTI for a successful block decoding. Once the receiver successfully decodes the data (i.e. CRC passes), it may ask the transmitter to stop transmission immediately, i.e., even before the TTI ends, which reduces transmit power consumption without impact to the reception quality.

An example of DL FET operation is illustrated in Figure 4.24.

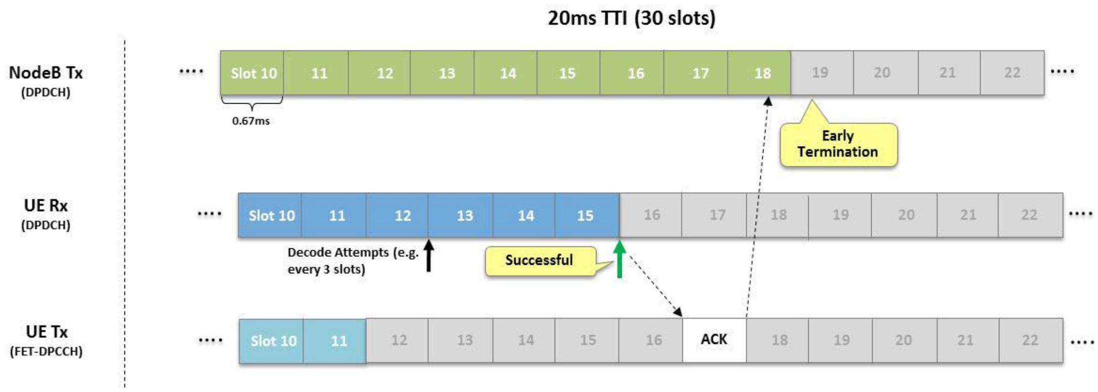

Figure 4.24. An example of DL FET operation.

The figure shows the case of a new PHY channel used to carry UL ACK, indicating successful frame decoding. Node B terminates DPDCH transmission after receiving the UL ACK.

A similar example of UL FET operation is illustrated in Figure 4.25. A new DL ACK channel is assumed to indicate successful frame decoding, after which UE terminates DPDCH transmission.

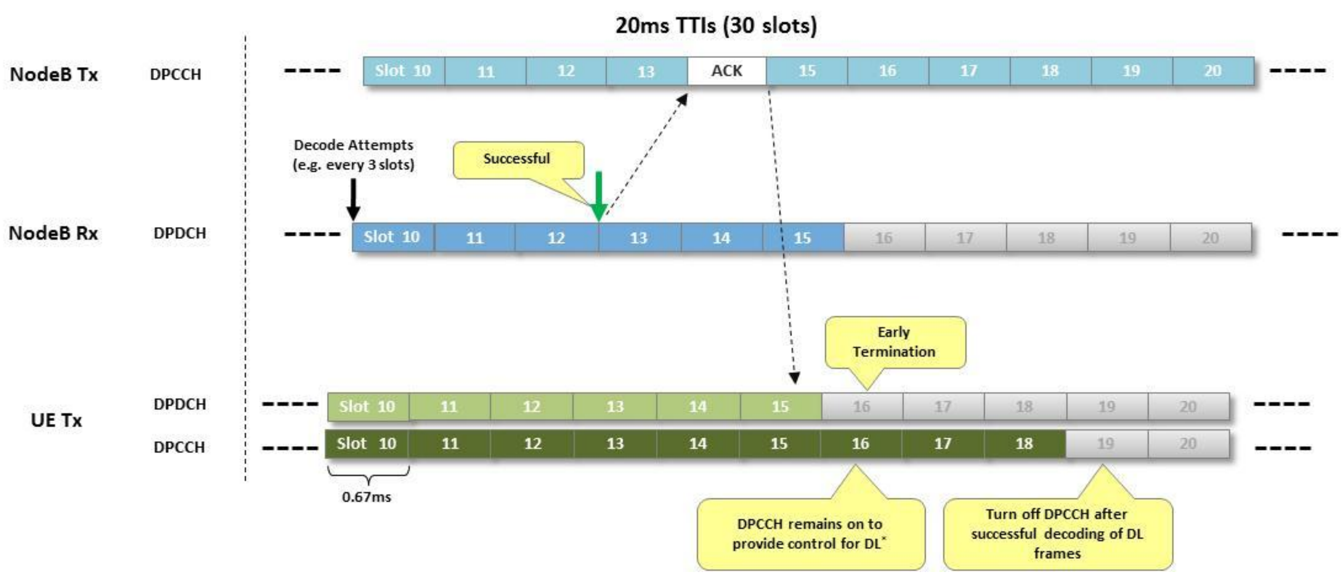

Figure 4.25. An example of UL FET operation.

UL/DL Overhead optimization

To assist UL FET, a few UL control channel (UL DPCCH) optimizations have been studied, e.g. on allowing Tranport Format Combination Index (TFCI) information to be delivered to Node-B as early as possible. A couple of options identified are:

1) TFCI transmitted on a new channel (FET-DPCCH), reusing the design of HS-DPCCH, with the CQI being replaced by TFCI and the ACK being used to enable DL FET

2) The TFCI information bits could be reduced thus occupying less DPCCH time slots

In DL, it has been observed that SNR measurements at the UE could be efficiently performed using the TPC bits instead of pilots. This eliminates the need for dedicated pilots for power control, hence improving link efficiency and inter-cell interference. To achieve that, new optimized slot-formats will be defined in which pilot bits are eliminated.

One example of DL power savings achievable by removing dedicated pilots is shown in Figure 4.26. For a voice-only scenario, on the downlink, it has been observed that around 24 percent of the total power can be spent on transmitting dedicated pilots. Such power can be optimized using the above enhancements.

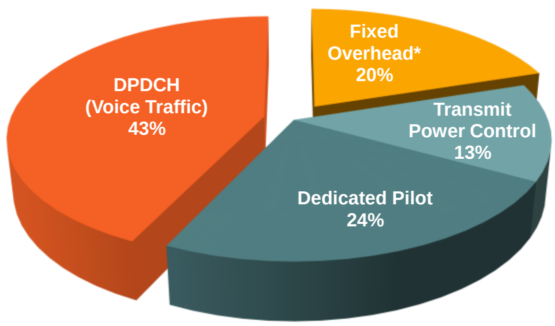

Figure 4.26. DL power savings achievable by removing dedicated pilots.

UE power consumption efficiency

The proposed enhancements to DCH provide significant opportunity to gate the modem transceiver and thus improve UE power consumption. The gating opportunity is a consequence of the design of DCH channels on the UL and DL, in a way that UL transmission can be terminated earlier through FET and DL transmission completes faster due to shorter TTI and also FET.

This Study Item has been closed, and a Work Item was ongoing in December 2013.

4.3 NETWORK AND SERVICES RELATED ENHANCEMENTS

Work in Rel-12 also included features for network and services enhancements for MTC, public safety and Wi-Fi integration, system capacity and stability, WebRTC, further network energy savings, multimedia and PCC framework.

4.3.1 MACHINE TYPE COMMUNICATIONS (MTC)

A third release of improvements is being developed for MTC devices and mobile data applications running in smart phones. This work is covered by the Rel-12 feature “Machine-Type and other mobile data applications Communications Enhancements (MTCe)”. Two main building blocks or features are being considered as part of Rel-12 and documented in

TR 23.887.[162] They were prioritized and some features such as MTC Groups and MTC Monitoring were dropped due to time limitations and parallel work. The two building blocks in Rel-12 are:

- Device triggering enhancements and Small Data Transmission (infrequent and frequent) (SDDTE)
- UE power consumption optimizations (UEPCOP)

Device Triggering Enhancements

Device triggering enhancements in Rel-12 are intended to address items that could not be completed in Rel-11. Some enhancements such as securing device trigger, therefore preventing fake SMS from reaching devices and increasing signaling, are being considered. These include overload control, recall and replace functionality for device triggering. The need for generic format-based triggering, using a control plane interface (T5a/b) between MTC-IWF and serving nodes (SGSN/MME), is also being studied and evaluated. The generic format can easily be extended, if additional functionalities or information are needed in future releases, and it can also be supported without the need for MSISDN to address the trigger recipient. This solution will fit an operator's need to move from SMS-focus to purely IP-data focus deployments, and also help move towards a full IP-based Packet Core. It is assumed that device triggering will become available when "T5 based small data service" (described in section below) is specified. The only additional requirement for device triggering might be defining an explicit criterion that makes a "T5 small data delivery" in downlink to the device a specific trigger request. At the end of the study, 3GPP decided not to standardize T5 based device triggering enhancements in Rel-12. It was agreed to introduce device triggering "recall and replace" functionality.

Small Data Transmission for MTC Devices

This feature is intended for use with MTC devices that need to transmit and receive only a small amount of data, i.e. data which can be classified as infrequent small data. Devices are currently known to transmit small data either using SMS or using plain user plane. The rationale for this feature is to study alternative solutions that can be deployed in a PS-only network, such as optimizing the use of network resources, and sending small data in an efficient way. Several solutions were originally documented in the TR for consideration. At the end of the study, 3GPP decided not to standardize any solution for small data transmission for MTC devices in Rel-12.

Small Data Transmission for Smart Phones

Due to the proliferation of smart phones, operators are increasingly faced with different challenges posed by diverse applications running in such devices. Many wireless data applications (for example social networking applications such as Facebook, Twitter, and Skype) are characterized by transmission of small data packets (in terms of packet size) in the UL and DL. Small data transmission may cause the UE to transition frequently between idle and connected state, if the UE is sent to idle mode soon after the transmission of small data is complete. If the UE is kept in connected mode for an extended duration, this has impact on UE power consumption and more extensive control plane signaling is required for handovers.

In short, such frequent transmissions can have the following adverse effects on the network and the UE:

- Increased control plane signaling in RAN (Radio Access Network) and CN (Core Network)
- Increased UE battery consumption

Work in 3GPP is mainly aimed at identifying mechanisms that help with signaling reduction and at the same time ensuring battery consumption is not negatively impacted. One solution considered in 3GPP is to keep the UE in RRC connected mode for a long(er) time to reduce state transition and to assign long DRX cycle for connected mode to ensure battery

[162] 3GPP TR 23.887, "Technical Specification Group Services and Systems Aspects; Machine Type and Other Mobile Data Applications Communications Enhancements (Release 12)", V0.2.1 (2012-08).

consumption is not negatively impacted. SA2 has agreed a Change Request (CR) for the solution "Mitigating Core Network overload by assisting eNodeB parameters tuning", but the finalization of the work has RAN dependencies and SA2 will align its specifications dependent on conclusions reached by RAN.

Low Power Consumption

Power consumption is important for UEs using a battery and also for UEs using an external power supply. Its importance increases with the continued need for energy savings and can be illustrated by the following scenarios:

- For M2M use cases like sensors that run on battery, it is a major cost issue for a large amount of devices to change (or charge) the batteries on site, and the battery lifetime may even determine the device's lifetime if it is not foreseen to charge or replace the battery
- A considerable number of applications (for example, mobile data applications or MTC applications) show communication patterns for which the 3GPP system could be optimized to provide services with the need for less optimized UE power consumption. For example, for mobile data applications, need for frequent communication with the network causes battery drain.

The major concern is that, if dramatic reduction of battery consumption cannot be achieved when using 3GPP access, M2M devices like smart meters may continue to use other access technologies. Following are the solution options that are considered in 3GPP to achieve power savings:

1. Introducing Extended DRX cycle in idle mode
2. Introducing Power saving state for devices
3. Introducing long DRX cycles in connected mode
4. Keeping UE(s) in detached state when not communicating

3GPP agreed to introduce power saving state for devices. Other solution options were not agreed for Rel-12 due to time constraints.

4.3.2 PUBLIC SAFETY

In February 2012, the U.S. Congress enacted Public Law 112-96 "The Middle Class Tax Relief and Job Creation Act of 2012"[163] to create a nationwide interoperable public safety broadband network. The Act includes the following:

- The public safety broadband network will be based a single national architecture based upon the LTE technology
- The governing framework for the deployment and operation of this high-speed network dedicated to public safety is the new "First Responder Network Authority" (FirstNet), an independent authority within National Telecommunications and Information Administration (NTIA)
- FirstNet will hold the spectrum license for the network, and is charged with taking "all actions necessary" to build, deploy, and operate the network, in consultation with Federal, State, tribal and local public safety entities, and other key stakeholders
- The Act allocates the 700 MHz D Block Band 14 (758-763 MHz and 788-793 MHz) to FirstNet for the construction of a single wireless nationwide public safety broadband network

[163] Public Law 112-96, Middle Class Tax Relief and Job Creation Act of 2012. February 22, 2012.

- Non-public safety entities will be allowed to lease the spectrum on a secondary basis

The FirstNet National Public Safety Broadband Network (NPSBN) must be a "Public Safety Grade" network. Efforts are underway in the National Public Safety Telecommunications Council (NPSTC) to develop a document to define "Public Safety Grade" with a target delivery date to FirstNet in early 2014. The general principles of "Public Safety Grade" are provided in Figure 4.27 from a June 2013 presentation of the Acting CTO and FirstNet Board Member, Craig Farrill.[164]

FirstNet Attribute	Defining Public Safety Grade
Coverage	**"Where public safety needs it"** (Geographic)
Reliability	**"You can bet your life on it"**
Resiliency	**"Multiple back-up options"**
Emergency Communications	**"Your trusted resource"**
Group Communications	**"Essential to teamwork"**

Figure 4.27. Defining Public Safety Grade.

The initial deployment of the FirstNet national public safety broadband network will be only for data services. The following example services will be implemented in subsequent deployment phases[165] [166]:

- Direct Mode off-network communications
- Mission Critical Voice
- Push-to-Talk (PTT) over LTE
- Video: 1 to many
- Messaging
- Images
- Group text
- Non-mission critical voice (e.g., voice over LTE)

164 Keynote presentation titled "Getting Ready to Create firstnet" at PSCR Conference, Westminster, Colorado given by Craig Farrill, Acting CTO and firstnet Board Member. June 5, 2013,

165 National Public Safety Telecommunications Council (NPSTC), Public Safety Broadband High-Level Launch Requirements Statement of Requirements for firstnet Consideration. December 7, 2012.

166 National Public Safety Telecommunications Council (NPSTC, Public Safety Broadband Push-to-Talk over Long Term Evolution Requirements. July 18, 2013.

Table 4.3 is quoted from the previously mentioned presentation by Craig Farrill, Acting CTO and FirstNet Board Member and it delineates the network guiding principles:

Table 4.3. FirstNet Network Guideline Principles.[167]

Network Principle	Description
Ubiquitous Coverage	1) "Where Public Safety needs it" from multiple terrestrial, satellite and deployable mobile networks 2) Continental US, Alaska, Hawaii, Puerto Rico, US territories, including tribal areas & coastal waters (56 geographic areas)
7 x 24 Availability / Uptime	"You can bet your life on it." Always on, fault-tolerant, non-stop, integrated Public Safety grade network
High Reliability	Network Resilience, Fault Tolerance, Redundancy, Diversity in all aspects of the network and its operations
Nationwide Distributed Network	1) Leverages multi-billion dollar investments in American terrestrial and satellite mobile networks 2) National distributed FirstNet Core Network directly interfacing with public, private and government networks for instant inter-agency coordination
"3-in-1" Network Platform	Combines three (3) types of backup networks for highest possible availability - - multiple terrestrial fixed mobile networks, multiple satellite mobile networks with terrestrial subnets with rapid-deployment FirstNet mobile terrestrial subnets
Priority Access and Local Control	1) Instant, automatic priority access for first responders 2) Local Network Operation Centers (NOCs) & real-time control of user prioritization and incident command
Excellent Voice Quality	QOS on all mission-critical voice services, Mean Opinion Score (MOS) greater than Land Mobile Radio (LMR), MOS equal to or better than commercial wireless networks
Fast Data Speeds / Throughput	Peak rates, burst rates, fixed rate speeds provide high speed data delivery and throughput

167 Keynote presentation titled "Getting Ready to Create firstnet" at PSCR Conference, Westminster, Colorado given by Craig Farrill, Acting CTO and firstnet Board Member. June 5, 2013,

Network Principle	Description
Best Available Speed	1) Network provides the best available data speed / throughput 2) Instant, automatic "fallback" to lower speed /quality of service to get the information / call through in case of network congestion, impairment or outage
Extensive Advanced Services	A large, growing number of advanced wireless services which meet or exceed PS user requirements
Flexible Service Delivery	Three service delivery options: 1) "Real-Time" (<50 msec end-end delay) 2) "ASAP" (as soon as possible but >50 msec) 3) "Scheduled" (prior to a future time)
Instant Group Communications	Offers a wide range of group text, voice, data and video services across all agencies and geographies at the touch of a button
Multiple RAN Diversity	Leverages alternative radio access routing through multiple 3G and 4G RANs for maximum geographic coverage, lowest cost, RAN diversity and fault tolerant Multi-Gen Radio Access Networks (RANs)
1000's of PS Applications	1) FirstNet App Store will provide latest App downloads instantly 2) Apple, Android, Microsoft App ecosystems
Latest 4G LTE	Pursuing and pressing future development of leading-edge 4G LTE technology as national standard for PS broadband services and applications
Highly Secure Communications	Dedicated, diverse core network interconnecting facilities; No dependence on the Public Switched Telephone Network (PSTN) or public Internet.
Dual-Track Network Deployment	Two separate network teams give Priority #1 to: "First Responders in Un-served/Under-served Areas" and to "First Responders in High Risk / High Density Areas",e.g. New York City, Washington DC
Low Cost	Provide excellent services & applications at less than commercial costs

There is interest beyond the United States in the 3GPP activities to support Public Safety communications. The TETRA and Critical Communications Association (TCCA) and ETSI Technical Committee TETRA are also backing LTE for the next generation broadband public safety networks. For example, the United Kingdom Home Office is currently evaluating replacements to their existing TETRA-based network and is considering an LTE-based network as an alternative.

The two main areas of 3GPP LTE enhancements for public safety are Proximity Services (ProSec) and Group Call System Enablers for LTE (GCSE_LTE). Both of these areas of enhancement are described in the following sections.

Proximity-based Services

Proximity services (ProSe) consist of discovering mobile devices in physical proximity and enabling optimized communications between them. In the NPSTC public safety broadband network documents, proximity services are described as either “Direct Mode” or “off-network communications” and the following items are some examples of the scenarios where this type of communication is needed:

- Firefighters responding to wildfires
- Police officers covertly monitoring criminal activities in densely populated areas
- Firefighters responding to building fires where network coverage does not cover entire building interior
- First Responder is outside the range of the fixed network (e.g., rural areas, remote areas, building interiors)

The 3GPP Proximity Services for support of public safety needs has the following main capabilities:[168]

1. Discovery of users who are in close physical proximity and wish to have direct communications[169]
2. Facilitating direct communications between users with or without supervision from the LTE network
3. Ability for a mobile device to function as “User Equipment to Network Relay” for another mobile device which is outside of the network coverage area. This network relay ability allows the out-of-coverage area mobile device to have access to network services and applications
4. Ability for a mobile device to function as “User Equipment to User Equipment Relay” between two other mobile devices which are out of direct communication with each other. This relay function allows communications between these mobile devices without the communications media (e.g., voice, data) being transported via the infrastructure of the public safety broadband network[170]

The following figure from the 3GPP white paper on public safety portrays the various proximity examples:

[168] 3GPP White Paper, Delivering Public Safety Communications with LTE, September 2, 2013, http://www.3gpp.org/IMG/pdf/130902_lte_for_public_safety_rev2_1.pdf

[169] Direct communications means that mobile devices are communicating among themselves without the communications media (e.g., voice) being transported via the infrastructure of the public safety broadband network.

[170] Because of the 3GPP workload, this functionality may not be included in Release 12 and may be postponed to future 3GPP releases.

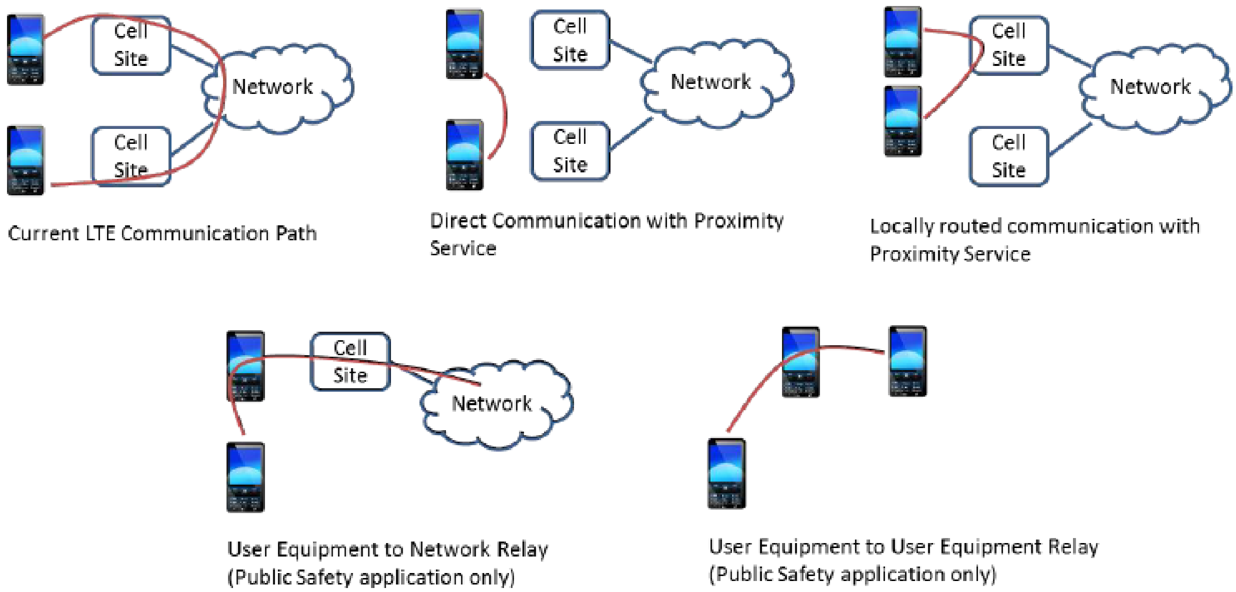

Figure 4.28. Proximity Service Examples.

The 3GPP SA1 feasibility study for proximity services is contained in 3GPP TR 22.803[171] and documented in 3GPP TR 36.843. The service requirements for proximity services have been incorporated into the service requirements for the Evolved Packet System (EPS) in 3GPP TS 22.278.[172] The 3GPP SA2 study on the architecture enhancements to support proximity services is contained in 3GPP TR 23.703.[173]

The 3GPP RAN groups are performing a feasibility study on the RAN Aspects of LTE device to device proximity services. Because of the 3GPP workload, it is anticipated that some of the capabilities to support Proximity Services (ProSe) will not be completed within the Rel-12 timeframe. As a result, such capabilities may be postponed to future releases.

Group Communication System Enablers

Group communications is a frequent mode of operations for public safety where simultaneously communicating with multiple users is needed. An example of a public safety group would be the firefighters that are battling a structure fire.

Push-to-Talk (PTT) is an example of voice-based multiple-user communications. However, because the capabilities of LTE allow for broadband communication, Group Communication Service is expected to support, voice, video or, more general data communication. LTE supports the capability for users to communicate in parallel at the same time with several groups with different media types (e.g., voice to one group, video stream to another group).[174] The Group Communication System Enablers work in 3GPP will optimize the LTE environment for the multiple user environments.

The following are some of the key requirements for Public Service Grade PTT which are identified in the NPSTC PTT over LTE requirements:

- 1-to-many communication groups

171 3GPP TR 22.803, Feasibility study for Proximity Services (prose).
172 3GPP TS 22.278, Service requirements for the Evolved Packet System (EPS).
173 3GPP TS 23.703, Study on architecture enhancements to support Proximity Services (prose).
174 3GPP TS 22.468, Group Communication System Enablers for LTE (GCSE_LTE).

- Dynamic group creation
- Monitoring of multiple PTT groups
- Authentication, authorization, and security controls for PTT groups
- 1-to-1 private calls
- Announcement group calls
- Support of ruthless pre-emption
- Support of Imminent Peril and Responder Emergency Calls including prioritization above normal PTT calls
- Identity and personality management
- Location information for PTT group members

There is one aspect of group communication still under consideration. Specifically, how much group communications and PTT functionality should be “baked in” to the LTE infrastructure versus how much of this functionality should be delivered by non-standardized application servers. The use of these application servers may allow the different public safety organizations or regions to have the capability to customize the system operations to their specific needs and situation. However, a “baked in” solution in the LTE infrastructure may be more efficient and simpler. Further discussions in 3GPP are expected.

The service requirements for Group Communication System Enablers for LTE (GCSE_LTE) are contained in 3GPP TS 22.448. The study on the architecture enhancements to support Group Communication System Enablers for LTE (GCSE_LTE) is contained in 3GPP TR 23.768.

As of November 1st 2013, the 3GPP SA2 working group has agreed to the following items:

- Basic architecture diagram
- Use of eMBMS for group communication
- Standardization of GC2 interface for Release 12
- GC1 interface will be out of scope of Release 12

LMR to LTE Interoperability

The FirstNet National Public Safety Broadband Network (NPSBN) must operate concurrently with the existing LMR trunked systems. The NPSTC PTT over LTE Requirements[175] describes the PTT communications between LMR and the LTE based NPSBN service as follows:

> *“The goal of PTT communications between LTE and LMR subscribers is that, insofar as it is technically possible, LMR subscribers and dispatchers experience no essential differences in their communications with each other, and with PTT subscribers using an NPSBN-compliant PTT service. Likewise, insofar as a particular feature is interoperable, PTT subscribers experience no essential difference in the communications with LMR subscribers versus those using an NPSBN-compliant PTT service.”*

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175 National Public Safety Telecommunications Council (NPSTC, Public Safety Broadband Push-to-Talk over Long Term Evolution Requirements. July 18, 2013.

A model of the LMR to LTE interoperability is illustrated in Figure 4.29.

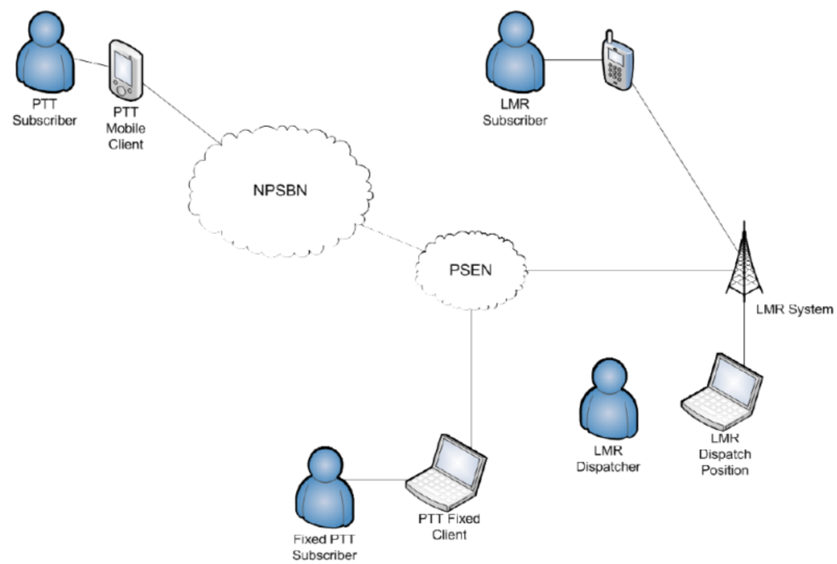

Figure 4.29. PTT LTE and LMR Interoperability Model. The LMR subscribers and dispatchers are able to communicate with PTT subscribers and dispatchers by virtue of transport and services provided by the Public Safety Entity Network (PSEN) and Nationwide Public Safety Broadband Network (NPSBN).

A joint project has been completed between the Alliance for Telecommunications Industry Solutions (ATIS) and the Telecommunications Industry Association (TIA) to develop a standard to define the interoperability between LMR and LTE. ATIS is the lead group for this joint project.

4.3.3 WI-FI INTEGRATION

As mobile networks evolve to all –IP and traffic continues to build and constrain network capacity, the importance of Wi-Fi cellular interworking remains essential. Rel-12 provides additional Work Items to improve Wi-Fi as an access point for mobile networks.

4.3.3.1 NETWORK SELECTION

As discussed previously, Wi-Fi interworking with 3GPP technologies is already supported at the CN level. However, as operator controlled Wi-Fi deployments become more common and Wi-Fi usage increases, RAN level enhancements for Wi-Fi interworking that improve user experience, provide more operator control and better access network utilization is desired. Rel-12 focuses on the study of solutions enhancing mobility between LTE/UMTS and Wi-Fi for access points deployed and controlled by cellular operators and their partners. There can be several Wi-Fi access points within the coverage of a single UTRAN/E-UTRAN cell. The eNB/RNC may know the location or other Wi-Fi access points parameters (e.g. Base Station Subsystem ID (BSSID), channel, etc.), however scenarios where such information is not available should be supported as well.

The main objectives of the Rel-12 feasibility studies on Wi-Fi-cellular interworking are to:

- Identify solutions that enable enhanced operator control for Wi-Fi interworking, and enable Wi-Fi to be included in the operator's cellular Radio Resource Management
- Study enhancements to access network mobility and selection which take into account information such as radio link quality per UE, backhaul quality, load, etc. for both cellular and Wi-Fi accesses

- Evaluate the benefits and impacts of identified mechanisms over existing functionality, including core network-based Wi-Fi interworking mechanisms (e.g. Access Network Discovery and Selection Function (ANDSF)), insuring that such benefits cannot be solved using existing standardized mechanisms

Three potential solutions for Wi-Fi interworking were being discussed in 3GPP in December 2013. None of the solutions were approved or agreed for inclusion in Rel-12, so the information following should be viewed as exemplary of the types of solutions being discussed in 3GPP for potential inclusion in Rel-12 or beyond.[176] Given that different operators have different deployment scenarios, RAN agreed that both deployment scenarios, with and without ANDSF, shall be addressed in the study.

Solution 1: In this solution, RAN provides RAN assistance information to the UE through broadcast signaling (and optionally dedicated signaling). RAN assistance information would include such things as load and resource allocation information and Wi-Fi/RAN signal strength, channel quality and load thresholds. The UE then uses the RAN assistance information, UE measurements and information provided by the Wi-Fi network and policies that are obtained via the ANDSF or via existing Open Mobile Alliance - Device Management (OMA-DM) mechanisms or pre-configured at the UE to steer traffic to Wi-Fi or to RAN.

Figure 4.30 illustrates the solution 1 candidate call flow:

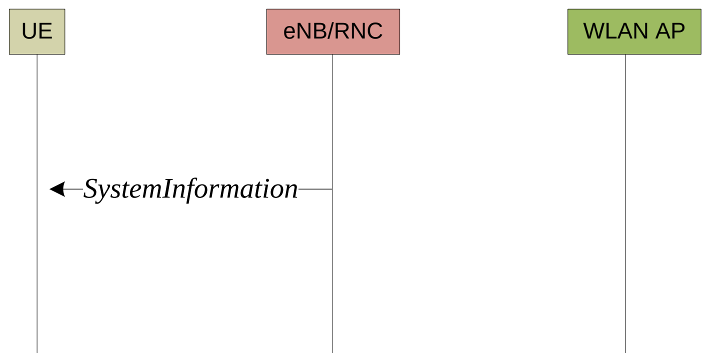

Figure 4.30. Solution 1 Traffic steering.

The policies provided to the UE are enhanced by having the RAN assistance information. The policy may include multiple candidate information simultaneously. An example of such policy may be as follow:

- 3GPP → Wi-Fi: If RAN RSRP is less than threshold *s* and RAN direct load is greater than threshold *x*, and if Wi-Fi Received Signal Strength Indicator (RSSI) is greater than threshold *r* and Wi-Fi BSS load is less than threshold *y*, move flow to Wi-Fi

- Wi-Fi → 3GPP: If RAN RSRP is greater than threshold *s'* and RAN direct load is less than threshold *x'*, and if Wi-Fi RSSI is less than threshold *r'* and Wi-Fi BSS load is greater than threshold *y'*, move flow to UMTS/LTE

This can be realized, for example, with a new policy structure (similar to ISRP). The value of the thresholds (e.g. RAN RSRP/ Received Signal Code Power (RSCP) thresholds) may be provided by RAN and used in the ANDSF policy. Otherwise threshold values may also be provided by the ANDSF itself.

[176] TR37.834 v1.0.0, "Study on WLAN/LTE Radio Interworking (Release 12)"

Policies specific to the UE can be configured or pre-provisioned based on the UE subscription. Optionally, per UE control for traffic steering can be achieved using dedicated signaling during connected mode (e.g., the RAN may send different values of the above parameters to different UEs in connected mode). Policies specific to a target Wi-Fi system (e.g., SSID, realm) can be configured or pre-provisioned.

Policies and network assisted information can also be used to route some flow to Wi-Fi and some to 3GPP.

Solution 2: In this solution, RAN provides assistance information to the UE through dedicated and/or broadcast signaling. Based on this information and rules specified in the RAN specification, as well as measurements and information provided by the Wi-Fi network, the UE steers traffic to a Wi-Fi or RAN.

This solution consists of the following steps, which is described in Figure 4.31.

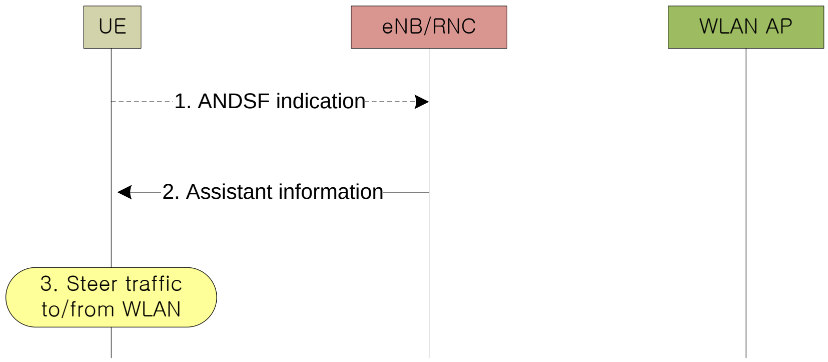

Figure 4.31. Solution 2 Traffic steering.

For the above signaling procedure, each step is elaborated in the following:

1. (Optional) Reporting of ANDSF: In this step, the UE in RRC CONNECTED mode may report the basic information regarding ANDSF. Alternatively, the eNB/RNC may also receive the ANDSF information via OAM.

2. Provision of RAN assistance information: In this step, RAN provides the assistant information through dedicated and/or broadcast signaling. RAN assistance information would include such things as load and resource allocation information and Wi-Fi/RAN signal strength, channel quality and load thresholds. If the UE has valid access network selection parameters provided through dedicated signaling, the UE ignores the related information provided in broadcast signaling. Otherwise, the UE utilizes the broadcast information.

3. Access network selection: If the UE is provided with ANDSF policy, the UE may use ANDSF. Otherwise, the UE may utilize the RAN specified rules. Even if the ANDSF policy is provided to the UE, RAN has the option to indicate the preferred rule to be used by the UE. The rules provided by RAN do not need to contradict or supersede the rules provided by ANDSF and may only consist of rules not provided by ANDSF. If the UE utilizes ANDSF policy, the UE AS forwards the received assistant information to the interworking upper layer of the UE. Otherwise, the UE AS performs the offloading based on the specified rule and the received assistant information.

Solution 3: In this solution, the traffic steering for UEs in RRC CONNECTED/CELL_DCH state is controlled by the network using dedicated traffic steering commands, potentially based also on Wi-Fi measurements (reported by the UE). For UEs in IDLE mode and CELL_FACH, CELL_PCH and URA_PCH states, the solution is similar to solution 1 or 2. Alternatively, UEs in those RRC states can be configured to connect to RAN and wait for dedicated traffic steering commands.

In this solution, the traffic steering commands can override the ANDSF policy only for the traffic indicated in the command. All other traffic continues to be subject to the ANDSF policy as applicable. Other potential interaction aspects with ANDSF may be studied further, e.g.:

- Some information on UE-specific ANDSF configuration may be available in RAN, either provided by the core network, or by Operation and Maintenance (O&M) so that RAN can take appropriate actions

- The UE could provide information to the RAN e.g. indicate what can be offloaded to a reported Wi-Fi

As an example, traffic steering for UEs in RRC CONNECTED/CELL_DCH comprises the following steps as shown in Figure 4.32:

1. Measurement control: The eNB/RNC configures the UE measurement procedures including the identity of the target Wi-Fi network to be measured

2. Measurement report: The UE is triggered to send MEASUREMENT REPORT by the rules set by the measurement control

3. Traffic steering: The eNB/RNC sends the steering command message to the UE to perform the traffic steering based on the reported measurements and loading in the RAN

4. UE Ack/Response: The UE acknowledges reception of the traffic steering command

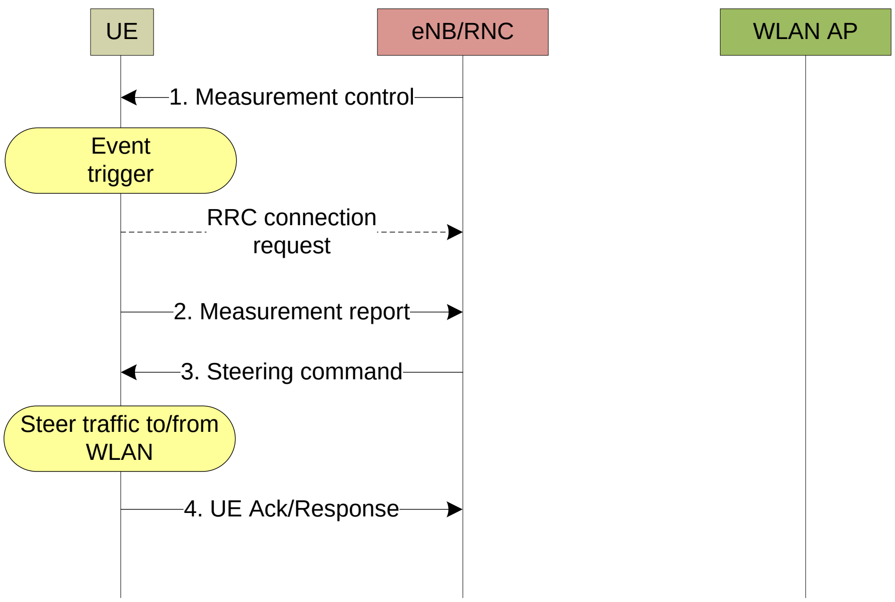

Figure 4.32. Solution 3: Traffic steering for UEs in RRC CONNECTED/CELL_DCH state.

Note that the above procedures do not take into account user preference and/or the Wi-Fi radio state. It was agreed during the study that user preference will take precedence over RAN and ANDSF rules. For example, based on user preferences and/or Wi-Fi radio state, a UE may not be able to perform the configured measurement events. Additionally, the procedures need to allow a UE to be able to prioritize non-operator Wi-Fi over operator Wi-Fi. For example, the UE may disassociate from the operator Wi-Fi and associate with the higher priority non-operator Wi-Fi at any time during the measurement process. The details of how this is managed are FFS.

Note also that the procedure previously illustrated, and the following description can apply to UMTS CELL_FACH as well. The procedure can also be extended to UMTS/LTE Idle modes and UMTS CELL/URA_PCH states, e.g. UEs may be configured to report some indication (e.g. on available Wi-Fi measurements) in a RRC UL message, e.g., RRC connection request (from Idle, in UMTS/LTE) or CELL UPDATE (in UMTS CELL/URA_PCH states).

Finally, it should be noted that some of the steps above, e.g. steps 1 and 2, can be optional, based on RAN/UE configuration.

The Study Item was ongoing in December 2013, thus it was too early to conclude on possible standard solutions.

4.3.3.2 SAMOG

In S2a Mobility based on GPRS Tunneling Protocol (SaMOG) is standardized in Rel-12. Prior to 3GPP Rel-12, UEs could already establish a PDN connection via a trusted WLAN (TWAN) or perform non-seamless WLAN offload (NSWO). However, this was only supported with the following limitations:

- No IP address preservation in case of mobility between a 3GPP access and a TWAN
- A UE could not explicitly request the type of connectivity (i.e. an NSWO connection or a PDN connection)
- The UE could not signal the Access Point Name (APN) for connectivity; thus only connectivity to a default APN (selected by the network) was supported
- Only one PDN connection per UE was supported over trusted WLAN
- Only either a PDN connection or an NSWO was supported (i.e. NSWO was not possible in parallel to a PDN connection over WLAN)

In Rel-12 3GPP addressed these shortcomings by enabling UEs to:

- indicate the requested connectivity type (PDN connection to EPC or non-seamless WLAN offload (NSWO))
- indicate the APN to establish PDN connectivity
- request to hand over an existing PDN connection
- establish multiple PDN connections in parallel over trusted WLAN
- establish an NSWO connection in parallel to PDN connection(s) over WLAN

To enable the market to flexibly adopt the different Rel-12 S2a Mobility based on GTP (SaMOG) features when they are needed; two types of UEs are supported for Rel-12 SaMOG: Single PDN connection UEs and multiple PDN connection UEs. Single PDN connection UEs are considered a simple extension on top of Rel-11 which still only support either a PDN connection over WLAN or an NSWO, but which can in contrast to Rel-11 UEs (a) explicitly request a specific connectivity type (PDN connection to the EPC or NSWO), (b) indicate the requested APN to connect to (in the case of PDN connection), and (c) explicitly request to hand over an existing PDN connection.

Multiple PDN connection UEs address use cases where multiple PDN connections are needed in parallel (e.g., to access both the IMS APN and the Internet APN via WLAN) or an NSWO is needed in parallel to PDN connections over WLAN.

To achieve this, 3GPP agreed on the following extensions (note that as of December 2013, the details were still subject to on-going discussions within 3GPP). EAP-AKA' will be extended to enable the UE and the network to negotiate the mode of operation (single-connection mode or multi-connection mode) and to allow a single connection UE to indicate the requested connectivity type (PDN connection or an NSWO), the APN to connect to (in case of PDN connection), and whether a hand over is requested.

To support the multi-connection mode additional extensions are needed. A new WLAN control protocol (WLCP), which runs between UEs and the Trusted WLAN Access Gateway (TWAG), enables UEs in multi-connection mode to establish/hand over/tear down PDN connections. WLCP will be defined by 3GPP and is expected to reuse a subset of the session management protocol defined in 3GPP TS 24.008. In multi-connection mode, IP packets belonging to the different PDN connections and the NSWO connection need to be multiplexed across WLAN between the UE and the

TWAN. Since the related IP address ranges could potentially overlap, a mechanism was needed to separate the user planes of the related PDN connections/the NSWO connection.

This mechanism is achieved by using different destination Media Access Control (MAC) addresses on the TWAG for different PDN connections (and the NSWO connection). When the UE requests a PDN connection to a given APN, the TWAG assigns a unique MAC address for the new PDN connection (for this UE) and indicates this MAC address to the UE. When the UE needs to send uplink packets for the new PDN connection, it sends the packets to the destination MAC address assigned for this PDN connection by the TWAG. In the downlink direction, if the TWAG needs to send packets to the UE it uses the unique MAC address assigned for this PDN connection as the source MAC address. This scheme enables both UE and TWAG to identify the PDN connection (or the NSWO connection) that a given downlink or uplink packet, respectively, belongs to.

The Work Item was targeted to be completed as part of Release 12 in December 2013.

4.3.3.3 OPTIMIZED OFFLOADING TO WLAN IN 3GPP RAT MOBILITY

The optimized offloading feasibility study looked at possible issues with features defined in previous releases for WLAN offload, such as IFOM, Internet Wireless Local Area Network (I-WLAN) mobility, SaMOG and ANDSF. The aim was to optimize the procedures for offloading traffic to WLAN from 3GPP AN's, and to improve network and interface selection for this traffic.

Several key issues were investigated:

- Existing ANDSF policies do not provide for mechanisms to indicate preferences with granularity at the 3GPP RAT level within network policies. This restricts the ability for the operator to provide policies that favor a specific 3GPP RAT over another one with reference to the WLAN preference

- Whether mechanisms currently specified for mobility of IP traffic between a 3GPP RAT and WLAN are allowed to mitigate the impact on the service and the user experience caused by the potential loss, degradation or suspension of bearers resulting during mobility between 3GPP RATs

- After offloading some traffic over WLAN as a result of Inter-RAT handover or CSFB, whether it would be beneficial to move the offloaded IP traffic back to the original 3GPP RAT when e.g. RAT mobility to the original RAT (e.g. E-UTRAN) is performed again in a short period of time, or the CS service was of short duration

The study investigations and conclusions are captured in 3GPP TR 23.890. It was concluded at the end of the study that the first key issue can be addressed by normative changes to Inter-System Routing Policies (ISRPs) and the last two key issues can be addressed by a number of informative notes added to the 3GPP specifications.

It was agreed that for Inter-System Routing Policies, the prioritized list of access technologies included in the rules for IFOM and MAPCON may contain 3GPP access, WLAN access, as well as specific 3GPP RATs such as GERAN, UTRAN and E-UTRAN. The order of the access technologies in this list allows the operator to prioritize specific 3GPP RATs with respect to WLAN access. In other words the operator could, for example, set a policy such that E-UTRAN was first, followed by WLAN, and then UTRAN and GERAN, in that order.

The informative agreements were:

- During inter-RAT handover, when the default bearers are deleted, the P-GW can delay deletion of the PDN connection in the core network to allow the UE to handover these connections to a WLAN

- The P-GW can delay deleting the default bearer during handover to allow for the possibility that it could be moved to a non-3GPP AN

- For 3GPP to non-3GPP handover, if bearers are suspended when the P-GW receives a Proxy Binding Update, the bearers are to be considered resumed, and then the handover is performed

In the CSFB case, if all the PDN connections have been handed over to non-3GPP access according to existing procedures, the UE does not need to resume the PS traffic over the current cell. In addition, in cases in which the UE would have returned to E-UTRAN, the UE does not need to return to E-UTRAN.

The Work Item was completed in Release 12.

4.3.4 CORE NETWORK OVERLOAD

The original focus of the Core Network Signaling Overload investigation was initiated to address HLR overload scenarios that could result from any of a number of causes (e.g. RNC failure or restart, Denial of Service attacks, etc.).

Increases in signaling speed and the concentration of subscribers into fewer HLR nodes creates a more complicated environment, and one in which situations can change quickly. Since more subscribers are supported per HLR, more subscribers are also impacted. The HLR is a not unique network element in this regard. Similar scenarios might also occur to other “core” network elements as the behavior of the UE becomes increasing complex. In general, it was deemed that Core Network Overload aspects ought to be studied further both in terms of scenarios leading up to it, and more importantly appropriate mitigation actions spawned therein. This resulted in Core Network Overload Solutions study (FS_CNO) which started in Rel-11, but could not be completed due to work prioritization by SA plenary at the time. Subsequently, key themes for Rel-12 were identified which included FS_CNO as one of the mainstays for achieving System Capacity and Stability.

The objectives of this Study Item are to:

- Identify and document scenarios that may result in signaling overload for core network entities and that are not yet covered by other Work Items, such as the above-outlined event, denial of service attacks, and misbehaving/non-compliant mobiles

- Analyze the criticality of the scenarios and determine whether it is required to take action for the identified scenarios

- Study ways to mitigate and handle signaling overload scenarios that are identified to be critical

The study aimed at providing solution(s) without UE modifications to allow for backward compatibility. Broadly speaking, FS_CNO work has spawned off three threads:

- DIAMETER-related (FS_DOCME in Stage 3, and DIME WG in IETF)

- GTP-c related (FS_GOCME (acronym to be defined and approved))

- ULI enhancements related (discussions ongoing)

The following sections briefly overview these different segments.

DIAMETER Overload Control:

Stage 2 FS_CNO Phase 1 study on MAP and DIAMETER overload control concluded the following:

For MAP protocol: The recommendation is to use existing mechanisms of SS7 and Transaction Capabilities Application Part (TCAP) in particular to handle congestion. SS7 signaling, including SCCP and TCAP as defined by the ITU-T, has evolved as an international standard since 1980. SS7 has an overload control mechanism for its links that are quite robust. SS7/TCAP does not have end-to-end overload control mechanisms. However, if the MAP entity is overloaded, HLR can discard lower priority signaling as described in TS 29.002 in order to relieve congestion. If this overload control mechanism is changed significantly, it may result in other instability. This is a mature system with deployments and experience that can be used to manage a network that has predictable overload control.

- For DIAMETER protocol: A problem was identified that overload signaling in Diameter is of coarse granularity and is deployed in a hop-by-hop manner. This is more relevant in large scale deployments with multiple clients, servers and agents in the middle of the communication. Diameter applications need to respond to overload. Without standardized mechanisms at some layer (Diameter application, base protocol, transport, network, etc.) the Diameter-based protocol interfaces used by functional entities in the 3GPP architecture cannot obtain detailed or useful information to avoid overload or respond to congestion in such large deployments. Therefore:
    - IETF Diameter Maintenance and Extensions Working Group (DIME WG) is to evaluate enhancements to base DIAMETER protocol to find a standardized means to convey necessary congestion information between functional entities that use a Diameter-based protocol interface
    - CT3, CT4 and SA5 should take into account the work done in IETF at Diameter protocol level and consider investigating Diameter protocol end points behavior and any other changes needed in 3GPP Stage 3 specifications to support overload control mechanisms on Diameter interface for 3GPP applications. Particular overload aspects to investigate relate to the difference between session-oriented Diameter interactions and Diameter interactions relying on implicitly terminated Diameter sessions (i.e. the server does not maintain the state of the session) and the effect of Diameter Agents between end points when deployed
    - Mechanisms similar to the ones described in clause 6.2.5 of TR 23.843 for Diameter Load Managers (DLM) could be studied in Stage 3 for potential benefits in server congestion management.

IETF DIME WG Dependency

3GPP DIAMETER overload control enhancements has a dependency on completion of IETF DIME WG work which has the charter to enhance base DIAMETER protocol to account for overload control.

To this extent, IETF DIME WG has identified the overall requirements of the DIAMETER overload control problem space under draft-ietf-dime-overload-reqs.

Discussions are to focus around identification of Overload Control (OC) semantics and data elements first, with the subsequent goal for a means of exchanging OC information. In this regards, the following solutions were being discussed:

- draft-roach-dime-overload-ctrl
- draft-korhonen-dime-ovl
- draft-tschoefing-dime-overload-arch (and correspondingly draft-tschoefing-dime-dlba, draft-tschoefing-dime-overload-piggybacking)

The goal of DIME WG was to have a solution ready for IETF adoption by November 2013 so as to facilitate completion of 3GPP Stage 3 FS_DOCME study in Rel-12.

GTP Overload Control

Stage 2 FS_CNO Phase 2 study on GTP-c identified the following scenarios which had the potential of causing GTP-c overload:

Frequent Idle -> Connected, and Connected -> Idle transitions causes due to e.g. eNB idle timer. Depending on the value of eNB idle timers (which may result in a large number of e.g. SERVICE REQUESTs from UEs in a busy hour), session overload may occur in either an S-GW managing TA/TAs or a set of S-GWs managing TAs

1. Large number of users performing TAU/RAU. In a typical network deployment, the number of MMEs and S-GWs is considerably large(r) than the number of P-GWs. In densely populated areas such as in North-Eastern U.S. e.g. New York City, metro Boston, metro Philadelphia etc., mass transit systems transfer a large number of users on a daily basis. This results in large number of simultaneous Target Acquisition and Tracking Unit (TAU)/RAUs towards MMEs/SGSNs and corresponding Modify Bearer Requests towards S-GWs. This may result in large number of MBRs towards a single or very few P-GWs

2. An overload of a downstream node (e.g. P-GW) may also potentially cause overload of an upstream node (e.g. S-GW) e.g. due to GTP-c signaling retransmissions

3. At the failure of an EPC node (e.g. S-GW) where the network would try to re-establish the GTP-c session via a new EPC node (S-GW) that would replace the failing one. The risk is that the failure of a node (e.g. S-GW) would trigger a spike in GTP-c signaling to restore the PDN connections affected by the failure within the shortest time. These attempts to restore PDN connections affected by the failure would overflow other nodes (e.g. other S-GW, P-GW) and transform a local failure (e.g. of an S-GW) into a complete network issue via a snowball effect. The same applies to a failure of a P-GW, MME or SGSN

4. At overload or failure of a GTP-c node (e.g. S-GW) where the network would need to establish subsequent (new) GTP-c sessions via a smaller number of GTP-c nodes (e.g. using only other S-GW of the same cluster). The risk is that the overload / failure of a node (S-GW) would trigger an increase of GTP-c signaling that would overflow other nodes (other S-GW of the same cluster) and transform a local failure (of an S-GW) into a complete network issue via a snowball effect

5. A GTP-c node (e.g.P-GW) may encounter issues to handle traffic on a non-overloaded GTP-c interface (e.g. S5 interface) when another of its (possibly non GTP-c) interfaces (e.g. Gx) is overloaded

6. Application signaling that induces creation of dedicated bearers served by a MME or pool of MME: A large number of users may start application related interactions (e.g. IMS SIP call) simultaneously when some exceptional event occurs, which leads to a large amount of almost simultaneous Create/Update Bearer Requests sent from P-GW to MME

It was concluded that GTP-c needs enhancements to account for graceful entry and exit from overload condition in order to avoid service impacts, e.g.:

- loss of PDN connectivity (IMS, Internet etc) and associated services
- loss of ability to setup and release radio and core network bearers necessary to support services e.g. GBR bearers for VoLTE
- Loss of ability to report to the P-GW/PCRF user information's changes, e.g. location information for emergency services and lawful intercept, changes in RAT or QoS
- Billing errors and loss of revenue

As a result, two sub-features namely GTP-c Load Control and GTP-c Overload Control are to be specified in Rel-12.

GTP-c Load Control Feature

- "Load Information" reflects the operating status of the resources of the originating GTP-c node

- Exact format is up to Stage 3
  - How this gets computed is implementation dependent
  - Used during S-GW/P-GW selection to support load balancing of the PDN connections for UEs
  - Applicable only in GW MME/SGSN direction
  - Included in existing GTP-c messages (request / response)
- Learning support of this capability could be simply configuration-based
  - Whether protocol support for feature capability is required is up to Stage 3
- Frequency of transfer of Load Control Information is up to Stage 3
  - Should not add significant additional load to the node and the peer node
- How existing Domain Name Server (DNS) Weight Factors can be used in conjunction with Load Information received via GTP control plane signaling is left up to Stage 3
- Depending on configuration
  - Inter-network (roaming) and on intra-network (non-roaming) interfaces can have different values for "Load Information"
  - VPLMN may act upon information sent by HPLMN

GTP-c Overload Control Feature

- "Overload Information" reflects an indication of when the originating node is running above its nominal capacity which may cause severe issues in handling the incoming traffic
  - Conveys information about node itself and/or regarding specific APN(s)
  - How a node determines it is under overload is implementation-specific. But, computation and transfer of Overload control Information shall not add significant additional load to the node itself and to its corresponding peer nodes
  - Used to reduce / throttle the amount of GTP-c signaling traffic between the GTP-c nodes
  - Provides guidance to the receiving node to decide action leading to mitigation towards the sender
  - Included in existing GTP-c messages (request / response)
  - The exact format depends upon stage 3
  - Included bi-directionally (GWs -> MME/SGSN, MME/SGSN -> GWs)
- Learning support of this capability could be simply configuration-based
  - Whether protocol support for feature capability is required depends upon Stage 3
- Frequency of transfer of Overload Control Information depends upon stage 3
  - Should not add significant additional load to the node and the peer node

- Depending on configuration
    - Inter-network (roaming) and on intra-network (non-roaming) interfaces can have different values for "OverLoad Information"
    - VPLMN may act upon information sent by HPLMN

Overload Control related with ULI

A massive number of users simultaneously inducing ULI update notifications may cause an excessive signaling load within the PLMN, i.e. within

- the MME/SGSN (source of the ULI update)
- the S-GW, P-GW, and possibly V-PCRF in roaming case (relay of the ULI update)
- the PCRF/OCS and TDF (consumer of the ULI update)

This massive number of ULI update notifications may be caused, for example, by massive mobility of users in a specific location (e.g. train stations or business districts during busy hours, football stadium, city centers during the weekend) or by the use for a greater number of users of ULI subscriptions at finer granularity (e.g. cell level). To address these risks, three solutions are being studied:

- **Solution 1**: ULI reporting only when the UE is in "CONNECTED" state. For ULI reporting related to UE change of RA/TA, a new option is added to enable the PCRF/OCS to request ULI reporting to be sent only when the UE is in "CONNECTED" state: the Node serving the UE (MME/SGN) defers ULI reporting related with RA/TA change as long as the UE is either without active radio and S1/Iu user plane bearers or is in 2G STAND-BY state
- **Solution 2**: ULI reporting at Presence Reporting Area level. In some use cases, policy/charging decisions and also e.g. statistics gathering per specific IP-CAN session, depend on whether the UE is inside or outside a specific set of cells and/or serving areas associated with the user subscription:
    - PCRF should be notified when an individual UE enters or leaves a specific area of interest (e.g. group of cells or Routing Area (RA)/TA) provided by the PCRF therefore avoiding notifications inside or outside the specific area of interest. Note for example, that this is to define suitable QoS and charging policies to apply to the data service of the user in that set of cells and/or serving areas
    - Thus a (new) granularity of User Location Information reporting "at Presence Reporting Area level" is defined. The ULI reporting at Presence Reporting Area level works the same way as ULI reporting defined in TS 23.203 [9] with the following modification: The PCRF may send via the PCEF towards the CN node serving the UE, a Location change reporting request at "Presence Reporting Area" level, telling it wants to be notified only when the UE enters or leaves a Presence Reporting Area together with the definition of the Presence Reporting Area(s)
- **Solution 3:** New "change of eNB" reporting event. The ULI reporting at Presence Reporting Area level works the same way as ULI reporting defined in TS 23.203 [9] with the following modification: another ULI reporting capability is added, i.e. reporting at ENB level. This avoids the extra signaling related with the use of Location reporting that is required in case of ULI reporting at cell level

Currently, the Study Item is ongoing with the following progress:

- Stage 2 (3GPP SA2) analysis completed
- Stage 3 work ongoing under Study Item FS_DOCME with the general directive from Stage 2 (3GPP SA2) being:

- Diameter based protocol needs to account for load and overload information exchange but the exact nature of load and overload information transmission is left up to protocol groups. Since, base DIAMETER is an IETF-defined protocol, IETF DIME working group would work on the necessary enhancements
- Stage 3 (3GPP CT4, CT3, SA5) to build on top of base DIAMETER enhancements with a view of looking at:
  - deployment of Diameter Load Managers (DLM) within 3GPP system
  - Analyzing system level impacts due to overload when indicated via DIAMETER signaling
  - Evaluating impacts in session-oriented v/s non-session oriented DIAMETER signaling

- Similar to DIAMETER protocol, GTP-c protocol was identified as a candidate for further system level improvements in order to dynamically convey load and overload information. It was successfully analyzed in Stage 2 (3GPP SA2) with the corresponding study phase and normative work completed. There are ongoing discussions related to the overload mitigation due to UL1 reporting.

4.3.5 WEB REAL-TIME COMMUNICATION (WEBRTC)

WebRTC is an enabler which enhances web browsers with support for Real-Time Communications (RTC) capabilities via Javascript APIs, and is supported by a number of web browser developers including Google, Mozilla, and Opera. 3GPP Rel-12 is developing specifications for clients to access the IMS services using WebRTC. TS 22.228 provides requirements to support IMS subscriber access to IMS services via WebRTC enabled devices and an application (client) that is provided by the IMS operator or a third party.

At this time architecture work is being studied and documented in TR 23.701.[177] The architecture study involves developing support for IMS media (including transcoding) and protocol interworking necessary for WebRTC client to access IMS services.

Services:

The WebRTC IMS client will be able to support originating and terminating access to IMS multimedia telephony (except emergency sessions, fax, and CS data), early media, and network tones and announcements, including access to call management. The available IMS services and capabilities accessible via the WebRTC IMS client will be determined according to operator policy and user subscription settings in IMS.

NOTE: The available services and capabilities may be limited by the provider of the WebRTC IMS client (operator or a third party), by the capabilities of the WebRTC IMS client (e.g. no video support), and/or by the IP access used to access the IMS network (e.g. IP access networks without QoS support).

Charging and QoS:

The IMS supports online and offline charging for WebRTC IMS client access (including clients provided by the operator or a third party) and will provide the appropriate QoS (based on operator policy and user subscription) for WebRTC IMS client traffic originating from an access network supporting QoS.

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[177] TR23.701, “Study on Web Real Time Communication (webrtc) access to IMS”

Authentication and Security:

The IMS authenticates an IMS subscriber accessing IMS services using operator provided credentials via a WebRTC IMS client (whether provided by the operator or a third party) or WebRTC server. It then associates the subscriber to one or more public identities (e.g. IMS Public User Identity or MSISDN). When accessing the IMS via a WebRTC client the IMS will maintain the equivalent levels of security and integrity when accessing IMS services in other ways.

Use Cases:
The following use cases have been defined to describe WebRTC access to IMS:

- WebRTC-based application supports broad IMS client capabilities
- User gets his/her IMS service via third-party WebRTC-based application
- User gets third-party IMS service via WebRTC-based application
- Anonymous user gets IMS service via third-party WebRTC-based application

In its December 2013 meeting, the SA2 Study reached the conclusion for network based solution architecture and flows, as documented in latest TR 23.701. The Working Group expected completion of normative work for webRTC by mid-January 2014, however, there may be some changes on Stage 3 specs, with full completion in mid-2014.

4.3.6 FURTHER NETWORK ENERGY SAVING

Further studies are introduced in Rel-12 for the purpose improving network power efficiency, and helping to reduce CO2 emission and the OPEX of operators.[178]

One part of the study is on the mechanisms for cell switch-on in intra-LTE overlaid scenarios (UL-based solutions like IoT measurements or Sounding Reference Signal (SRS) detection by the eNB, or DL-based solution (probing) as introduced for the inter-RAT scenario in Rel-11). In addition, the possible need for further support of QoS aspects in network energy saving procedures is also considered.

Another part of the study is on energy saving in the E-UTRAN coverage layer, based on compensation. Compensation in this context denotes a method where accessibility to the network in a coverage area of a cell to be moved in Energy Saving mode is provided by the coverage of one or more other cells.

A third scenario assumes the TX power of LTE cells can be reduced. This approach to save energy is to optimize the transmission power of all or most cells, so that without switching off any cell, overall energy consumption is minimized.

The Study Item was ongoing in December 2013.

4.3.7 MULTIMEDIA

The specification of 3GPP multimedia services, codecs, and protocols is developed in the 3GPP SA4 working group. In Rel-12, SA4 is developing a new speech codec for VoIP that provides improved speech quality and operation at lower data rates; investigating adoption of a new video codec that promises to provide significantly better performance over the

[178] TR 36.887 v0.2.0, "Study on Energy Saving Enhancement for E-UTRAN"

current video codec; developing features and enhancements for MBMS; enhancing QoS procedures for conversational IMS services; and developing acoustic tests and requirements for LTE VoIP terminals. The following provide an overview of key features and their status.

EVS Codec:

Enhanced Voice Services (EVS) is the conversational voice codec currently being standardized in 3GPP SA4 for use in next generation voice services primarily over LTE and LTE-A. The EVS codec will be the successor to Adaptive Multi-rate (AMR) and Adaptive Multi-rate WideBand (AMR-WB) codecs that are extensively used in 3GPP systems for voice services as of 2013. The goals of EVS as envisaged in the TSG-SA TR 22.813 include:

- Enhanced quality by the introduction of super-wideband (SWB) speech, leading to improved user experience. The EVS codec would be the first conversational codec that can encode voice and other audio signals with a super wideband bandwidth (50 Hz-16 kHz) at bit rates as low as 13.2 kbps. Super-wideband coded speech sounds closer to the original human voice compared to wideband (WB) and narrowband (NB) speech and therefore provides a sense of “presence”

- Enhanced quality and coding efficiency for NB and WB speech services, leading to improved user experience and system efficiency compared to codecs used in pre Rel-12 voice services. At similar bit rates as current 3GPP conversational codecs (AMR and AMR-WB), the EVS codec is expected to offer better quality for NB and WB inputs. Equivalently, the EVS codec is expected to provide improved coding efficiency by coding NB and WB signals at lower bit rates for similar quality as AMR and AMR-WB, respectively

- Enhanced quality for mixed content and music in conversational applications (for example, in-call music, music on hold etc.), leading to improved user experience for cases when the selection of dedicated 3GPP audio codecs is not possible

- Robustness to packet loss and delay jitter, leading to optimized behavior in IP application environments like Multimedia Telephony Service for IMS (MTSI). Further, the bit rates for the EVS codec are selected to optimally utilize the LTE transport block sizes chosen for AMR-WB

- Backward interoperability to the 3GPP AMR-WB codec by having some WB EVS modes supporting the AMR-WB codec format used throughout 3GPP conversational speech telephony service (including circuit-switched). The AMR-WB interoperable operation modes of the EVS codec may be either identical to those in the AMR-WB codec or different, but the bit-stream will be interoperable with them.

Table 4.4 shows a comparison of features of AMR, AMR-WB and the EVS codecs.

Table 4.4. Comparison of AMR, AMR-WB and EVS.

Features	AMR	AMR-WB	EVS
Input and output sampling frequencies supported	8KHz	16KHz	8KHz, 16KHz, 32KHz, 48 KHz
Audio bandwidth	Narrowband	Wideband	Narrowband, Wideband, and Super wideband
Coding capabilities	Optimized for coding human voice signals	Optimized for coding human voice signals	Optimized for coding human voice, and general purpose audio (music, ringtones, mixed content) signals

Features	AMR	AMR-WB	EVS
Bit rates supported (in kb/s)	4.75, 5.15, 5.90, 6.70, 7.4, 7.95, 10.20, 12.20	6.6, 8.85, 12.65, 14.25, 15.85, 18.25, 19.85, 23.05, 23.85	5.9, 7.2, 8, 9.6 (NB and WB only), 13.2 (NB, WB and SWB), 16.4, 24.4, 32, 48, 64, 96, 128 (WB and SWB only)
Number of audio channels	Mono	Mono	Mono and Stereo
Frame size	20 ms	20 ms	20 ms
Algorithmic Delay	20 ms/ 25 ms	25 ms	Up to 32 ms

The EVS Work Item commenced in 3GPP SA4 in March 2010. A total of 13 proponent companies submitted candidates for the qualification phase of the standardization process. The qualification exercise included 12 subjective experiments to test the EVS codec against performance requirements in 148 different conditions spanning three bandwidths (NB, WB and SWB), clean and noisy speech inputs, and under both error free and delay & loss-prone channel conditions. At the 3GPP SA4 #72 Bis meeting in March 2013, five candidates among the 13 were selected to move on to the next phase of the standardization process. The milestones for the completion of the EVS Work Item in Rel-12 are shown in Figure 4.34.:

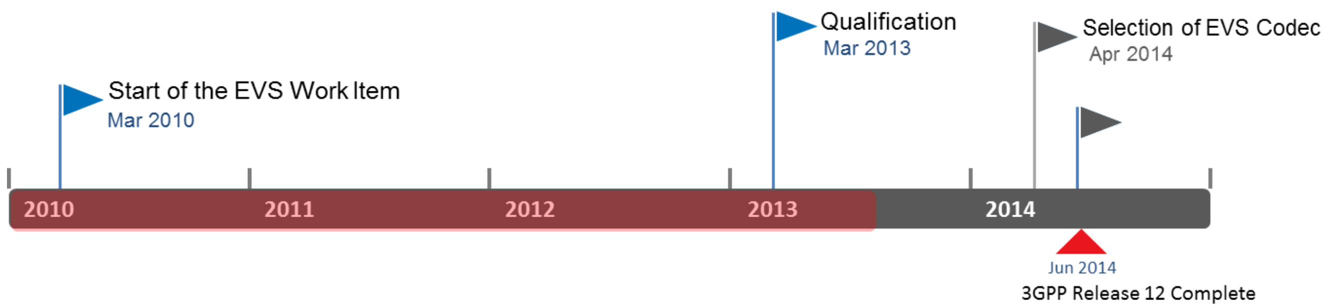

Figure 4.34. Timeline for EVS standardization in Rel-12.

The Work Item is ongoing with completion scheduled in June 2014.

Multicast on Demand

The Evolved Multimedia Broadcast/Multicast Service (eMBMS) operating over an LTE network provides an efficient way to deliver files and streaming content to a group of users over a point-to-multipoint channel. This “one-to-many” distribution provides a resource-efficient alternative to delivery over multiple unicast bearers when a large number of users are interested in the same content.

3GPP SA4 is developing a feature that will allow the network to dynamically establish an MBMS user service on the fly and seamlessly migrate existing unicast services to the established MBMS service. In scenarios where a particular piece of content is being consumed by more than a preconfigured number of users in a geographic area, unicast delivery is dynamically switched to broadcast delivery.

One use case where this feature is needed is when live “breaking news” becomes available and many users start watching the content through separate unicast bearers. When the network detects that the number of viewers exceeds a certain threshold, the network can broadcast the content over the MBMS bearer and direct the UEs to receive the content over broadcast. A similar scenario can occur when a software update for a smart phone app is being downloaded by multiple terminals in a geographic area.

Another use case that benefits from this feature is group calls. When the number of UEs in the call and in a specific cell exceeds a threshold, an MBMS bearer can be established for the group to enable efficient delivery of the group call content. When the network detects a significant drop-off in user access to the content over a dynamically provisioned MBMS service, the network determines that it is no longer beneficial for overall network utilization to maintain a dedicated MBMS bearer for delivering the content. The network then deactivates this MBMS user service and the associated network capacity is re-allocated for delivery of the content over unicast.

SA4 has agreed on the use cases for this feature and the Stage 2 call flows for switching between unicast and broadcast operation. Figure 4.35 shows the high level architecture of the "MBMS Operation on Demand" feature. The solid red, blue, and orange lines describe the flow of content over unicast bearers. When the network detects a high rate of attachment to a unicast service, it requests that the BM-SC activate an MBMS user service to deliver the same content over a broadcast bearer. The unicast traffic is re-routed through the BM-SC as shown by the dashed lines and then delivered over the broadcast bearer in the green line.

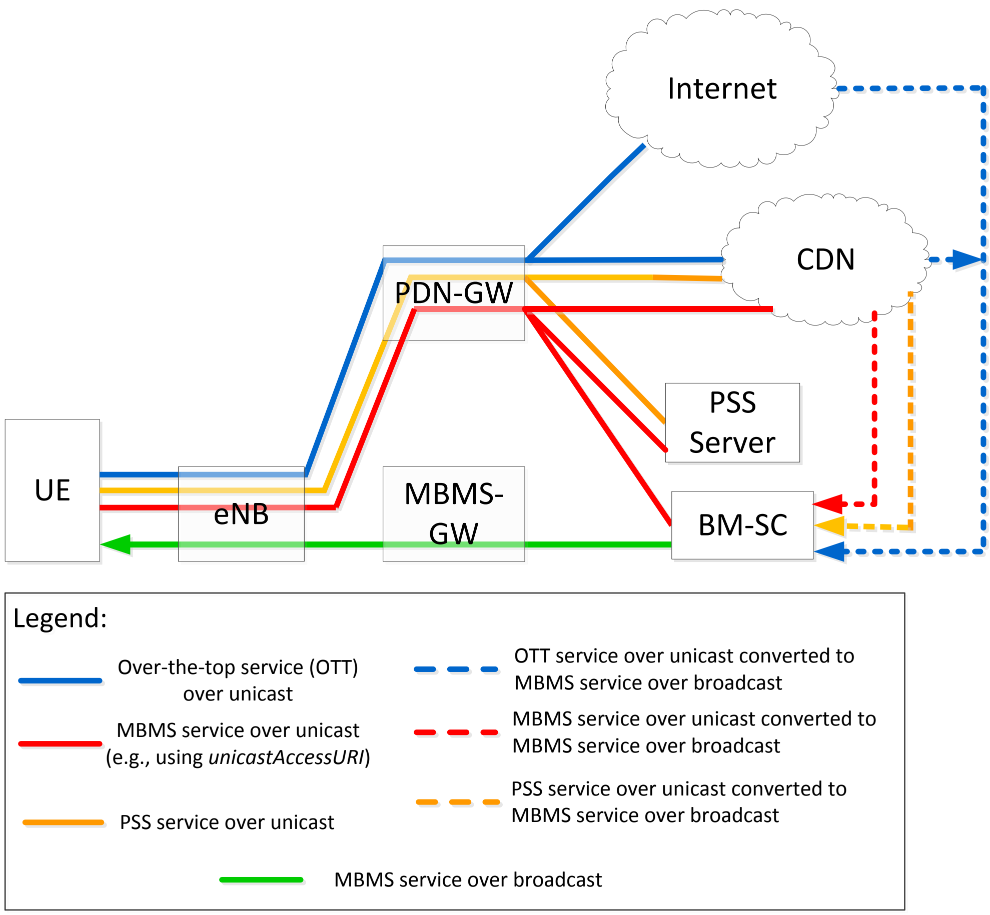

Figure 4.35. High-level architecture of MBMS Operation on Demand. The solid red, blue, and orange lines describe the flow of content over unicast bearers.

Video:

One of the new features planned for Rel-12 is the support of the High Efficiency Video Coding (HEVC) codec in 3GPP multimedia services, including 3GPP Dynamic Adaptive Streaming over HTTP (3GP-DASH), PSS, MBMS, MTSI and MMS. The rapid increase in the consumption of video data over the Internet and wireless networks has prompted mobile operators to plan capacity upgrades for their wireless networks and services, as well as seek better video compression techniques to enable more efficient use of their network capacity. At the same time, end user's expectation of video quality is increasing as more high definition displays and content become widely available.

The High Efficiency Video Coding (HEVC/H.265) codec has recently been developed by the Joint Collaboration Team on Video Coding (JCT-VC) of ISO/IEC SC29 WG11 (MPEG) and ITU-T SG16 Q6 (VCEG). Subjective tests have shown that HEVC is able to achieve the same quality with roughly half of the bitrate compared to Advanced Video Coding (AVC/H.264). Thus, support of HEVC in 3GPP multimedia services could provide a bandwidth-efficient means to meet the requirements for enhanced video quality from end users and operators.

Similar to earlier hybrid-video-coding based standards including AVC, the following basic video coding design is employed by HEVC. A prediction signal of the image frame is first formed either by intra- or motion-compensated prediction. The difference between the original image and the prediction is then transformed coded, followed by entropy coding. The gains in coding efficiency are achieved by redesigning and improving almost all parts of the codec over earlier designs. In addition, HEVC also includes several tools to enable its efficient implementation on parallel architectures.

As AVC/H.264 is the codec specified for use in 3GPP multimedia services before Rel-12, SA4 has performed various objective and subjective tests comparing the performance of HEVC/H.265 versus AVC/H.264 across the 3GPP multimedia services. The test conditions and results are documented in the technical report, 3GPP TR 26.906.

The objective test results show that for the same objective quality as measured by Peak Signal to Noise Ration (PSNR), the average decrease in bitrate for HEVC compared to AVC is 30-40 percent and that the performance gain of HEVC is larger for higher spatial resolutions. Within each spatial resolution, the performance gain for HEVC is larger at the lower bitrates. For example, the gain at 1080p resolution was around 35 percent for the higher bitrate range and 50-55 percent for the lower bitrate range. Figure 4.36 shows the plot of PSNR versus bitrate for a typical sequence (BasketballDrive) at the 720p resolution.

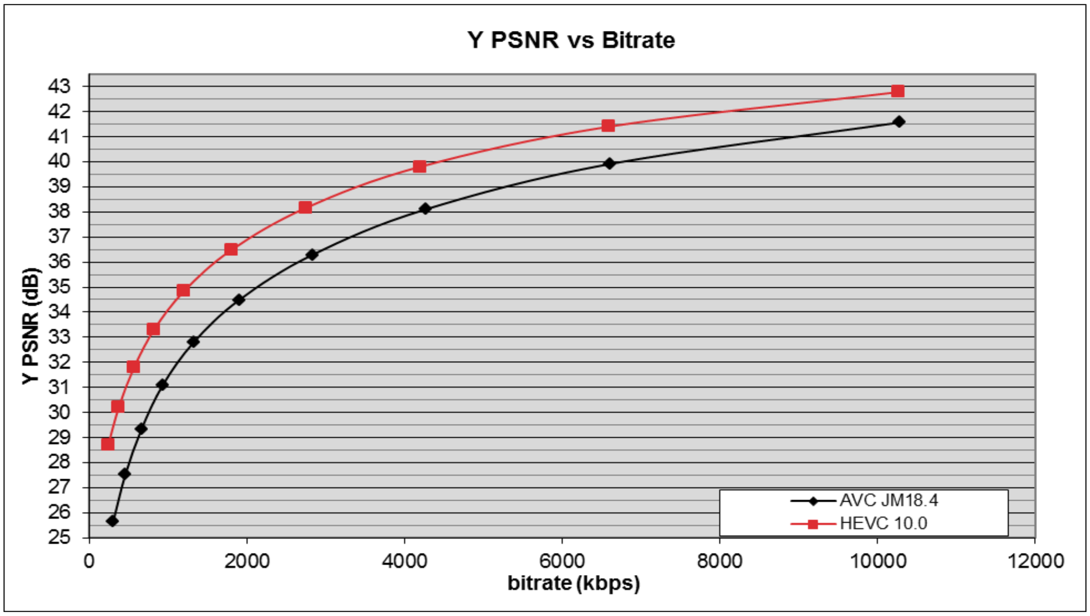

Figure 4.36. PSNR vs. bitrate at 720p for BasketballDrive sequence for HEVC and AVC. The average decrease in bitrate for HEVC compared to AVC is 30-40percent and that the performance gain of HEVC is larger for higher spatial resolutions.

The subjective test results show that the bitrates to achieve a certain MOS are clearly lower for HEVC than for AVC. This is valid for all content, format, and devices (smartphones and tablets) in the test. The bitrates to achieve MOS=3.5 using HEVC is about 50 percent of the bitrate using AVC, with some variation for different content types, resolutions, and device types. The performance gain is larger at lower bitrates. Figure 4.37. shows the summary of the MOS values for smartphones.

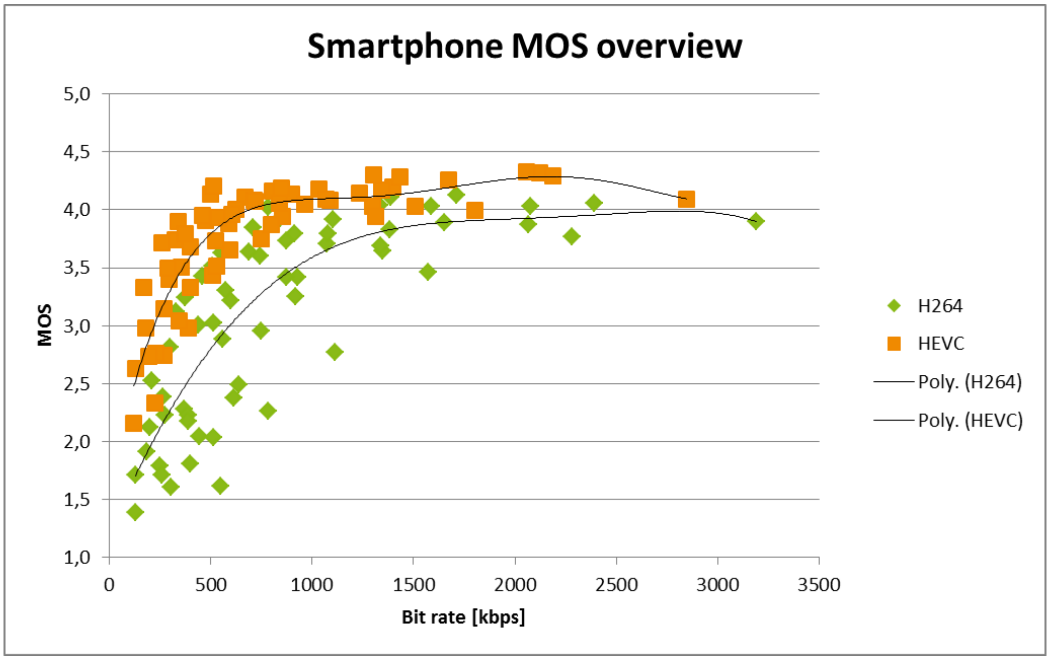

Figure 4.37. MOS vs. bitrate for Smartphone devices (included trend lines use a 5th order polynomial approximation). The bitrates to achieve a certain MOS are clearly lower for HEVC than for AVC.

As of December 2013, 3GPP SA4 has agreed to specify the support of HEVC for the 3GP-DASH, PSS, and MBMS services. The current working assumption is that HEVC Main profile, Main tier, Level 3.1 will be the recommended minimum HEVC decoding capability for clients operating these services. The most representative format for this capability is the 720p resolution @30fps.

Further studies are being conducted to investigate the gains of HEVC for MTSI and MMS that take into consideration the additional constraints on encoder complexity and latency of these services.

4.3.8 POLICY AND CHARGING CONTROL (PCC) FRAMEWORK ENHANCEMENTS

Starting from Release 11, it is possible for the Policy and Charging Control (PCC) architecture to provide application awareness even when there is no explicit service level signaling. The application detection and control can be implemented either by the Traffic Detection Function (TDF) entity or by the Policy and Charging Enforcement Function (PCEF) enhanced with Application Detection and Control (ADC) entity. The mechanisms of detection and, in case of solicited application reporting also the mechanisms of control (i.e. gating, bandwidth limitation, redirection and usage monitoring per detected application), are applicable also for applications with non-deducible service data flows. ADC Rules are defined per each application, which is required to be detected and controlled in the case that TDF and PCC Rules are defined per each application. This is required to be detected and controlled in the case of PCEF enhanced with ADC. In contrast to the TDF, the Rel-11 PCEF enhanced with ADC also supports charging per detected application.

In Rel-12, system enhancements are introduced on top of the existing PCC framework in order to fulfil application-based charging for the detected applications; also, in the case of the TDF system enhancements are needed so that the applications can not only be detected and enforced but also be charged by the TDF.

On top of Rel-11 Service Awareness and Privacy Policies extensions, which were defined for TDF and the Sd interface related to application detection, enforcement control and usage monitoring, the following additional modifications were defined under ABC:

Support of application based charging includes defining the corresponding charging functionality, necessary extensions to Sd interface to handle charging, including ADC Rules extensions to include all charging control related parameters provided by the PCRF, and Gyn/Gzn interfaces between the TDF and the OCS/ Offline Charging System (OFCS).

The major features supported by this enhancement are:

- Apply charging for network usage per detected application in the system when TDF performs application detection, according to rules received from the PCRF
- Both online and offline charging can be supported
- In case of Event based charging, it can be configured at TDF, per each Application Identifier, which events to count
- Applicable also when the TDF applies enforcement actions to the detected application's traffic: gating, bandwidth limitation and redirection and the corresponding charging can be provided properly e.g. gated traffic is not to be counted
- Apply different rates and charging models per detected application in case of roaming
- Apply different rates and charging models based on the location of a user, beyond the granularity of roaming, and/or Time of the Day
- Apply a separate rate to the network usage for a specific detected application, e.g. allow the user to access an application deemed by the operator as no charge and another application with a rate causing a charge
- Enforce per-detected application usage limits for the network usage by an application using online charging on a per user basis
- Set and send the thresholds (time and/or volume based) for the amount of remaining credit per detected application
- The charging system maintains the tariff information, determining the rate based on the above input

Figure 4.38 shows the enhanced solution architecture (non-roaming case) as per TS 23.203:

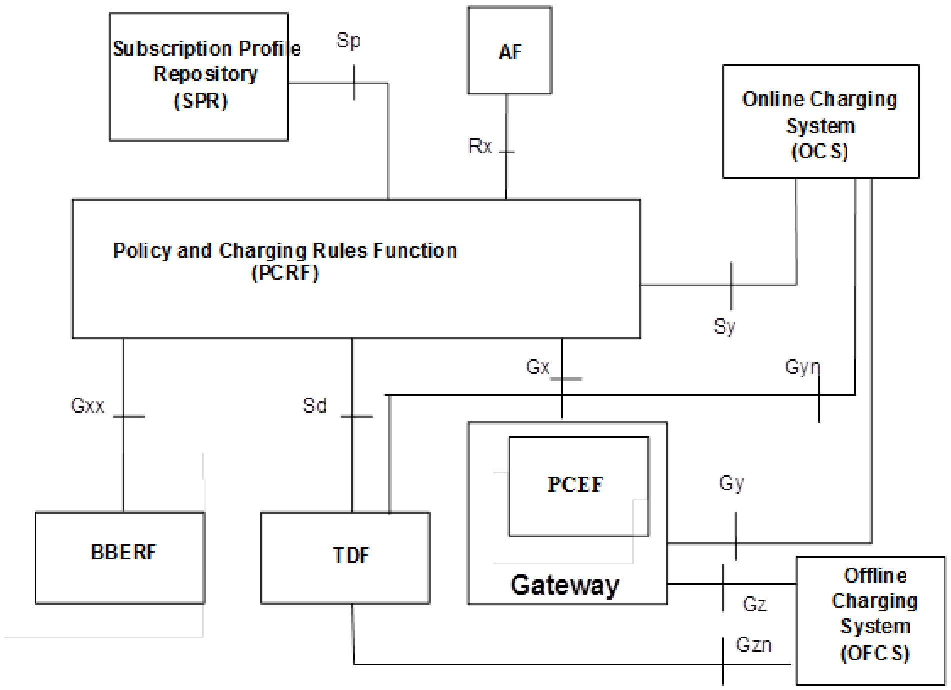

Figure 4.38. Enhanced solution architecture for non-roaming case.

The requirements for Application Based Charging (ABC) have been documented in the Rel-12 TS 23.203 and a number of Stage 3 specifications are expected to be updated in Rel-12 time frame.

Time Based Usage Monitoring:

Up to Rel-11, standards support only volume-based usage monitoring. The time-based usage monitoring is a new feature in Rel-12, which supports the following:

- The usage monitoring thresholds set by the PCRF are based either on time, or on volume.
  - The PCRF may send both thresholds to the PCEF or TDF per each Monitoring key
  - The PCEF or TDF notify the PCRF when a threshold is reached and report the accumulated usage since the last report
  - If both time and volume thresholds were provided to the PCEF or TDF, the accumulated usage is reported when either the time or the volume threshold is reached. For example, if the volume threshold is reached, the consumed time is reported as well
  - In order to continue combined volume and time measurements, the PCRF provides a new time threshold along with a new volume threshold
- Usage Monitoring Congestion handling defined in Rel-11 is enhanced with Time based Usage Monitoring: When the Monitoring time occurs, the accumulated volume and/or time usage can be recorded by the PCEF/TDF and:
  - If the subsequent usage threshold value is provided, the usage threshold is reset to this value by the PCEF/TDF

    - Otherwise, the usage threshold is set by the PCEF/TDF to the remaining value of the threshold previously sent by the PCRF (i.e. excluding the accumulated usage)
    - The first usage report after the Monitoring Time was reached will indicate the usage up to the Monitoring time and usage after the Monitoring time

- Inactivity Detection Time: The PCRF may indicate to the PCEF/TDF the Inactivity Detection Time (the time interval after which the time measurement shall stop for the Monitoring key, if no packets are received belonging to the corresponding Monitoring Key during that time period)
    - Time measurement will resume on receipt of a further packet belonging to the Monitoring key

- If an Inactivity Detection Time value of zero is provided, or if no Inactivity Detection Time is present within the usage monitoring information provided by the PCRF, the time measurement is continuous

Features and procedures for Time Based Usage Monitoring have been documented in the Rel-12 TS 23.203, and an update to TS 29.212 will be completed in Rel-12 time frame.

4.4 RELEASE INDEPENDENT FEATURES

Some work in 3GPP is considered 'release independent,' however, the work is essential to the successful technology evolution and standards development. One very important category is spectrum management. As regulators in various countries reallocate spectrum for mobile radio use, the 3GPP standards organization continuously updates and adds corresponding new frequency bands. While new frequency bands and carrier aggregation schemes are introduced in a particular release, they may be used in UEs which otherwise implement an earlier release. These additional bands are completed in "point releases" not just the whole numbered releases. Consequently, allowing frequency band support to be a release independent feature speeds the deployment of new spectrum and allows terminal and base station manufacturers to support various frequency bands without needless delay and having to otherwise upgrade the entire terminal's or base station's features to the latest release level.

Rel-12 has specifically added four new bands and an additional three that are under consideration (labeled TBD below), as indicated in Table 4.5.

Table 4.5. New Frequency Bands scheduled to be added in Rel-12.

Frequency Band Description	Band Number	Work item Description Document
700 Asia Pacific Telecommunity (APT) (703-748 & 758-803 MHz) FDD, Asia Pacific Teleco	28	RP110875
LTE in the US Wireless Communications Service (WCS) Band	30	RP-130843
Introduction of LTE 450 MHz band in Brazil	31	RP-121414
700 APT (703-803 MHz) TDD	44	RP110875

Supplemental Downlink 1452-1492 MHz (for UMTS and LTE)	TBD	RP-130829
LTE in the 1670-1675 MHz Band for US (FDD) 1646.7-1651.7	TBD	RP-121397
LTE in the US Upper L-band (1670-1675 MHz)	TBD	RP-120360

Aggregated over all releases, and assuming that the three bands are completed, Rel-12 brings the up total to 43 bands identified for UTRA/EUTRA, as tabulated in Appendix A in this paper. The growth in the number of bands standardized is shown graphically below in Figure 4.39. There are historically about 3 new bands added each year.

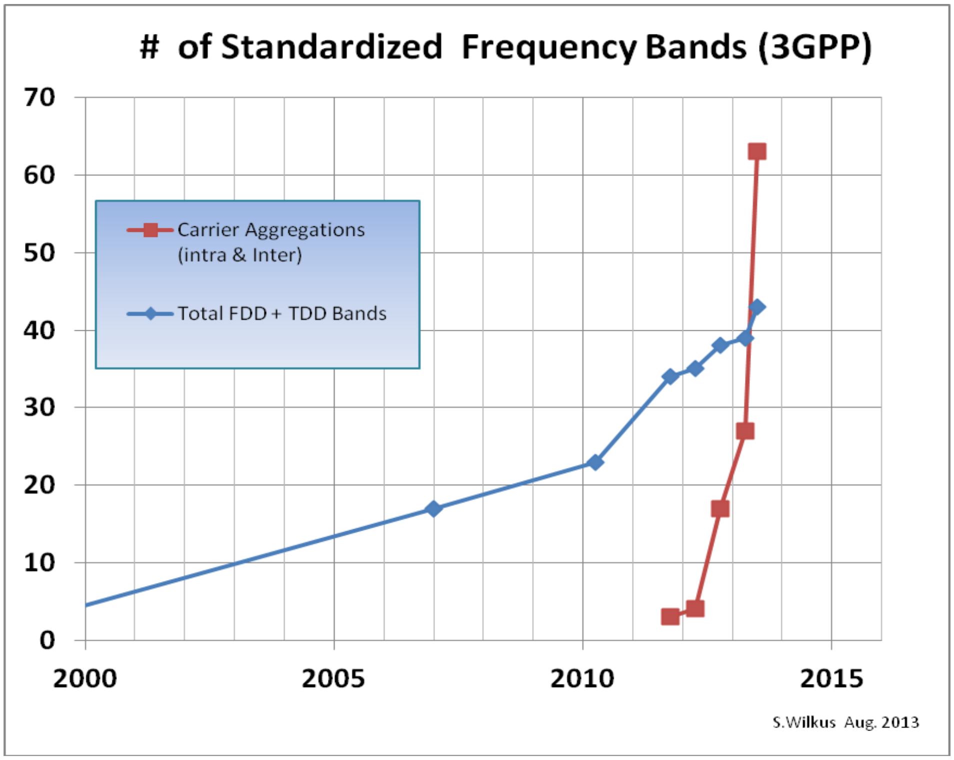

Figure 4.39. Showing the growth in the number of bands carrier aggregation cases over time.

Figure 4.39 also shows the impressive speed with which carrier aggregation cases have been added. Table 4.6 enumerates the EUTRA intra-band carrier aggregation schemes currently in Releases 10 through 12, including some still under study.

In Appendix A, Table 5.1 lists the EUTRA inter-band carrier aggregation cases. Table 5.2 shows inter-band carrier aggregation schemes up till Rel-12 including TDD component carriers, as well as combinations of dual-uplink component carriers, non-contiguous intra-band cases, and triplets of downlink for a single uplink component carrier. There are a few cases where there are seemingly duplicate rows where the same component carriers are aggregated, but in different cases, such as for band 4 and 41 two uplink carriers are aggregated, though most are aggregating two downlinks with a single uplink. There is provision for contiguous carriers and, more recently, non-contiguous carriers. In addition, Rel-12 is also introducing 2 uplink carriers (2UL) and 3 downlink carriers (3DL1UL). These additional cases are shown tabulated in different rows of the Table 5.2.

In 2012, there were only 21 carrier aggregation schemes while in 2013, there are 13 intra-band and 50 inter-band configurations, an increase of 180 percent, an indication of the explosive demand for spectrum and the demand for increasing the typical end user's peak throughputs.

Table 4.6. EUTRA Intra-band Carrier Aggregation Band Combinations.

Intra-band Carrier Aggregation						
Case #	Bamd #	Cont-iguous	Common Names	Status	3GPP Descriptive Document	UID
1	1	Contig	"2100"	Complete R10		550111
2	3	C&NC	"1800"	for Rel-12	550011	550111
3	4	Non C.	AWS	for Rel-12	560016	
4	4	2UL	AWS Non. Contig.	for Rel-12	600024	
5	7	Non C.	"2600"	Complete R11	530028	530128
6	23	C&NC	S-Band contig&non	for Rel-12	600025	
7	25	Non C.	PCS+G nonContig	Complete R12	530029	530129
8	27	Contig	Lower E850	for Rel-12	580036	
9	38		MBS of 2.6 GHz	Complete R11	520015	520115
10	39	Contig	1880-1920 TDD	for Rel-12	590027	
11	40		IMT 2K	Complete R10	460007	
12	41	NC	2600 MHz BRS/EBS	Complete R11	520016	520116
13	41	2UL NC	2600 MHz BRS/EBS	for Rel-12	600023	

With arbitrary 2 DL and 2 UL component carriers, intermodulation products can easily desensitize the receiver when the component carriers are harmonically related, so 3GPP has designated 5 classes of self interference behavior to ease the standardization:

A1: Low-High band combination without harmonic relationships between bands or intermodulation problem

A2: Low-high band combination with harmonic relation between bands

A3: Low-low or High-high band combination without intermodulation problem (low order Inter-Modulation Products, IMPs)

A4: Low-low, low-high, or high-high band combinations with intermodulation problem (low order IMPs)

A5: Combinations except for A1 through A4

For example, band 17's 3[r] harmonic UE transmissions are in the band 4's downlink band where it can desensitize reception, so it is designated as A2 as are CA_B4+B12, CA_B3+B8, for example.

In Appendix A, Table 5.2., there are also cases (#40 through #48) with three downlink component carriers supported by a single uplink carrier. This reflects the overwhelming preponderance of downlink traffic in today's typical wireless data network and the need for additional downlink capacity to serve it. This ability to serve typical traffic patterns with appropriate combinations of uplink and downlink blocks of spectrum is a major appeal of Carrier Aggregation and is driving the rapid adoption of this capability.

5 CONCLUSION

Clearly, the pace of work in 3GPP Rel-11 and Rel-12 has been an attempt at matching the relentless march of mobile data traffic growth. With the closing of Rel-11 standards, this white paper focused on the features of Rel-12 as they also near completion, with expected core specifications to freeze in June 2014.

Rel-12 contains a vast array of features for both LTE and HSPA+ that will result in greater efficiencies for networks and devices. For example, active antenna arrays and downlink MIMO enhancements further boost what is possible on the LTE macro side, while the work on small cells and femto enhancements continues to advance HetNets, including work on mobility. Solutions for machine-type-communications also continue to be a topic of interest across RAN and network services. Offloading is becoming ever more flexible as well. On the broadcast side, MBMS enhancements which include recovery and measurements will be completed in Rel-12. On the TDD side, dynamic traffic adaption as well as carrier aggregation between FDD and TDD are also scheduled to be completed in Rel-12, among many other features.

For HSPA+, HetNets and their enhancements are part of Rel-12, as well as further improvements to Home NodeB's such as the emergency warning area, positioning and mobility. Scalability of UMTS, as well as further EUL enhancements, is also being studied.

On the network and services side, public safety is driving new items into 3GPP standards, with the two main areas of 3GPP LTE enhancements in Proximity Services (ProSec) and Group Call System Enablers for LTE (GCSE_LTE). Wi-Fi integration, both on the network selection side as well as the APN/PDN side, is also receiving significant attention. RAN level enhancements for Wi-Fi interworking that improves user experience and provides more operator control and better access network utilization, are part of the work item.

Finally, additional work on WebRTC, multimedia codecs, energy saving, policy and charging, and the new frequency bands and carrier combinations round out Rel-12.

Looking forward, there are also a number of potential work items for Rel-13. Given the large number of features introduced in Rel-12, many were not completed and thus moved over to Rel-13. One reconsidered potential work item is user-plane congestion, which aims at detecting and mitigating situations where the offered load exceeds the capacity of the RAN to transfer user data for a few seconds or longer. Active continuing work on the RAN side, such as 3D beamforming, network assisted IC, multi-RAT coordination and advanced receivers, as well as further work on D2D, dual connectivity, energy saving and group calls, are also potential items in Rel-13. For HSPA+, further work on EUL may be included. On the network and services side, proposed topics already include application specific congestion control, RAN sharing, security assurance and public warning broadcasts.

The continued evolution of 3GPP technology is on track, providing significant new capabilities and enhancements to HSPA+ and LTE-Advanced with the completion of Rel-11 and great progress on Rel-12 to provide operators with the solutions for meeting the fast-growing wireless data usage demands of consumers and the industry.

APPENDIX A: RELEASE INDEPENDENT FREQUENCY BANDS

Table 5.1. Bands for UTRA and EUTRA including Rel-11 and expected Rel-12 bands.

UTRA eUTRA Band	UL Transmit	DL Transmit	Alias
I (1)	1920 to 1980 MHz	2110 to 2170 MHz	Core IMT, "2100" (EU, Africa, Asia)
II (2)	1850 to 1910 MHz	1930 to 1990 MHz	PCS, "1900" (US, Canada, Americas)
III (3)	1710 to 1785 MHz	1805 to 1880 MHz	DCS 1800, "1800" (EU, Africa, Asia)
IV (4)	1710 to 1755 MHz	2110 to 2155 MHz	AWS, "1.7/2.1 GHz" (Americas, US)
V (5)	824 to 849 MHz	869 to 894 MHz	Cellular 850, UMTS850 (Americas...)
VI (~~6*~~)	830 to 840 MHz	875 to 885 MHz	UMTS800 obsolete
VII (7)	2500 to 2570 MHz	2620 to 2690 MHz	IMT-E, "2.6 GHz" (EU, Africa, Asia...)
VIII (8)	880 to 915 MHz	925 to 960 MHz	GSM, UMTS900, EGSM900 (EU...)
IX (9)	1749.9 to 1784.9 MHz	1844.9 to 1879.9 MHz	UMTS1700 (Japan)
X (10)	1710 to 1770 MHz	2110 to 2170 MHz	IMT 2000 (Expanded B14)
XI (11)	1427.9 to 1447.9 MHz	1475.9 to 1495.9 MHz	PDC (Japan)
XII (12)	699 to 716 MHz	729 to 746 MHz	lower 700MHz blocks A/B/C (US)
XIII (13)	777 to 787 MHz	746 to 756 MHz	upper 700MHz block C (US)
XIV (14)	788 to 798 MHz	758 to 768 MHz	upper 700MHz block D (US)
17	704 to 716 MHz	734 to 746 MHz	LTE B&C block (US)
18	815 to 830 MHz	860 to 875 MHz	ESMR (Japan)
XIX (19)	830 to 845 MHz	875 to 890 MHz	(Japan)
XX (20)	832 to 862 MHz	791 to 821 MHz	EU's Digital Dividend 800 MHz
XXI (21)	1447.9 to 1462.9 MHz	1495.9 to 1510.9 MHz	(Japan)
XXII (22)	3410 to 3490 MHz	3510 to 3590 (MHz)	3.5 GHz band (EU)
23	2000 to 2020 MHz	2180 to 2200 MHz	S-Band (US)
24	1626.5 to 1660.5 MHz	1525 to 1559 MHz	L-Band (US)
XXV (25)	1850 to 1915	1930 to 1995	expanded B2 Sprint's G-Block (US)
XXVI (26)	814 to 849 MHz	859 to 894 MHz	E850 Upper Band
27	807-824 MHz	852-869 MHz	E850 Lower band
28	703-748 MHz	758 to 803 MHz	APT - 700 (Asia Pacific, C&SAmerica)
29	NA	716 to 728 MHz	Lower 700 MHz D&E Block (US)
30	2305 to 2315 MHz	2350 to 2360 MHz	WCS Band (US)
31	452.5 to 457.5 MHz	462.5 to 467.5 MHz	450 MHz band in Brazil
TBD	1646.7 to 1651.7 MHz	1670 to 1675 MHz	upper L band (US)
TBD		1452 to 1492 MHz	Supplemental DL in Dig. Div. (EU)
33	1900 to 1920 MHz TDD		3G Core band
34	2010 to 2025 MHz TDD		3G Core band
35	1850 to 1910 MHz TDD		PCS1900 uplink band
36	1930 to 1990 MHz TDD		PCS1900 downlink band
37	1910 to 1930 MHz TDD		Duplex gap in PCS B2
38	2570 to 2620 MHz TDD		MBS (US) 3G Ext. (EU, Africa, Asia..)
39	1880 to 1920 MHz TDD		TDSCDA band (China)
40	2300 to 2400 MHz TDD		IMT-2000 (China)
41	2496 to 2690 MHz TDD		Clearwire's BRS/EBS (US)
42	3400 to 3600 MHz TDD		lower 3500 MHz band (EU)
43	3600 to 3800 MHz TDD		Upper 3500 MHz band (EU)
44	698 to 803 MHz TDD		APT- 700 MHz

source: TS36.101 V12 (2013-09) and TS 25.101 V12 S.A.Wilkus Oct. 2013

Table 5.2. EUTRA Inter-Band Carrier Aggregation cases through current working view of Rel-12.

Inter-band Carrier Aggregation schemes					
Case #	Lower Band #	Higher Band #	Common Names	Status	3GPP Descriptive Document
1	1 +	5	2100+cell	Complete R10	460007
2	1 +	7	2100+2.6	for R12	530025
3	1 +	8	2100+900	Complete R12	570018
4	1 +	18	2100+ESMR	Complete R11	540021
5	1 +	18	2100+ESMR additions	Complete R12	600030
6	1 +	19	2100+880	Complete R11	540022
7	1 +	21	2100+1.5G	Complete R11	540023
8	1 +	26	2100+860SMR	Complete R12	580032
9	2 +	4	PCS+AWS	Complete R12	560017
10	2 +	5	PCS+Cellular	Complete R12	600029
11	2 +	12	PCS+ABC	for R12	580034
12	2 +	13	PCS+upper C	Complete R12	590022
13	2 +	17	PCS+B&C	Complete R11	510025
14	2 +	29	PCS + D&E	Complete	130884
15	3 +	5	1800+cell	Complete R11	530026
16	3 +	5	2UL 1800+cell with 2UL	Complete R12	550010
17	3 +	7	1800+2.6	Complete R11	480023
18	3 +	8	1800+900	Complete R11	550018
19	3 +	19	1800+880	Complete R12	570014
20	3 +	20	1800+DD	Complete R11	530023
21	3 +	26	1800+860	Complete R12	570013
22	3 +	28	1800+APT700	Complete R12	570026
23	4 +	5	AWS+Cellular	Complete R11	510026
24	4 +	7	AWS+2.6	Complete R11	530027
25	4 +	12	AWS+ABC	Complete R11	510022
26	4 +	13	AWS+upperC	Complete R11	500018
27	4 +	17	AWS+B&C	Complete R11	500017
28	4 +	29	AWS+D&E	Complete R12	RP-130887
29	5 +	12	cell+ABC	Complete R11	510023
30	5 +	17	cell+B&C	Complete R11	510027
31	5 +	25	cell+extended PCS	for R12	R4-136056
32	7 +	20	2.6+DD	Complete R11	510024
33	8 +	20	900+DD	Complete R11	530024
34	8 +	26	900+860SMR	for R12	590025
35	11 +	18	PDC+ESMR	Complete R11	540020
36	12 +	25	ABC+PCS+G	for R12	600028
37	19 +	21	880+1500	Complete R12	590024
38	23 +	29	S-Band + D&E	Complete R12	570012
39	38 +	39	Exten + TDSCDMA	Rel-12	RP-121178
40	39 +	41	1900TDD+BRS/EBS	for R12	580033
41	2+17 +	30	3DL/1U PCS+B/C+WCS	for R12	600032
42	2+2 +	13	3DL/1U PCSx2+upC	for R12	600038
43	2+29 +	30	3DL/1U PCS+D/E+WCS	for R12	600033
44	2+4 +	13	3DL/1U PCS+AWS+upC	for R12	600037
45	2+5 +	30	3DL/1U PCS,cell,WCS	for R12	600031
46	4+17 +	30	3DL/1U AWS+B/C+WCS	for R12	600035
47	4+29 +	30	3DL/1U AWS+D/E+WCS	for R12	600036
48	4+4 +	13	3DL/1U AWSx2+upC	for R12	600039
49	4+5 +	30	3DL/1U AWS+cell+WCS	for R12	600034
					SA Wilkus Nov. 4, 2013

For HSPA+, the following Dual Band Dual Cell (DB-DC), Four Carrier (4C-HSDPA) bands and multi-carrier combinations are specified as release independent.

Table 5.3. DB-DC scenarios up to Rel-12.[179]

DB-DC-HSDPA Configuration	UL Band	DL Band A	DL Band B
1	I or VIII	I	VIII
2	II or IV	II	IV
3	I or V	I	V
4	I or XI	I	XI
5	II or V	II	V

Single band Four Carrier HSDPA is designed to operate in the following configurations:

Table 5.4. Single-band 4C-HSDPA scenarios up to Rel-12.

Single band 4C-HSDPA Configuration	Operating Band	Number of DL carriers
I-3	I	3
II-3	II	3
II-4	II	4
NOTE: Single band 4C-HSDPA configuration is numbered as (X-M) where X denotes the operating band and M denotes the number of DL carriers.		

[179] 3GPP TS 25.101 V12.1.0 (2013-09)

Single Band Non Contiguous Four Carrier HSDPA (NC-4C-HSDPA) is designed to operate in the following configurations:

Table 5.5. Single-band Non contiguous 4C-HSDPA scenarios up to Rel-12.

Single band NC-4C-HSDPA Configuration	Operating Band	Number of DL carriers in one sub-block	Gap between subblocks [MHz]	Number of DL carriers in the other sub-block
I-1-5-1	I	1	5	1
I-2-5-1	I	2	5	1
I-3-10-1	I	3	10	1
IV-1-5-1	IV	1	5	1
IV-2-10-1	IV	2	10	1
IV-2-15-2	IV	2	15	2
IV-2-20-1	IV	2	20	1
IV-2-25-2	IV	2	25	2
NOTE: Single band NC-4C-HSDPA configuration is numbered as (X-M-Y-N) where X denotes the operating band, M denotes the number of DL carriers in one sub-block, Y denotes the gap between sub-blocks in MHz and N denotes the number of DL carriers in the other sub-block. M and N can be switched				

Dual band 4C-HSDPA is designed to operate in the following configurations:

Table 5.6. Dual-band 4C-HSDPA combinations up to Rel-12.

Dual band 4C-HSDPA Configuration	UL Band	DL Band A	Number of DL carriers in Band A	DL Band B	Number of DL carriers in Band B
I-2-VIII-1	I or VIII	I	2	VIII	1
I-2-VIII-2	I or VIII	I	2	VIII	2
I-1-VIII-2	I or VIII	I	1	VIII	2
I-3-VIII-1	I or VIII	I	3	VIII	1
II-1-IV-2	II or IV	II	1	IV	2
II-2-IV-1	II or IV	II	2	IV	1
II-2-IV-2	II or IV	II	2	IV	2
I-1-V-2	I or V	I	1	V	2
I-2-V-1	I or V	I	2	V	1
I-2-V-2	I or V	I	2	V	2
II-1-V-2	II or V	II	1	V	2
NOTE: Dual band 4C-HSDPA configuration is numbered as (X-M-Y-N) where X denotes the DL Band A, M denotes the number DL carriers in the DL Band A, Y denotes the DL Band B, and N denotes the number of DL carriers in the DL Band B					

Single band 8C-HSDPA is designed to operate in the following configurations:

Table 5.7. Single band 8C-HSDPA configurations.

Single band 8C-HSDPA Configuration	Operating Band	Number of DL carriers
I-8	I	8
NOTE: Single band 8C-HSDPA configuration is numbered as (X-M) where X denotes the operating band and M denotes the number of DL carriers.		

APPENDIX B: GLOBAL DEPLOYMENTS STATUS – HSPA/HSPA+/LTE/LTE-ADVANCED

Americas - Latin America & Caribbean						
Country	Operator/Network Name	HSPA (101)	HSPA+ (74)		LTE (32)	LTE Spectrum (Band)
Anguilla	Cable & Wireless Anguilla / LIME	In Service 2011	Oct-13	21Mbps		
Anguilla	Digicel	In Service 2013	May-13	21Mbps		
Antigua & Barbuda	Cable & Wireless Antigua & Barbuda / LIME	Planned				
Antigua & Barbuda	Digicel	In Service 2012	Oct-12	21Mbps	**In Service Nov 2012**	LTE-700 TDD (17)
Argentina	Arsat	Planned			Planned	LTE-850, 1900
Argentina	Claro	In Service 2007	Oct-11	21Mbps	Planned 2014	
Argentina	Nextel	Planned			Planned 2014	
Argentina	Personal	In Service 2007	Dec-12	21Mbps	Planned	LTE-2100
Argentina	Movistar	In Service 2007	Oct-12	21Mbps	Planned	LTE-2100
Aruba	Digicel	In Service 2011	Sep-12	21Mbps		
Aruba	SETAR	In Service 2008	Nov-11	21Mbps	**In Service Nov 2013**	LTE-1800
Bahamas	Batelco BTC / C&W	In Service 2011	Jan-12	21Mbps	Planned 2014	LTE-700, 850
Barbados	LIME Barbados	In Service 2011	Dec-11	21Mbps	Planned	LTE-1900
Barbados	Digicel	In Service 2011	Dec-11	21Mbps		
Belize	BTL	In Service 2013	Jan-13	21Mbps	Planned 2014	LTE-850, 1900
Bermuda	CellOne (Bermuda Dig. Corp) / M3 Wireless	In Service 2009	Jan-11	21Mbps	Planned	LTE-850
Bermuda	Digicel	In Service 2010	Jul-10	21Mbps		
Bolivia	Movil de Entel	In Service 2011	Apr-11	21Mbps	**In Service Dec 2012**	LTE-700
Bolivia	Tigo	In Service 2008			Planned	LTE-700,1900 AWS
Bolivia	Viva	In Service 2010				
Brazil	Claro	In Service 2007	Aug-11	21Mbps	**In Service Dec 2012**	LTE-2600 FDD
Brazil	CTBC Telecom / Algar Telecom	In Service 2008	Nov-11	21Mbps	Planned	LTE-850, 1800
Brazil	Nextel	In Service 2012			Planned	

Brazil	On Telecomunicações				**In Service Mar 2013**	***LTE-2600 TDD (38)***
Brazil	Oi	In Service 2008			**In Service Apr 2013**	LTE-2600
Brazil	Sercomtel Celular	In Service 2008			Planned	
Brazil	Sky Telecom (Broadband)				**In Service Dec 2011**	***LTE-2500 TDD (38)***
Brazil	TIM Brasil	In Service 2008	Oct-12	21Mbps	**In Service Apr 2013**	LTE-450
Brazil	Vivo	In Service 2007	Nov-11	21Mbps	**In Service Apr 2013**	LTE-2100
British Virgin Islands	Digicel	In Service	Nov-12	21Mbps		
British Virgin Islands	C&W/Lime	In Service 2012	Mar-12	21Mbps		
Cayman Islands	C&W/Lime	In Service 2011	Oct-11	21Mbps	**In Service Nov 2013**	LTE-700 (17)
Cayman Islands	Digicel	In Service 2011	Oct-11	21Mbps	**In Service Nov 2013**	LTE-700 (3, 13)
Chile	Claro	In Service 2007	Aug-11	21Mbps	**In Service June 2013**	LTE-2600
Chile	Entel	In Service 2007	Dec-09	42Mbps	Planned 2014	LTE-2600
Chile	Movistar	In Service 2007	Jul-10	42Mbps	**In Service Nov 2013**	LTE-2600
Chile	Nextel	In Service 2012			Planned	
Chile	VTR	Planned			Planned	LTE-1700
Colombia	Avantel				Planned	LTE-2100 (4)
Colombia	Comcel	In Service 2008	Aug-11	21Mbps	Planned	LTE-1900, 2100
Colombia	ETB				Planned	LTE-2100 (4)
Colombia	Movistar	In Service 2008	Oct-12	21Mbps	**In Service Dec 2013**	LTE 1700/2100 AWS (4)
Colombia	Tigo	In Service 2008	Oct-13	21Mbps	**In Service Dec 2013**	LTE 1700/2100 AWS (4)
Colombia	UNE (EPM Telecomunicaciones)				**In Service June 2012**	LTE-2600
Costa Rica	Claro	In Service 2011	Nov-11	21 Mbps	Planned	LTE-2100
Costa Rica	ICE / Kölbi	In Service 2009			**In Service Nov 2013**	LTE-2600
Costa Rica	Telefonica Moviles Costa Rica	In Service 2011			Planned	
Dominica	Cable & Wireless /LIME	In Service 2012	Oct-12	21Mbps		
Dominican Rep.	Claro	In Service 2007	Aug-11	21Mbps		
Dominican Rep.	Orange Dominicana	In Service 2010	Oct-11	42Mbps	**In Service July 2012**	LTE-1800

Dominican Rep.	Tricom (CDMA to LTE)				**In Service March 2013**	LTE-1900 (2)
Dominican Rep.	WIND (WiMAX)				In Trial	LTE-2600 (38)
Ecuador	Claro (ex-Porta)	In Service 2007	Aug-11	21Mbps	Planned 2014	LTE-700
Ecuador	CNT Mobile	In Service 2009	Jul-13	21Mbps	Planned	LTE-1700,2100
Ecuador	Movistar	In Service 2009	Jul-11	21Mbps	Planned	
El Salvador	Claro	In Service 2008	Feb-11	21Mbps		
El Salvador	Movistar	In Service 2008				
El Salvador	Tigo	In Service 2008	Jan-12	21Mbps		
French Guiana	Digicel	In Service 2010	Nov-12	21Mbps		
French Guiana	Outremer Telecom/Only	Planned				
French Guiana	Orange Caraibe	In Service 2009	Jan-14	21Mbps		
French West Indies	Outremer Telecom/Only	In Service 2008				
French West Indies	Orange Caraibe	In Service 2009	Aug-13	21Mbps		
French West Indies	Digicel	In Service 2010	Dec-10	21Mbps		
Guatemala	Claro	In Service 2008	Mar-12	21Mbps		
Guatemala	Movistar	In Service 2009	Dec-11	21Mbps		
Guatemala	Tigo	In Service 2010	Feb-12	21Mbps		
Guyana	Digicel	In Service 2010				
Haiti	Digicel	In Service 2013	May-13	21Mbps		
Haiti	Natcom	In Service 2011				
Honduras	Claro	In Service 2008	Oct-12	21 Mbps		
Honduras	Tigo	In Service 2008				
Jamaica	Cable & Wireless/LIME	In Service 2009	Jun-11	21Mbps		
Jamaica	Digicel	In Service 2008	Jun-12	21Mbps	Planned	
Mexico	Iusacell / Unefon	In Service 2010	Nov-10	21Mbps	Planned	
Mexico	Telcel	In Service 2008	Aug-11	21Mbps	**In Service Nov 6, 2012**	LTE-1700/2100 AWS

Mexico	Nextel	In Service 2011	Sep-12	21Mbps	Planned	LTE-1700/2100 AWS
Mexico	Movistar	In Service 2009	May-12	21Mbps	**In Service Oct 2012**	LTE-1700/2100 AWS
Montserrat	Cable & Wireless/LIME	Planned				
Netherlands Antilles	Digicel (Bonaire & Curaçao)	In Service 2012	Mar-12	21Mbps		
Netherlands Antilles	Setel / UTS	In Service 2011				
Netherlands Antilles	Telcel	In Service 2011	Planned		Planned	
Nicaragua	Claro / enitel	In Service 2008	Oct-12	21 Mbps	Planned	LTE-700
Nicaragua	Movistar	In Service 2009			Planned	LTE-700
Panama	Claro Panama	In Service 2009	Aug-11	21Mbps		
Panama	C&W +Movil	In Service 2011	Jun-11	21Mbps	Potential Network	
Panama	Digicel	In Service 2011	Nov-11	21Mbps		
Panama	Movistar	In Service 2008				
Paraguay	Claro	In Service 2007	Jul-11	21Mbps	Planned	
Paraguay	COPACO / VOX	In Service 2012	May-12	21Mbps	**In Service Feb 19, 2013**	LTE-1700/2100
Paraguay	Personal / Núcleo	In Service 2008	Feb-12	42Mbps	**In Service Feb 8, 2013**	LTE-1900
Paraguay	Tigo	In Service 2008			Planned	LTE-2600
Peru	Americatel Peru				Planned	
Peru	Claro	In Service 2008	Aug-11	21Mbps	Planned 2014	LTE-1900
Peru	Nextel	In Service 2009			Planned 2014	
Peru	Movistar	In Service 2009	Nov-11	21Mbps	Planned Jan 2014	LTE-700
Peru	Viettel Peru				Planned 2014	
Puerto Rico	AT&T Mobility	In Service 2006	Jan-11	21Mbps	**In Service Nov 2011**	LTE-1700/2100 AWS
Puerto Rico	Claro	In Service 2007	Feb-11	21Mbps	**In Service Nov 2011**	LTE-700
Puerto Rico	Open Mobile				**In Service Apr 2012**	LTE-700
Puerto Rico	Sprint Nextel Puerto Rico				**In Service Dec 2012**	LTE-850, 1900
Puerto Rico	T-Mobile	In Service 2009	Dec-10	42Mbps	**In Service July 2013**	LTE-1700/2100
Saba	Satel / UTS	In Service				

St. Kitts & Nevis	Cable & Wireless/LIME	In Service	Oct-12	21Mbps		
St. Kitts & Nevis	Digicel	In Service	Apr-13	21 Mbps		
St. Lucia	Cable & Wireless/LIME	In Service	Jul-13	21Mbps		
St. Vincent & Gren.	LIME	Planned				
Suriname	UNIQA	In Service 2011				
Trinidad & Tobago	TSTT	In Service 2012	Nov-12	21Mbps		
Trinidad & Tobago	Digicel	In Service 2012	May-12	21Mbps	Planned	
Turks & Caicos	Cable & Wireless / LIME	Planned	Planned			
Turks & Caicos	Digicel	Planned	Planned		Planned	LTE-700
Turks & Caicos	Islandcom	In Service 2010	Jul-12	21Mbps		LTE-700
Uruguay	Antel/Ancel	In Service 2007	Jun-11	21Mbps	**In Service Dec 2011**	LTE 1700/2100
Uruguay	Claro	In Service 2007	Oct-11	21Mbps	Planned	LTE 1700/2100
Uruguay	Dedicado (WiMAX)				Planned	LTE-3500 TDD
Uruguay	Movistar	In Service 2007			Planned	LTE 1900
US Virgin Islands	AT&T Mobility	In Service 2008			**In Service July 2013**	LTE 1700/2100 (17)
US Virgin Islands	Sprint	In Service 2009			**In Service April 2013**	LTE 1900 (25)
Venezuela	Digitel	In Service 2009			**In Service Sept 2013**	LTE-1800 (2)
Venezuela	Movilnet	In Service 2009			Planned 2014	LTE-1900 (2)
Venezuela	Movistar	In Service 2008			Planned 2014	LTE-2100
Venezuela	Movilmax (WiMAX)				Planned	LTE-2600

Americas - Canada		**HSPA (16)**	**HSPA+ (14)**		**LTE (42)**	**LTE Spectrum (Band)**
Canada	Bell Mobility	In Service	Nov-09	42Mbps	**In Service Sept 2011**	LTE-1700/2100 (IV)
Canada	Telus	In Service	Nov-09	42Mbps	**In Service Feb 2012**	LTE-1700/2100 (IV)
Canada	Eastlink Wireless	In Service	Feb-13	21Mbps	**In Service Feb 2013**	LTE-1700/2100 (IV)
Canada	Mobilicity	In Service	Oct-12	21Mbps	Planned 2015	LTE-1700/2100 (IV)
Canada	MTS Mobility /Allstream	In Service	Mar-11	21Mbps	**In Service Sept 2012**	LTE-1700/2100 (IV)
Canada	Public Mobile (CDMA)	Planned			Planned 2016	

Canada	Rogers Wireless Communications	In Service	Jul-09	21Mbps	**In Service July 2011**	LTE-1700/2100 (IV) 2.6 MHz
Canada	SaskTel Mobility	In Service	Aug-10	21Mbps	**In Service Jan 2013 VoLTE in Deployment**	LTE-2100 (IV) LTE-TDD 2.6 GHz
Canada	T-Bay-Tel (CDMA)	In Service	Nov-10	21Mbps		
Canada	Videotron (Quebecor Media)	In Service	Sep-10	42Mbps	Planned 2016	
Canada	WIND /Globalive	In Service			Planned 2016	
Canada	Xplornet (Barrett Xplore))Rural WiMAX				Planned	LTE-2600
Americas - US		**HSPA**	**HSPA+**		**LTE**	**LTE Spectrum (Band)**
USA	MiSpot / Agri-Valley (CDMA) (Michigan)				**In Service Mar 2013**	LTE-700
USA	Adams Networks / Illinois				**In Service May 2013**	LTE-700 (17)
USA	Alaska Communications (CDMA) (AWN)		Oct-12	21Mbps	**In Service Oct 2012**	LTE-700
USA	Appalachian Wireless/Kentucky (Rural CDMA)				**In Service June 2013**	LTE-700
USA	AT&T Mobility	In Service	Nov-10	21Mbps	**In Service Sept 2011**	LTE-700, 1700/2100 (IV)
USA	BayRICS (San Fran Public Safety)				In Trial	LTE-700
USA	BendBroadband	In Service	Dec-09	21Mbps	**In Service May 2012**	LTE-1700/2100
USA	Bluegrass Cellular/Kentucky (Rural CDMA)				**In Service Nov 2012**	LTE-700
USA	Carolina West Wireless				Planned	
USA	Cellcom (WI, MI) (Rural CDMA)				**In Service May 2012**	LTE-700
USA	C Spire Wireless Cellular South (CDMA)				**In Service Sept 2012**	LTE-1700/2100, 1900 (12/25)
USA	CenturyLink (former CenturyTel)				Planned	LTE-700
USA	Chariton Valley/Missouri (Rural CDMA)				**In Service Sept 2012**	LTE-700
USA	Chat Mobility/Iowa (Rural CDMA)				**In Service May 2013**	LTE-700
USA	Cincinnati Bell Wireless	In Service	Jun-11	21Mbps	Planned	LTE-700
USA	Clearstream / North Carolina				Planned	LTE-700
USA	Colorado Valley Communications /Texas				Planned	LTE-700
USA	CommNet Wireless (Navajo Nation)				Planned	LTE-700
USA	Convergence Technologies/Indiana (Rural CDMA)				Planned	LTE-700
USA	Copper Valley Telecom				**In Service Sept 2013**	LTE-700
USA	Cross Wireless/Sprocket/Oklahoma (Rural CDMA)				**In Service Nov 2012**	LTE-700

USA	Custer Telephone/Idaho (Rural CDMA)				**In Service July 2013**	LTE-700
USA	Enhanced Telecommunications Corp ETC / Indiana				**In Service Aug 2013**	LTE-700
USA	Evolved Broadband / Texas				**In Service July 2013**	LTE 700 (17) (VoLTE)
USA	Ketchikan Public Utilities KPU/Alaska				Planned 2014	LTE 700
USA	Leap Wireless/Cricket Comm. (CDMA)				**In Service Dec 2011**	LTE-1700/2100 (IV)
USA	Matanuska Telephone Association /Alaska (MTA)				**In Service July 2013**	LTE-700
USA	Mid-Rivers Communications /Montana				**In Service Dec 2013**	LTE-700
USA	Mosaic Telecom (Rural CDMA)	In Service			**In Service July 2011**	LTE 700 & 1700/2100
USA	NetAmerica Alliance (Rural operators)				In Trial	LTE 700 & 1700/2100 (IV)
USA	nTelos (CDMA)				Planned	LTE-700 (2,4,25)
USA	nTelos + Dish Network/Virginia				In Trial	LTE 700 & 1700/2100 (IV)
USA	NorthwestCell/Missouri (Rural CDMA)				**In Service May 2013**	LTE-700
USA	Nortex Communications (Texas)				**In Service Sept 2012**	LTE-700 (17)
USA	Panhandle (PTCI) Bonfire				**In Service Mar 2012**	LTE-700
USA	Penasco Valley Wireless/Fuego (Texas)				**In Service May 2013**	LTE-700
USA	Peoples & Etex Telephone Coop (Texas)	In Service			**In Service Feb 2012**	LTE-700
USA	Pioneer Cellular (OK) (Rural CDMA)				**In Service May 2012**	LTE-700
USA	Public Service Wireless (GA)				Planned	LTE-700
USA	Sagebrush/Nemont (MT, ND) (CDMA)				Planned	LTE-700
USA	Shenandoah Telecommunications (Sprint Nextel Affiliate)				**In Service Nov 2012**	LTE-700
USA	SouthernLINC				Planned 2018	
USA	S Georgia Reg. Info. Technology Authority				Planned	LTE-700

USA	SpeedConnect (Michigan (WiMAX)				Planned	
USA	Sprint & Affiliates (WiMAX)				**In Service July 2012**	LTE 850, 1900 FDD & TDD
USA	S&R Communications (Indiana)				**In Service Dec 2013**	LTE-700
USA	SRT Communications (North Dakota)				Planned	
USA	Strata Networks (Rural CDMA)				**In Service Nov 2012**	LTE-700
USA	Syringa Wireless/Idaho				**In Service Oct 2013**	LTE-700
USA	Texas Energy Network /TEN (oil & gas)				Planned	
USA	T-Mobile USA	In Service	Sep-09	42Mbps	**In Service Mar 2013**	LTE-1700/2100
USA	T-Mobile USA / Metro PCS (CDMA)				**In Service Sept 2010 VoLTE Aug 2012**	LTE-1900,2100 (IV)
USA	Thumb Cellular (Rural CDMA)				**In Service Jan 2013**	LTE-700
USA	United Wireless (CEMA)				Planned	LTE-700 (12)
USA	US Cellular/King Street Wireless				**In Service Mar 2012**	LTE 700 & 1700/2100
USA	Verizon Wireless				**In Service Dec 2010**	LTE 700 & 1700/2100
USA	Vtel Wireless				Planned	LTE-700
USA	West Central Wireless				Planned	LTE-700

Africa	Operator	HSPA (112)	HSPA+ (52)	Speed	LTE (17)	LTE Spectrum (Band)
Algeria	Algérie Télécom - Mobilis	Planned			Planned 2014	LTE-TDD
Algeria	Orascom Telecom Algeria / Djezzy	Planned				
Algeria	Nedjma / Ooredoo	In Service Dec 2013				
Angola	Movicel	In Service Dec 2010			**In Service April 2012**	LTE-1800
Angola	Unitel	In Service 2007	Jul-10	21Mbps	**In Service Dec 2012**	LTE-2100
Benin	Bell Benin Communications	Planned				
Benin	Etisalat Benin/ Moov	Planned				
Benin	Globacom / Glo Mobile Benin	Planned				
Benin	Libercom	Planned				
Benin	Spacetel Benin / MTN	In Service Dec 2012	Planned			
Botswana	Mascom Wireless	In Service Aug 2008			Pilot network Jun12	
Botswana	Orange Botswana	In Service			Planned	

		Aug 2009				
Burkina Faso	Bharti Airtel Burkina Faso	In Service	May-13	21Mbps		
Burkina Faso	Telmob Onatel	In Service	May-13	42Mbps		
Burkina Faso	Telecel	Planned				
Burundi	Lacell	Planned				
Burundi	U-COM Burundi	In Service	Oct-11	21Mbps		
Cameroon	MTN Cameroon	Planned				
Cameroon	Orange Cameroon	Planned				
Cameroon	YouMee				Planned	
Cape Verde	Cabo Verde Telecom / CVMóvel	In Service				
Cape Verde	Unitel T+	In Service	Dec-11	21Mbps		
Central African Rep.	Atlantique Cellular / Moov	Planned				
Central African Rep.	Nationlink	Planned				
Central African Rep.	Orange	In Service	Mar-13	21Mbps		
Central African Rep.	Telecel	Planned				
Chad	Bharti Airtel Chad	In Service	Oct-11	21Mbps		
Chad	Millicom / Tigo Chad	Planned				
Congo	Bharti Congo Airtel BV	In Service	Oct-11	21Mbps		
Congo	MTN Congo	Planned				
Congo	Warid Congo	Planned				
Côte D'Ivoire	Atlantique Telecom / Moov	In Service	Dec-12	21Mbps		
Côte D'Ivoire	Comium Côte D'Ivoire	Planned				
Côte D'Ivoire	MTN	In Service				
Côte D'Ivoire	Orange	In Service	Apr-12	42Mbps		
Dem. Rep. Congo	Bharti Airtel RDC	In Service	Mar-13	21Mbps		
Dem. Rep. Congo	Oasis Telecom	In Service	May-13	21Mbps		
Dem. Rep. Congo	Orange	In Service	Dec-12	21Mbps		
Dem. Rep. Congo	Smile Communications DRC				Planned	
Dem. Rep. Congo	Vodacom	In Service	Oct-12	21Mbps		
Djibouti	Djibouti Telecom / Evatis	In Service	Dec-12	21Mbps		
Egypt	ECMS / MobiNil	In Service 2008	Apr-13	42Mbps	In Trial	
Egypt	Etisalat Misr	In Service 2007	Jun-10	42Mbps	In Trial	LTE-2100
Egypt	Vodafone Egypt	In Service 2007	Oct-12	42Mbps	In Trial	
Equatorial Guinee	HiTs Telecom	In Service 2009				
Equatorial Guinee	Guineanet (WiMAX)				Planned	LTE-700
Eritrea	Eri-Tel	Planned			Planned	
Ethiopia	Ethiopian Telecom/Ethio-Mobile	In Service 2008			Planned	
Gambia	Gamcel	Planned				

Gambia	QuantumNet / Qcell	In Service 2009				
Ghana	Airtel Ghana /Bharti	In Service 2010	Jan-12	21Mbps		
Ghana	Glo Mobile Ghana	In Service 2012	Apr-12	21Mbps	Planned	
Ghana	Millicom /Tigo Ghana	In Service 2011				
Ghana	MTN Ghana	In Service 2010			Potential License	
Ghana	National Information Technology Agency (WiMAX) (NITA)				Planned	LTE-2600
Ghana	Surfline Communications				Planned Q1 2014	
Ghana	Vodafone Ghana	In Service 2011				
Guinea	Cellcom Guinée	In Service	Jan-12	21Mbps		
Guinea	Intercel Holdings	Planned				
Guinea	Investcom Guinée	Planned				
Guinea	Orange	In Service 2011				
Guinea	Sotelgui	Planned				
Guinea Bissau	Guinetel	Planned				
Guinea Bissau	Orange Bissau	Planned				
Guinea Bissau	Spacetel	Planned				
Kenya	Bharti Airtel Kenya B.V.	In Service	Feb-12	21Mbps		
Kenya	Telkom Kenya / Orange	In Service	Sep-12	42Mbps		
Kenya	Safaricom	In Service 2008	Aug-11	42Mbps	In Trial	
Lesotho	Econet Telecom Lesotho	In Service 2010				
Lesotho	Vodacom Lesotho	In Service 2009				
Liberia	Atlantic Wireless Liberia	Planned				
Liberia	Cellcom Liberia	In Service	Jun-12	21Mbps	Planned	
Liberia	Novafone Liberia (ex Comium)	In Service	Sep-13	42Mbps		
Liberia	Lonestar Comm. Corp.	Planned				
LIbya	Almadar Aljadeed	Planned			Planned	
Libya	Libyana	In Service 2009				
Madagascar	Bharti Airtel Madagascar / Airtel	In Service	Jul-12	21Mbps		
Madagascar	Blueline (WiMAX)				Pre-commercial	LTE-2300 TDD
Madagascar	Orange	Planned				
Madagascar	Telecom Malagasy / Telma	In Service 2009				
Malawi	Bharti Airtel Malawi	In Service 2010	Jul-12	21Mbps		
Malawi	Telekom Networks Malawi (TNM)	In Service				

		2009				
Mali	Alpha Telecom					
Mali	Malitel	In Service 2012				
Mali	Orange Mali	In Service 2010				
Mauritania	Chinguitel	In Service 2011				
Mauritania	Mattel	In Service 2011				
Mauritania	Mauritel Mobiles	In Service 2010				
Mauritius	Emtel Mauritius	In Service 2004			**In Service July 2012**	LTE-1800
Mauritius	Mahanagar Telephone Mauritius	Planned				
Mauritius	Orange Mauritius	In Service 2007			**In Service June 2012**	LTE-1800
Mayotte	Outremer Telecom Mayotte	In Service 2010				
Mayotte	SFR Mayotte	In Service 2011				
Morocco	Ittissalat Al-Maghrib/Maroc Telecom	In Service 2008			Potential License	
Morocco	Médi Télécom/Méditel	In Service 2007			Potential License	
Morocco	Wana/Inwi				Potential License	
Mozambique	Mocambique Celular / mCel	In Service 2008			Potential License	
Mozambique	Vodacom	In Service 2010				
Mozambique	Movitel Mozambique	In Service				
Namibia	Cell One	In Service				
Namibia	TN Mobile /Telecom Namibia / (Leo)	In Service 2007	Planned		**In Service Nov 2013**	LTE-1800 (B3)
Namibia	MTC	In Service 2006	Planned		**In Service May 2012**	LTE-1800
Niger	Bharti Airtel Niger	Planned				
Niger	Orange Niger	In Service 2011				
Niger	Sahelcom	Planned				
Niger	Telecel (Moov)	Planned				
Nigeria	Alheri Engineering Co.	In Deployment				
Nigeria	Bharti Airtel / Zain Nigeria	In Service 2009	Feb-12	42Mbps	Trial Complete	
Nigeria	CAPCOM (Starcomms, Multilinks & MTS First Wireless)				Planned	LTE-1900
Nigeria	Etilisat Nigeria (EMTS)	In Service 2009	Sep-11	42Mbps	Potential License	
Nigeria	Globacom/Glo Mobile	In Service 2008			Planned	LTE-2100
Nigeria	Mobitel (WiMAX)				Planned	LTE-2300 TDD

Nigeria	MTN Nigeria	In Service 2008			Planned	
Nigeria	Smile Communications DRC				**In Service May 2013**	LTE-800
Nigeria	Spectranet (WiMAX)				**In Service Aug 2013**	LTE-TDD 2300
Nigeria	SWIFT Networks (WiMAX)				Planned 2013	LTE-TDD 2300/3500
Nigeria	Visafone (CDMA)				Planned	
Nigeria	Zoda Fones / Megatech Engineering				Deploying	LTE-TDD 2600 (B38)
Réunion	Orange Reunion	In Service 2008	Dec-13	42Mbps		
Réunion	Outremer Telecom Reunion / Only	In Service 2008				
Réunion	SFR Reunion	In Service 2008				
Rwanda	Altech Stream Rwanda				Planned	
Rwanda	Bharti Airtel Rwanda	In Service 2012	Jul-12	21Mbps		
Rwanda	MTN Rwanda	In Service 2009	Aug-08	21Mbps		
Rwanda	Tigo Rwanda	In Service 2010				
São Tome & Principe	CST Mobicel	In Service 2012				
Senegal	Orange/Sonatel	In Service 2008			In Trial	LTE-1800
Senegal	Tigo/Sentel	In Service	Sep-13	21Mbps	In Trial	
Senegal	Expresso/Sudatel	In Service 2010			In Trial	
Seychelles	Telecom Seychelles / Airtel	In Service 2008				
Sierra Leone	Bharti Airtel Sierra Leone	In Service 2012				
Somalia	Somtel	In Service 2011				
Somalia	Hormuud Telecom (HorTel)	In Service 2013	Dec-12	21Mbps		
Somalia	Nordic Group Somalia				License Awarded	
Somalia	Telesom	In Service 2011				
South Africa	Cell C	In Service 2010	Aug-10	42Mbps	Pre-commercial	LTE-2100
South Africa	iburst South Africa (WBS)				Planned	LTE-1800, 2600
South Africa	MTN	In Service 2009	May-10	42Mbps	**In Service Dec 2012**	LTE-1800, 2100
South Africa	Neotel South Africa (CDMA)				**In Service Aug 2013**	LTE-1800
South Africa	Telkom (8ta)	In Service 2009	Jun-11	21Mbps	**In Service Apr 2013**	LTE-2300 TDD

South Africa	Vodacom	In Service 2009	Apr-11	42Mbps	**In Service Oct 2012**	LTE-1800
South Africa	WBS				Planned	
Sudan	MTN Sudan	In Service 2009				
Sudan	Sudatel (Sudan Telecom)	In Service 2009				
Sudan	Zain Sudan	In Service 2008				
Swaziland	MTN	In Service 2011			Planned 2014	
Tanzania	Bharti Airtel Tanzania	In Service 2008	Mar-12	21Mbps		
Tanzania	Rural Telco	In Service 2010				
Tanzania	SMILE				**In Service May 2012**	LTE-800 (B20)
Tanzania	Telesis Tanzania (MVNA)				Planned	
Tanzania	Tigo Tanzania	In Service 2011	May-13	42Mbps		
Tanzania	Vodacom Tanzania	In Service 2007	Oct-12	21Mbps	Planned	LTE-800, 1800
Tanzania	Zanzibar Telecom / Zantel	In Service 2011	May-12	21Mbps		
Togo	Telecel Togo	Planned				
Togo	Togo Cellulaire / TogoCel	In Service 2011	Dec-11	21Mbps		
Tunisia	Orange Tunisie	In Service 2010	Aug-10	42Mbps	Potential License	
Tunisia	Tunisiana	In Service 2012	Jul-12	42Mbps	Planned 2014-2015	
Tunisia	Tunisie Télécom	In Service 2010	Aug-11	42Mbps	Potential License	
Uganda	Bharti Airtel Uganda	In Service Aug 2012	Aug-12	21Mbps		
Uganda	MTN Uganda	In Service 2010	Mar-13	42Mbps	**In Service Apr 2013**	LTE-2600 TDD (B41)
Uganda	Orange Uganda	In Service 2009	Apr-12	21Mbps	**In Service Aug 2013**	LTE-800 (B20)
Uganda	Smile Telecom (WiMAX)				**In Service Oct 2012**	LTE-800 (B20)
Uganda	TMP Uganda				Planned	LTE-2300
Uganda	Uganda Telecom	In Service 2008				
Uganda	Warid Telecom	In Service 2011				
Zambia	Bharti Airtel Zambia	In Service 2012	Jan-12	21 Mbps		
Zambia	MTN Zambia	In Service 2011				
Zambia	Massnet				Planned	LTE-2600

Zambia	ZamTel / Cell Z	In Service 2012	May-12	21Mbps	Trail Demo Aug 13	
Zimbabwe	Aquiva (WiMAX)				Planned 2016	
Zimbabwe	Econet Wireless	In Service 2009			**In Service Aug 2013**	LTE-1800
Zimbabwe	NetOne	In Service 2011				
Zimbabwe	Telecel	In Service 2011				

Asia Pacific		**HSPA (106)**	**HSPA+ (65)**		**LTE (42)**	**LTE Spectrum (Band)**
Australia	Energy Australia				Planned	
Australia	NBN Co.				**In Service April 2012**	***LTE-2300 TDD***
Australia	Optus (SingTel)	In Service	Apr-11	21Mbps	**In Service July 2012 Testing VoLTE**	***LTE-1800, 2100 TDD***
Australia	Telstra	In Service	Feb-09	42Mbps	**In Service Sept 2011 Testing VoLTE, LTE-Advanced**	LTE- 850/1800
Australia	vividwireless (Seven Group) (WiMAX)				Planned 2014	LTE-TDD
Australia	Vodafone Hutchison (VHA)	In Service	Sep-12	42Mbps	**In Service June 2013**	LTE-1800
Bangladesh	Airtel / Warid Bangladesh	Planned			Planned 2016	
Bangladesh	Bangalink	In Service	Oct-13	21Mbps		
Bangladesh	GrameenPhone	In Service	Oct-13	21Mbps	Planned 2015	
Bangladesh	Robi Axiata Bangladesh	In Service	Oct-13	21 Mbps	Planned 2016	
Bangladesh	Teletalk	In Service	Oct-12	21Mbps	Planned 2016	
Bhutan	Bhutan Telecom / B-Mobile	In Service			**In Service Oct 2013**	LTE-1800
Bhutan	Tashi Infocomm	In Service	Dec-13	21Mbps	Planned 2016	
Brunei	B-Mobile Brunei	In Service			Planned 2015	
Brunei	DSTCom	In Service			**In Service Nov 2013**	LTE-1800
Cambodia	Alltech Telecom				Planned	
Cambodia	Cadcomms / qb	In Service			Planned 2015	
Cambodia	CamGSM/Cellcard (MobiTel)	In Service			Planned 2014	

Cambodia	CamShin / Mfone	In Service			Planned 2015	
Cambodia	Hello Axiata	In Service				
Cambodia	Smart Mobile / Latelz	In Service	Aug-11	21Mbps		
Cambodia	Viettel Cambodia / Metfone	In Service				
China	China Mobile / TD-SCDMA				**In Service Dec 18 2013 VoLTE in Trial**	LTE 2600 TDD
China	China Telecom (CDMA)				Planned 2014	
China	China Unicom	In Service	May-11	42Mbps	Planned 2014	
Cook Islanda	Telecom Cook Islands	Planned				
East Timor	Telkomcel	In Service				
East Timor	Viettel	Planned				
East Timor	Timor Telecom	In Service			Planned 2016	
Fed. St. Micronesia	FSM Telecommunications	Planned				
Fiji	Digicel Fiji	In Service			Planned 2014	LTE-700, 1800
Fiji	Telecom Fiji Limited (TFL)				Planned	LTE-700, 1800
Fiji	Vodafone Fiji	In Service			**In Service Dec 2013**	LTE-1800
French Polynesia	Mara Telecom	In Deployment			Planned 2016	
French Polynesia	Tikiphone VINI 3G	In Service			Planned 2016	
Guam	DoCoMo Pacific Guam	In Service	Nov-11	21Mbps	**In Service Oct 4, 2012**	LTE-700
Guam	iConnect Guam				**In Service Mar 2013**	LTE-700
Guam	GTA	In Service	Jul-09	21Mbps	**In Service Oct 2013**	LTE-700 AWS
Guam	IT&E Guam				**In Service July 2012**	LTE-700
Hong Kong	CSL New World	In Service	Mar-09	42Mbps	**In Service Nov 2010** LTE-Adv. planned 1Q 2014	LTE-1800 / 2600
Hong Kong	Hutchison 3 / JV Genius	In Service	Jul-09	42Mbps	**In Service May 2012**	LTE-1800/2600 FDD & TDD
Hong Kong	PCCW Mobile / JV Genius	In Service	Jun-09	42Mbps	**In Service Apr 2012**	LTE-1800 / 2600
Hong Kong	SmarTone-Vodafone	In Service	Nov-09	42Mbps	**In Service Aug 2012**	LTE-1800
Hong Kong	China Mobile Hong Kong (CMHK)				**In Service Apr 2012**	***LTE-2300/2600 FDD & TDD***

India	Aircel (Maxis)	In Service	Feb-11	21Mbps	Planned	LTE-TDD
India	Augere				Planned	
India	Bharti Airtel	In Service	Dec-10	21Mbps	**In Service April 2012**	***LTE-2300 TDD***
India	BSNL	In Service			Planned	
India	Idea Cellular	In Service	Mar-11	21Mbps		
India	MTNL	In Service			Planned	LTE-2300
India	Qualcomm India LTE Venture				Planned	
India	Reliance/Infotel Broadband	In Service	Dec-10	21Mbps	Planned	
India	Tata DoCoMo Teleservices	In Service	Nov-10	21Mbps	Planned	
India	Tikona Digital				Planned	LTE-TDD
India	Vodafone Essar	In Service	Mar-11	21Mbps	Planned	
India	Videocon				Planned	LTE-1800
Indonesia	Axis	In Service				
Indonesia	Berca Hardayaperkasa (WiMAX)				Planned	LTE-2300 TDD (40)
Indonesia	XL Axiata / Excelcomindo	In Service			Planned	
Indonesia	3 Indonesia	In Service			Planned	
Indonesia	First Media (WiMAX)				Planned	LTE-2300 TDD (40)
Indonesia	Natrindo Telepon Seluler Axis	In Service			Planned	
Indonesia	Indosat/Satelindo/Qtel	In Service	May-10	42Mbps	Planned	LTE-1800
Indonesia	Telkomsel	In Service	Nov-09	21Mbps	Planned	
Indonesia	PT Internux/BOLT (WiMAX)				**In Service Nov 2013**	LTE-2300 TDD
Japan	eAccess / emobile	In Service	Jul-09	42Mbps	**In Service Mar 2012**	LTE-1700 (9)
Japan	KDDI / au (CDMA)				**In Service Sept 2012** LTE-Adv 2014	LTE-800, 1500, 2100 (1)
Japan	NTT DoCoMo / Xi	In Service			**In Service Dec 2010** LTE-Adv 2015	LTE-2100, 1500 (21)
Japan	Softbank Mobile	In Service	Feb-11	42Mbps	**In Service Feb 2012**	***LTE-2500 FDD/TDD (1, 41)***
Japan	IIJ (Internet Initiative Japan)				Planned 2013	
Kiribati	Telecom Services Kiribati Ltd (TSKL)	Planned 2013			**In Service Sept 2013**	LTE-700 (12)
Laos	Beeline	In Service	Jan-12	21Mbps	Planned	LTE-1800, 2600
Laos	ETL	In Service				
Laos	LaoTel (LTC)	In Service			Planned 2014	
Laos	Star Telecom/Unitel	In Service			Planned 2015	
Macau	CTM (C&W)	In Service	Jan-10	21Mbps	Planned 2015	
Macau	Hutchison 3	In Service	Jul-11	21Mbps	Planned 2015	

Macau	SmarTone-Vodafone	In Service	Jul-10	21Mbps	Planned 2015	
Malaysia	Asiaspace (WiMAX)				Planned 2014	LTE-2300
Malaysia	P1				Planned	LTE-2600
Malaysia	REDtone Mobile Services				Planned	LTE-2600
Malaysia	Celcom (Axiata)	In Service	Aug-12	21Mbps	**In Service Apr 2013**	LTE-2300
Malaysia	DiGi	In Service			**In Service July 2013**	LTE-2600
Malaysia	Maxis Communications/UMTS	In Service	Jun-10	42Mbps	**In Service Jan 2013**	LTE-1800 / 2600
Malaysia	PacketOne Networks (WiMAX to TD-LTE)				Planned	LTE-2300 TDD
Malaysia	Puncak Semangat				Planned 2014	LTE-2600
Malaysia	U Mobile	In Service	Nov-10	42Mbps	**In Service Dec 2013**	LTE-2600
Malaysia	Telekom Malaysia				Planned	LTE-800
Malaysia	Y-Max				Licence Awarded	LTE-2600
Maldives	Dhiraagu	In Service	Apr-13	21Mbps	Planned 2014	
Maldives	Wataniya Maldives (Qtel)	In Service			**In Service April 2013**	LTE-2600
Mongolia	G-Mobile (CDMA)	In Service	Sep-12	42Mbps	Potential License	LTE-450
Mongolia	Mobicom	In Service				
Mongolia	Mongolia Telecom				Planned	
Mongolia	Skytel (CDMA to GSM)	In Service	Sep-10	21Mbps		
Mongolia	Ulusnet (WiMAX)				Planned	LTE-3500 TDD
Mongolia	Unitel	In Service				
Myanmar	Myanmar P&T	Planned			Planned	LTE-1800
Nepal	Ncell (TeliaSonera subsidiary)	In Service			Planned	
Nepal	Nepal Telecom	In Service			Planned	LTE-2300 TDD
New Caledonia	OPT New Caledonia	In Service				
New Zealand	2degrees Mobile	In Service	Aug-10	42Mbps		
New Zealand	Telecom NZ (CDMA to GSM)	In Service	Aug-10	42Mbps	**In Service Nov 2013**	LTE-700, 2100
New Zealand	Vodafone New Zealand	In Service	Mar-11	42Mbps	**In Service Feb 2013**	LTE-700, 1800 / 2100
Northern Marianas	iConnect Northern Marianas				Planned 2016	
Northern Marianas	DoCoMo Pacific Northern Marianas	In Service			Planned 2015	
North Korea	Koroyolink (CHEO/Orascom Telecom)	In Service				
Pakistan	PMCL / Mobilink	Planned			Planned 2014	
Pakistan	PTML	Planned				

Pakistan	Telenor	Planned			Planned 2014	
Papua New Guinea	Digicel Papua New Guinea	In Service			Planned 2016	
Philippines	Bayan Communications				Planned	LTE-1800
Philippines	Digitel/Sun Cellular	In Service				
Philippines	Globe Telecom/Tattoo	In Service	Apr-11	21Mbps	**In Service Sept 2012**	LTE-1800
Philippines	Smart Communications	In Service	Aug-11	21Mbps	**In Service Aug 2012** LTE-Adv. in Trial	LTE-850 (5), 1800 (3), 2100 (1)
Philippines	Umobile (CURE)	In Service	Mar-11	42Mbps		
Philippines	Piltel				Planned	
Samoa	BlueSky Samoa	In Service	Mar-12	21Mbps		
Samoa	Digicel	In Service	Mar-12	21Mbps		
Singapore	MobileOne/M1 3G	In Service	Jul-09	28Mbps	**In Service June 2011**	LTE-1800, 2600
Singapore	SingTel Mobile/Broadband on Mobile Prestige 75	In Service	Dec-09	21Mbps	**In Service Dec 2011**	LTE-1800, 2600
Singapore	StarHub	In Service	Mar-09	21Mbps	**In Service Sept 2012**	LTE-1800
Solomon Islands	Bemobile Solomon Islands	In Service				
Solomon Islands	Our Telekom / Solomon Telekom	In Service			Planned 2017	
South Korea	KT Corp	In Service	In Deployment		**In Service Jan 2012** **VoLTE Oct 2012** **LTE-Advanced Sep13**	LTE-1800 (3)
South Korea	LG Uplus				**In Service July 2011** **VoLTE Aug 2012** **LTE-Advanced Jul13**	LTE-850 (5), 2100 (1)
South Korea	SK Telecom	In Service	Jul-10	21Mbps	**In Service July 2011** **VoLTE Aug 2012** **LTE-Advanced Jul13**	LTE-850, 1800
Sri Lanka	3 / Hutch Lanka	In Service	Apr-12	21Mbps		
Sri Lanka	Bharti Airtel Sri Lanka	In Service	Mar-12	21Mbps		
Sri Lanka	Dialog Axiata	In Service	Apr-11	42Mbps	**In Service Jan 2013**	***LTE-1800 FDD/TDD (40)***
Sri Lanka	Etisalat Sri Lanka	In Service	Jan-11	42Mbps	Planned	LTE-2600

Sri Lanka	Lanka Bell				Planned	
Sri Lanka	Mobitel M3	In Service	Dec-12	42Mbps	**In Service Jan 2013**	LTE-1800
Taiwan	Asia Pacific Telecom				Planned	LTE-APT700
Taiwan	Chunghwa Telecom	In Service	Dec-11	21Mbps	Planned 2014	LTE-900, 1800
Taiwan	FarEasTone / China Mobile	In Service	Nov-10	42Mbps	Planned 2014	LTE APT700, 1800
Taiwan	Global Mobile (WiMAX)				Planned	
Taiwan	Hon Hai				Planned	LTE APT700, 900
Taiwan	Star Mobile				Planned	LTE-900
Taiwan	Taiwan Mobile Company	In Service	Jan-12	42Mbps	Planned 2014	LTE APT700, 1800
Taiwan	VIBO	In Service			Planned 2015	
Thailand	AIS /Digital Phone Co.	In Service	May-13	21Mbps	Planned	LTE-2300
Thailand	Trinet / DTAC /Telenor	In Service	Aug-11	42Mbps	Planned	LTE-1800
Thailand	TOT / Thai Mobile	In Service	Apr-12	42Mbps	Planned	
Thailand	True Move Corp (Hutch)	In Service	Feb-12	42Mbps	**In Service May 2013**	LTE-1800, 2100
Tonga	Digicel Tonga	Planned				
Tonga	Tonga Communications Corp.	In Service				
Vanuatu	Digicel Pacific Vanuatu	In Service			Planned 2017	
Vietnam	CMC Telecom				License Awarded	
Vietnam	EVN Telecom (E-Mobile)	In Service			License Awarded	
Vietnam	FPT Telecom				License Awarded	
Vietnam	Hutchison Vietnam/ Vietnamobile	In Service	Dec-11	21Mbps		
Vietnam	Mobifone	In Service	Apr-12	21Mbps	Planned 2016	
Vietnam	RusViet Telecom				Planned	LTE-2600
Vietnam	S-Phone	Planned				
Vietnam	Vietnam Data Communications				In Trial	
Vietnam	Viettel Vietnam	In Service	Mar-10	21Mbps	Planned 2016	
Vietnam	VinaPhone (VNPT)	In Service	Oct-12	21Mbps	Planned 2016	
Vietnam	VTC (Vietnam Multimedia Corporation) Vietnamobile	In Service	Nov-11	21Mbps	License Awarded	

Europe - Eastern		**HSPA (88)**	**HSPA+**		**LTE (39)**	**LTE Spectrum (Band)**
Abkhazia	Aquafon	In Service			In Trial	LTE-800
Albania	Albanian Mobile (AMC)	In Service	Jan-12	42Mbps	Planned 2014	
Albania	Eagle Mobile / Albtelecom	In Service	Feb-13	42Mbps	Planned 2014	
Albania	Vodafone Albania	In Service			Planned 2014	

Armenia	Armentel/Beeline	In Service			Planned	
Armenia	K-Telecom/VivaCell-MTS	In Service	Mar-11	21Mbps	**In Service Dec 2011**	LTE-2600 FDD (VoLTE)
Armenia	Karabakh Telecom	In Service				
Armenia	Orange Armenia	In Service	Jan-12	42Mbps	Planned 2014	
Azerbaijan	Azercell	In Service	Nov-11	21Mbps	**In Service June 2012**	LTE 1800
Azerbaijan	Azerfon/Nar Mobile/Vodafone	In Service			Planned 2014	
Azerbaijan	Bakcell / sur@	In Service	Nov-11	28Mbps	Planned 2014	
Azerbaijan	Sazz (Azqtel) (WiMAX)				Planned	LTE-3500 TDD (42,43)
Belarus	BeST / life:)	In Service	Jun-10	21Mbps	In Trial	LTE-2600
Belarus	Dialog (CDMA)				Planned	LTE-450
Belarus	Mobile TeleSystems /MTS	In Service	May-10	42Mbps	Planned 2014	Testing LTE-Advanced
Belarus	Velcom	In Service	Mar-10	42Mbps	Planned 2014	
Bosnia Herz.	GSM BiH	In Service			Planned 2014	
Bosnia Herz.	Mobilne Sprske (mtel)	In Service			Planned 2014	
Bulgaria	Cosmo Bulgaria Mobile/GloBul	In Service			Planned 2014	
Bulgaria	MobilTel / M-Tel	In Service	Sep-09	42Mbps	Pre-commercial	LTE-1800
Bulgaria	Vivacom	In Service	Feb-13	42Mbps	Planned 2014	
Croatia	Tele2	In Service	Dec-10	21Mbps		
Croatia	Croatian Telekom (T-Mobile) T-Hrvatski	In Service	Oct-12	21Mbps	**In Service Mar 2012**	LTE-800, 1800
Croatia	Velatel (Novi-net)				Planned	LTE-3500 TDD
Croatia	VIPnet	In Service	Dec-09	42Mbps	**In Service Mar 2012**	LTE-800, 1800
Czech Republic	Mobilkom Czech Republic				Potential License	LTE-800,1800, 2600
Czech Republic	Telefonica O2 Czech Republic	In Service	Apr-13	42Mbps	**In Service June 2012**	LTE-1800
Czech Republic	T-Mobile Czech Republic	In Service	Nov-10	42Mbps	**In Service Oct 2013**	LTE-800,1800, 2600

Czech Republic	Ufone (CDMA)				Permission Requested	LTE-450
Czech Republic	Vodafone Czech Republic	In Service	Oct-11	42Mbps	Planned 2014	LTE-900
Estonia	Elisa	In Service	Apr-10	21Mbps	**In Service Feb 2013**	LTE-800,1800, 2600
Estonia	EMT / Telia Sonera	In Service	Nov-09	21Mbps	**In Service Dec 2010**	LTE-800, 1800, 2600
Estonia	Tallinn 3G Mobile	In Service				
Estonia	Tele2	In Service			**In Service Nov 2012**	LTE-1800, 2600
Georgia	A-Mobile	In Service				
Georgia	Aquafon	In Service				
Georgia	Geocell	In Service	Jul-12	21Mbps	Planned 2013	
Georgia	Magticom	In Service	Feb-12	21Mbps	In Trial	
Hungary	Magyar Telekom (MT) (T-Mo)	In Service	Jul-11	42Mbps	**In Service Jan 2012**	LTE-1800
Hungary	Telenor Hungary	In Service	Dec-11	42Mbps	**In Service Jul 2012**	LTE-1800
Hungary	Vodafone Hungary	In Service	Feb-10	42Mbps	Planned 2013	
Kazakhstan	Altel / Kazakhtelecom (CDMA)				**In Service Dec 2012**	LTE-1800
Kazakhstan	Kcell / GSM Kazakhstan	In Service	Dec-10	42Mbps	Planned	
Kazakhstan	Beeline /Kar-Tel	In Service			Pilot Network	LTE-700
Kazakhstan	Tele2 Kazakhstan	In Service	Apr-11	21Mbps	Planned	
Kyrgyzstan	AkTel (Fonex)	Planned				
Kyrgyzstan	Katel	Planned				
Kyrgyzstan	MegaCom	In Service			Planned 2016	
Kyrgyzstan	Saima Telecom				**In Service Dec 2011**	LTE-2600
Kyrgyzstan	Sky Mobile / Beeline	In Service	Dec-10	28Mbps	Planned 2016	
Kosovo	Ipko Net	Planned			Planned 2015	LTE-2100
Kosovo	Vala	Planned			Potential License	LTE-2100
Latvia	Bité	In Service	Sep-10	21Mbps	In Trial	LTE-2600
Latvia	LMT - Latvijas Mobilais Telefons	In Service	Apr-11	42Mbps	**In Service May 2011**	LTE 1800
Latvia	Tele2	In Service	Oct-11	21Mbps	Planned	LTE-2600
Latvia	Triatel (CDMA)				In Trial	LTE-450, 800

Latvia	Telekom Baltija				Planned	LTE-2600
Lithuania	Bité	In Service	Sep-10	21Mbps	Planned	LTE-2600
Lithuania	Omnitel (TeliaSonera)	In Service	Jul-12	21Mbps	**In Service Apr 2011**	LTE-1800
Lithuania	Tele2	In Service	Mar-13	21Mbps	**In Service Mar 2013**	LTE-2600
Macedonia	ONE / Cosmofon / Telekom Slovenije)	In Service			Planned	LTE-2100
Macedonia	T-Mobile (Makedonski Telekom)	In Service			Planned	LTE-2100
Macedonia	VIP	In Service	Aug-12	21Mbps	Planned 2014	LTE-800
Moldova	InterDnestrCom (IDC)				**In Service April 2012**	LTE-800
Moldova	Mold Telecom/Unite	In Service	Mar-13	42Mbps	Planned	
Moldova	Moldcell (TeliaSonera)	In Service			**In Service Dec 2012**	LTE-2600
Moldova	Orange	In Service	Dec-09	21Mbps	**In Service Nov 2012**	LTE-2600
Montenegro	m:tel	In Service				
Montenegro	Telenor / Promonte (LTE in Cetinje)	In Service	Sep-10	21Mbps	**In Service Nov 2012**	LTE-2600
Montenegro	T-Mobile Crna Gora	In Service	Dec-10	42Mbps	**In Service Nov 2013**	LTE-2600
Montenegro	Velatel (Montenegro Connect)				Planned	LTE-3500 TDD
Poland	Aero 2 / Centernet Wrodzinie / Mobyland / Eutelia	In Service	Nov-10	28Mbps	**In Service Sept 2010**	***LTE-1800 FDD & TDD***
Poland	Milmex (WiMAX)				Planned 2014	LTE-3500 TDD
Poland	Orange Poland / PKT Centertel / Play (JV)	In Service	Oct-10	42Mbps	Planned	LTE-2600
Poland	P4 / Play	In Service	Dec-10	21Mbps	**In Service Nov 2013**	LTE-1800
Poland	Polkomtel / Plus	In Service	Jun-09	42Mbps	**In Service Sept 2012**	LTE-1800
Poland	T-Mobile / Polska Telefonia Cyfrowa / Era GSM	In Service	Sep-09	42Mbps	Planned 2014	LTE-1800

Poland	Sferia (CDMA)				Planned	LTE-850 (20)
Romania	2K Telecom				Planned 2014	LTE-2600
Romania	Cosmote (OTE)	In Service	Sep-09	42Mbps	**In Service Apr 2013**	LTE-1800
Romania	Orange Romania	In Service	Oct-11	42Mbps	**In Service Dec 2012**	LTE-1800
Romania	RCS&RDS / Digi.Mobil	In Service			Planned 2014	LTE-900
Romania	Telemobil (CDMA)	In Service	Aug-09	21Mbps	Permission Requested	LTE-450
Romania	Vodafone Romania	In Service	Mar-09	42Mbps	**In Service Nov 2012**	LTE-800, 1800, 2600
Russia	Belarusian Cloud Technologies (beCloud)				Testing LTE-Advanced	LTE-1700,1800,2500,2600
Russia	MegaFon	In Service	Sep-10	21Mbps	**In Service Sept 2012**	LTE-800 ***FDD & TDD*** *(38)*
Russia	Mobile TeleSystems /MTS	In Service	Dec-10	21Mbps	**In Service Sept 2012**	***LTE-800, 2600 FDD & TDD***
Russia	OJSC Osnova Telekom				Pre-commercial	LTE-2300
Russia	Rostelecom (WiMAX to LTE)	In Service	Nov-12	21Mbps	**In Service June 2013**	LTE-2300
Russia	Skylink (CDMA)				In Trial	LTE-450
Russia	Sibirtelecom/Svyazinvest				Planned	LTE-800, 2600
Russia	Smoltelecom				Planned	LTE-800, 2600 TDD
Russia	Tele2 Russia				In Trial	LTE 1800
Russia	Vainakh Telecom				**In Service Sept 2013**	LTE-2300 TDD (40)
Russia	VimpelCom / Beeline	In Service	Apr-12	21Mbps	**In Service May 2013**	LTE-2600
Russia	Yota Networks (WiMAX)				**In Service Jan 2012 TEST LTE-A Oct 2012**	LTE-2500, 2600
Serbia	Telekom Srbija /MT:S	In Service	Oct-12	42Mbps	Planned	
Serbia	Telenor	In Service	Jul-11	42Mbps	Planned	
Serbia	VIP Mobile	In Service	Feb-11	42Mbps		
Slovak Republic	Orange	In Service	Oct-11	42Mbps	Planned 2014	LTE-2600
Slovak Republic	Slovak Telecom / T-Mobile	In Service	Mar-11	42Mbps	**In Service Nov 2013**	LTE-1800

Slovak Republic	Telefónica O2	In Service			**In Service Aug 2012**	LTE-1800
Slovenia	Mobitel - Telekom Slovenije	In Service	Apr-10	42Mbps	**In Service Mar 2013**	LTE-800, 1800, 2600
Slovenia	Si.mobil	In Service	Dec-10	42Mbps	**In Service July 2012**	LTE-1800
Slovenia	T-2	In Service			Potential License	
Slovenia	Tus Mobil	In Service	Nov-10	21Mbps	Planned 2016	
Tadjikistan	Babilon Mobile	In Service			**In Service Sept 2012**	LTE-1800, 2100
Tadjikistan	Indigo-Somoncom /TeliaSonera	In Service			Planned 2014	
Tadjikistan	Tacom / Beeline	In Service			Planned 2015	
Tadjikistan	TT Mobile	In Service			Planned 2015	
Turkmenistan	MTS Turkmenistan /TM Cell / Altyn Asyr	In Service	Nov-10	21Mbps		
Ukraine	Life:) Astelit	Planned				
Ukraine	CDMA Ukaraine (ITC)				Potential Network	LTE-850
Ukraine	Kyivstar	Planned			Planned 2015	
Ukraine	MTS-Ukraine	Planned			Planned 2015	
Ukraine	Ukrtelecom / Utel	In Service			Planned	
Uzbekistan	Ucell/TeliaSonera	In Service	Feb-11	42Mbps	**In Service Aug 2010**	LTE-2600
Uzbekistan	Unitel LLC Beeline	In Service			Pre-commercial	LTE-2600

Western Europe		**HSPA (94)**	**HSPA+ (68)**		**LTE (62)**	**LTE Band**
Andorra	Andorra Telecom STA	In Service			Planned 2014	
Austria	A1 Telekom/Mobilkom (Telekom Austria)	In Service	Mar-09	42Mbps	**In Service Nov 2010**	LTE-2600
Austria	Hutchison 3 Austria	In Service	Aug-09	42Mbps	**In Service Nov 2011**	LTE-2600 FDD
Austria	Orange	In Service	Mar-13	42Mbps	Testing	LTE-2600

Austria	T-Mobile Austria	In Service	Jan-11	21Mbps	**In Service July 2011 VoLTE in Trial**	LTE-2600
Belgium	blite Telecom BVBA				Planned	LTE-3500 TDD (42)
Belgium	Belgacom Mobile/Proximus	In Service	Jun-13	42Mbps	**In Service Nov 2012**	LTE-1800
Belgium	KPN Group Belgium/BASE	In Service	Apr-13	42Mbps	**In Service Oct 2013**	LTE-1800
Belgium	Mobistar (France Telecom)	In Service	Dec-10	42Mbps	Planned 1Q 2014	LTE-1800, 2600
Belgium	Telenet Tecteo Bidco	Planned			Planned	LTE-1800, 2100
Cyprus	CYTA Mobile / Vodafone	In Service			Planned 2015	
Cyprus	Kibris Telsim	In Service			Planned 2015	
Cyprus	KKT Cell	In Service	Jan-13	42Mbps	Planned 2015	
Cyprus	MTN (Areeba)	In Service	Mar-12	21Mbps		
Denmark	HI3G Denmark / 3	In Service	Jun-09	21Mbps	**In Service Sept 2012**	LTE-1800, 2600
Denmark	TDC Mobil	In Service	May-10	42Mbps	**In Service Oct 2011**	LTE-2600
Denmark	Telenor	In Service	Oct-10	21Mbps	**In Service March 2013**	LTE-1800
Denmark	TeliaSonera Denmark	In Service			**In Service Dec 2010**	LTE-800,1800,2600
Faroe Islands	Faroese Telecom /Foroya Tele	In Service	Dec-10	21Mbps		
Finland	Alands Mobiltelefon	In Service				
Finland	Datame (WiMAX)				Planned	
Finland	DNA Finland/Oy	In Service	Oct-09	42Mbps	**In Service Dec 2011**	LTE-1800, 2600
Finland	Elisa	In Service	Apr-10	42Mbps	**In Service Dec 2010**	LTE-1800, 2600
Finland	TDC Song	Planned				
Finland	TeliaSonera	In Service	Oct-12	42Mbps	**In Service Nov 2010**	LTE-1800, 2600
France	Bollore (WiMAX)				Planned	LTE-3500 (42) TDD
France	Bouygues Telecom	In Service	Nov-11	42Mbps	**In Service May 2013 / Oct 2013**	LTE 1800, 2600

France	Free Mobile	In Service	Jan-12	42Mbps	**In Service Dec 2013**	LTE-2600
France	Orange France	In Service	Dec-11	42Mbps	**In Service Feb 2013**	LTE-800, 2600
France	SFR	In Service	Sep-10	42Mbps	**In Service Nov 2012**	LTE-800, 2600
Germany	E-Plus (KPN)	In Service	Dec-12	42Mbps	Planned Mar 2014	LTE-1800
Germany	Telefonica 02	In Service	Nov-09	42Mbps	**In Service July 2011 VoLTE Nov 2013**	LTE-800
Germany	T-Mobile / DeutscheTelekom	In Service	Apr-10	42Mbps	**In Service Apr 2011**	LTE-800, 1800, 2600
Germany	Vodafone D2	In Service			**In Service Dec 2010**	790-862 MHz (DigDiv) LTE-800/2600
Gibraltar	Gibtelecom (Telekom Slovenije)	In Service			Planned 2016	
Greece	Cosmote	In Service	May-09	42Mbps	**In Service Nov 2012**	LTE-1800
Greece	Vodafone / Panafone	In Service	Jul-09	42Mbps	**In Service June 2013**	LTE-1800
Greece	WIND Hellas	In Service	Jul-12	42Mbps	Planned 2015	LTE-1800
Greenland	Tele-Post Greenland	In Service			**In Service Dec 2013**	LTE-800 (20)
Guernsey	Airtel - Vodafone	In Service				
Guernsey	Sure/Cable & Wireless Guernsey	In Service				
Guernsey	JT Mobile (Guernsey Ltd.)	In Service	May-12	42Mbps		
Iceland	365 Media				Planned	LTE-800
Iceland	Iceland Telecom/Síminn	In Service			Planned	
Iceland	Nova	In Service	Aug-13	21Mbps	**In Service Apr 2013**	LTE-1800
Iceland	Vodafone /Teymi/Fjarskipti	In Service			**In Service July 2013**	LTE-800
Ireland	Hutchison 3	In Service	Mar-11	21Mbps	Planned 2014	
Ireland	Meteor Communications (eircom)	In Service			**In Service Sept 2013**	LTE-800, 1800
Ireland	O2	In Service	Nov-10	21Mbps	Planned 2014	

Ireland	Vodafone Ireland	In Service	Feb-10	42Mbps	**In Service Oct 2013**	LTE-800 (20)
Isle of Man	Sure/Cable & Wireless	In Service				
Isle of Man	Manx Telecom	In Service			In Trial	
Israel	Cellcom Israel	In Service			Planned	
Israel	Golan Mobile / Golan Telecom	In Service	May-12	42Mbps	Planned	
Israel	HOT Mobile	In Service	May-12	42Mbps	Planned	
Israel	Partner/Orange	In Service	Oct-12	42Mbps		
Israel	Pelephone (Bezeq)	In Service	May-10	42Mbps	Planned 2014	
Italy	3 Italy	In Service	Mar-12	42Mbps	**In Service Dec 2012**	LTE-1800, 2600
Italy	Telecom Italia/TIM	In Service	Jul-09	42Mbps	**In Service Nov 7, 2012**	LTE-1800
Italy	Vodafone Italia / Omnitel	In Service	Nov-10	42Mbps	**In Service Oct 30, 2012**	LTE-1800
Italy	Wind	In Service	Dec-12	42Mbps	Planned 2014	LTE-800, 2600
Jersey	JT Global	In Service	May-12	42Mbps		
Jersey	Airtel-Vodafone	In Service				
Jersey	Cable & Wireless Jersey/sure.Mobile	In Service				
Jersey	Clear Mobitel				Planned	LTE-2600
Liechtenstein	mobilkom	In Service			Planned 2013	
Liechtenstein	Orange	In Service			**In Service Sept 2013**	LTE-1800 / 2600
Liechtenstein	Tango Liechtenstein	Planned				
Luxembourg	Orange	In Service	Dec-12	42Mbps	**In Service Oct 2012**	LTE-1800
Luxembourg	Lux GSM /P&T Luxembourg	In Service	Dec-12	42Mbps	**In Service Oct 2013**	LTE-1800
Luxembourg	Tango (Belgacom)	In Service			**In Service Oct 2012**	LTE-1800
Malta	3G / Melita Mobile	In Service				
Malta	Go/MobileIsle Comm.	In Service	Mar-12	42Mbps		
Malta	Vodafone Malta	In Service	Apr-12	42Mbps	**In Service Nov 2013**	LTE-1800

Monaco	Monaco Telecom (C&W)	In Service			**In Service Sept 2013**	LTE-800, 2600
Netherlands	KPN Mobile	In Service	Feb-13	42Mbps	**In Service May 2012**	LTE-2600
Netherlands	T-Mobile Netherlands	In Service			**In Service May 2012**	LTE-2600
Netherlands	Vodafone Libertel	In Service	Jul-10	42Mbps	**In Service May 2012**	LTE-2600
Netherlands	Tele2				**In Service May 2012**	LTE-2600
Netherlands	Ziggo 4				**In Service May 2012**	LTE-2600
Norway	Tele2	In Service	Jul-11	21Mbps		
Norway	Netcom/Telia Sonera	In Service	Dec-10	42Mbps	**In Service Dec 2009**	LTE-1800 / 2600
Norway	Telenor	In Service	Dec-11	21Mbps	**In Service Oct 2012**	LTE-1800 / 2600
Portugal	Optimus Sonaecom	In Service	Aug-09	21Mbps	**In Service Mar 2012**	LTE-800, 1800, 2600
Portugal	TMN	In Service	Jun-09	21Mbps	**In Service Mar 2012**	LTE-800, 2600
Portugal	Vodafone Portugal	In Service	Jul-09	42Mbps	**In Service Mar 2012**	LTE-800, 1800, 2600
Spain	Cota / Murcia4G				**In Service Mar 2013**	***LTE-2600 TDD***
Spain	Euskaltel				Planned	LTE-2600
Spain	Jazztel				Planned	LTE-2600
Spain	ONO				Planned	LTE-2600
Spain	Orange	In Service			**In Service July 2013**	LTE-1800 / 2600
Spain	Telecable de Asturias SAU				Planned	LTE-2600
Spain	Telecom Castilla La Mancha				Planned	LTE-2600
Spain	Telefónica Móviles/Movistar	In Service	Nov-09	42Mbps	**In Service Sept 2013**	LTE-2600
Spain	Vodafone Espana	In Service	Dec-09	42Mbps	**In Service May 2013**	LTE-1800, 2600
Spain	Yoigo	In Service	Feb-12	21Mbps	**In Service July 2013**	LTE-1800
Sweden	HI3G/3 Sweden	In Service	Jun-09	42Mbps	**In Service Apr 2012**	***LTE 800,2600 FDD & TDD***
Sweden	TeleNor /Net4Mobility	In Service	Jun-09	42Mbps	**In Service Nov 2010**	LTE 800, 900, 2600
Sweden	Tele2 /Net4Mobility	In Service	Jun-09	21Mbps	**In Service Nov 2010**	
Sweden	TeliaSonera Sweden	In Service	Jun-09	21Mbps	**In Service Dec 2009**	LTE 800, 1800, 2600

Switzerland	Orange Switzerland	In Service	Nov-11	42Mbps	**In Service May 2013**	LTE 800, 1800, 2600
Switzerland	Swisscom Mobile/Natel	In Service	Oct-09	42Mbps	**In Service Nov 2012**	LTE 800, 1800, 2600
Switzerland	TDC Switzerland/sunrise	In Service	Dec-11	42Mbps	**In Service June 2013**	LTE 800, 1800, 2600
Turkey	AVEA	In Service	Jul-09	42Mbps	Planned 2016	LTE-2600
Turkey	Turkcell	In Service	Jul-09	42Mbps	Planned 2016	LTE-2600
Turkey	Vodafone	In Service	Jul-09	21Mbps	Planned 2016	LTE-2600
UK	EE/ Everything Everywhere /(Orange + T-Mobile)	In Service	Oct-12	42Mbps	**In Service Oct 2012** **LTE-Advanced Nov13**	LTE-1800
UK	Hutchison 3G / 3 UK	In Service	May-11	42Mbps	**In Service Dec 2013**	LTE- 800, 1800
UK	O2 (Telefonica)	In Service	Dec-12	21Mbps	**In Service Aug 2013**	LTE-800
UK	UKB / UK Broadband (Wholesale)				**In Service June 2012**	***LTE-3500 TDD***
UK	Vodafone	In Service			**In Service Aug 2013**	LTE-800, 2600

Middle East		**HSPA (26)**	**HSPA+ (20)**		**LTE (18)**	**LTE Band**
Afghanistan	Afghan Wireless/AWCC	Planned				
Afghanistan	Etisalat Afghanistan	In Service	Mar-12	21Mbps		
Afghanistan	MTN Afghanistan	In Service				
Afghanistan	Roshan (Telecom Dev. Comp) 3G Jahaan	In Service				
Bahrain	Batelco	In Service	Apr-10	42Mbps	**In Service Feb 2013**	LTE-900,1800, 2100
Bahrain	Menatelecom (WiMAX)				**In Service Dec 2013**	LTE-TDD
Bahrain	STC / Viva Bahrain	In Service	Mar-10	42Mbps	**In Service Jan 2012**	LTE-900,1800, 2100
Bahrain	Zain	In Service	Planned		**In Service Apr 2013**	LTE-900,1800, 2100
Iran	MTCE	Planned				
Iran	MTN Irancell	Planned				
Iran	Tamin Telecom / RighTel	In Service 2012	Feb-12	42Mbps		
Iran	TCI	Planned				
Iraq	SanaTel	Planned				
Iraq	Asiacell	Planned				
Iraq	Korek Telecom	Planned				
Iraq	MaxyTel				Planned	LTE-TDD

Iraq	Regional Telecom / Fastlink				**In Service June 2013**	LTE-2600
Iraq	Zain Iraq	Planned				
Jordan	Orange Jordan	In Service	Mar-11	21Mbps	Planned 2014	
Jordan	Umniah	In Service	Jun-12	42Mbps	Trials Complete	
Jordan	Zain Jordan	In Service	Mar-11	21Mbps	Planned 2015	LTE-2600
Kuwait	Kuwait Telecom Company/VIVA	In Service	Sep-09	42Mbps	**In Service Dec 2011**	LTE-1800, LTE-Adv. Trial
Kuwait	Wataniya Telecom	In Service			**In Service July 2013**	LTE-1800
Kuwait	Zain	In Service	Aug-09	21Mbps	**In Service Nov 2012**	LTE-1800
Lebanon	Alfa Telecom	In Service	Oct-12	21Mbps	**In Service May 2013**	LTE-800, 2600
Lebanon	LibanCell/MTC Touch	In Service	Sep-11	21Mbps	**In Service May 2013**	LTE-800, 1800
Oman	Nawras	In Service	Mar-13	42Mbps	**In Service Feb 2013**	LTE-1800,2300 TDD
Oman	Omantel/Oman Mobile	In Service	Sep-11	21Mbps	**In Service July 2012**	***LTE-1800,2300 FDD/TDD***
Palestine	Palestine Cellular	Planned				
Qatar	Ooredoo (Qatar Telecom)	In Service	Aug-10	21Mbps	**In Service Apr 2013**	LTE-800, 2600
Qatar	Vodafone	In Service			Planned 2013	LTE-800
Saudi Arabia	Etihad Etisalat/Mobily	In Service	Jan-10	21Mbps	**In Service Sept 2011**	***LTE-2600 TDD***
Saudi Arabia	Saudi Telecom Company / Al-Jawwal	In Service	Sep-09	42Mbps	**In Service Sept 2011**	***LTE-1800/2300 FDD & TDD***
Saudi Arabia	Zain	In Service	Dec-09	21Mbps	**In Service Sept 2011**	LTE-1800
Syria	MTN Syria	In Service				
Syria	Syriatel	In Service	Jun-13	21Mbps		
UAE	du	In Service	Mar-10	42Mbps	**In Service June 2012**	LTE-1800
UAE	Etisalat	In Service	Jan-10	42Mbps	**In Service Sept 2011**	LTE-1800, 2600
Yemen	MTN	Planned				
Yemen	Unitel	Planned				
Yemen	Yemen Mobile	Planned				

APPENDIX C: MEMBER PROGRESS

ALCATEL-LUCENT

Alcatel-Lucent is an industry leader in delivering LTE infrastructure to operators who want quality and experience while being able to get to market quickly. As a key component of the Ultra Broadband strategy, Alcatel-Lucent's Wireless Products and Services bring the experience of mobile broadband close to consumers. Alcatel-Lucent's LTE overlay approach allows operators to get to market faster and to full scale more quickly than traditional options. Coupled with small cells which add capacity to form high-performance Heterogeneous Networks, Alcatel-Lucent is helping mobile service providers quickly and decisively deliver the service users crave to the locations they need it.

Alcatel-Lucent has built the world's largest 4G LTE networks in the busiest cities in record time. Their Wireless IP solutions and lightRadio™ Network portfolio can help to deliver capacity and performance for today's needs and into the future—a future that will see traffic demand multiply by a factor of 25 over the next 5 years, according to Bell Labs research. The Alcatel-Lucent lightRadio Network is a world-class Mobile Broadband architecture that includes base stations and small cells including metro, enterprise, and residential, and is designed for flexibility, speed to market and high capacity. The end-to-end LTE solution also includes mobile backhaul, wireless transport, an IP Packet Core, VoLTE and IMS solutions, as well as Alcatel-Lucent's professional services and software expertise.

With time-to-market an important element in operators' LTE deployment strategies, Alcatel-Lucent's overlay solution and services expertise, proven methodologies and tools for planning, deployment, optimization and operations ensure our customers get to market faster. Our global experts bring both the radio and IP networking expertise required for LTE and metro cell introduction. And our world class design and RF optimization experts consistently deliver the best network performance, translating into top speed and reliability statistics.

Alcatel-Lucent has supported over 300 wireless networks including over 40 LTE and more than 50 small cell commercial deployments. They are 8th in the top 10 global mobile operator networks and are a major supplier in the two largest LTE deployments occurring in 2013 with Sprint and China Mobile. In addition, Alcatel-Lucent supports more than 200 operators with their Mobile Backhaul and Transport solutions. Recent contracts and innovations in 2013 include:

- Alcatel-Lucent and CNT deploy Ecuador's first 4G LTE ultra-broadband network
- Telefónica in Germany to deploy Alcatel-Lucent femtocells to boost mobile broadband indoor coverage for business customers
- Telefonica selects Alcatel-Lucent to supply ultra-broadband 4G LTE communications in Spain
- Alcatel-Lucent and Qualcomm Technologies plan to develop next-generation of small cells for ultra-broadband wireless access
- Surfline Communications Ltd deploy first 4G LTE network in West and Central Africa with Alcatel-Lucent
- Alcatel-Lucent small cells technology to boost mobile wireless enterprise services for Bouygues Telecom
- China Mobile providing live TD-LTE coverage at Mobile Asia Expo using Alcatel-Lucent's lightRadio™ Metro Radio
- Regional Telecom and Alcatel-Lucent launch Iraq's first 4G LTE network
- Verizon Wireless to introduce 4G LTE small cells with Alcatel-Lucent equipment
- Alcatel-Lucent and Iraq's Regional Telecom to bring lightning-fast Internet access to the country with its first 4G LTE wireless broadband network

- Etisalat Group signs 4G LTE agreements including Sri Lanka with Alcatel-Lucent
- Spanish cable operator ‘R’ trials innovative 4G services in Galicia using LTE solution from Alcatel-Lucent
- nTelos Wireless to launch regional 4G LTE services in US states of Virginia and West Virginia during 2013 using Alcatel-Lucent technology

AT&T

AT&T Inc. is a premier communications holding company and one of the most honored companies in the world. Its subsidiaries and affiliates – AT&T operating companies – are the providers of AT&T services in the United States and internationally. With a powerful array of network resources that includes the nation’s fastest and most reliable 4G LTE network, AT&T is a leading provider of wireless, Wi-Fi, high speed Internet, voice and cloud-based services. A leader in mobile Internet, AT&T also offers the best wireless coverage worldwide of any U.S. carrier, offering the most wireless phones that work in the most countries. It also offers advanced TV service with the AT&T U-verse® brand. The company’s suite of IP-based business communications services is one of the most advanced in the world.

AT&T's wireless network is based on the 3rd Generation Partnership Project (3GPP) family of technologies that includes LTE and HSPA+ mobile broadband as well as GSM and UMTS voice. GSM is the most open and widely-used wireless network platforms in the world. This means that AT&T customers benefit from broader global roaming capability, more efficient research and development, the best options in cutting-edge devices, and smoother evolution to newer technologies.

The GSM/UMTS platform enables continued enhancement of mobile broadband speeds as AT&T evolves to the next generation of technologies.

AT&T is building its network for speed and performance. Network radio components are placed near the top of the antenna which minimizes power loss. This translates into fast speeds and great reliability across AT&T’s 4G LTE network. The network also is designed with its core elements distributed across the country, meaning data traffic gets on the Internet faster, which increases mobile data speeds.

Over the past six years (2007-2012), AT&T invested more than $116 billion into its wireless and wireline networks across the country. AT&T has invested more capital into the U.S. economy than any other public company over this time period. In a September 2013 report, the Progressive Policy Institute ranked AT&T No. 1 on its list of U.S. “Investment Heroes.”

These advancements, when combined with an ongoing initiative to increase the number of high-speed backhaul connections to cell sites, are a part of AT&T’s strategy to provide customers with an enhanced mobile broadband experience, both today and in the future. As of summer of 2013, more than 90 percent of AT&T data traffic was being handled through cell sites with these enhanced, high-speed backhaul connections.

AT&T’s mobility network is also LTE-Advanced ready. They plan to implement a variety of LTE-Advanced features on portions of their network over the next several years to take full advantage of its rich functionality. These features include carrier aggregation, high-order MIMO and self-optimizing networks, to name a few.

CISCO

Cisco is a leading enabler of the next-generation mobile Internet. Mobility is an essential aspect of life for much of the world’s developed population. Cisco hardware, software and service offerings are used to create mobile Internet solutions that allow individuals, companies and countries to increase productivity, improve customer satisfaction and strengthen competitive advantage.

Cisco’s market presence is the culmination of the combination of a deep understanding of the mobile packet core and Cisco’s global scale and leadership in Internet Protocol (IP) networks. Combining Cisco’s video and IP market leadership, accelerated investment and market-leading mobile packet core solutions, creates a portfolio of products that addresses the needs of next-generation mobile IP networks to help offer rich, quality, multimedia experiences to mobile users on 3GPP based 3G and 4G networks. It enables Cisco service provider customers to efficiently launch new advanced mobile Internet services and applications with the reassurance that our combined heritage, culture and expertise, coupled with our global market presence, address our service provider customers' needs today and into the future.

Cisco is widely recognized as a leader in the mobile broadband IP core network, resulting in a large customer base worldwide, including the most ambitious LTE players in the U.S. Outside the U.S., Cisco mobile packet core leadership includes references with the world's most prominent service providers.

The Cisco ASR 5000 Series is a field proven, high-performance suite of platforms that have been deployed in more than 300 service providers' networks across the globe and in the most demanding environments. The Cisco ASR 5000 Series provides market-leading performance on all axes, such as signaling, throughput and subscriber density, and its versatility, or ability to integrate multiple functions on the same physical chassis, makes it the ideal platform suite for combined 2G, 3G and 4G deployments for small-to-large service providers. Cisco ASR 5000 Series supports 3G mobile networks today, and through software upgrades, supports 4G functionality without a forklift upgrade.

Cisco utilizes a simple, flexible distributed architecture that allows its solution to support multiple access technologies concurrently (e.g., 2G, 3G and 4G), subscriber mobility management and call control capabilities, integrated intelligent In-line Services with policy enforcement, integrated policy control, and high availability and geographic redundancy.

Cisco Mobile Packet Core Highlights

- Cisco ASR 5000 Series has been deployed by more than 300 service providers in more than 100 countries.
- More than 1 billion users are served by Cisco ASR 5000 Series.
- Cisco has earned the no. 1 market share for mobile packet core (MPC) and evolved packet core (EPC) products, according ACG Research.
- The Cisco ASR 5000 Series powers nearly 60 percent of the all world's LTE connections.
- 60 LTE deployments by service providers around the world are enabled by Cisco ASR 5000 Series.
- Cisco ASR 5000 Series' service provider customers include Verizon Wireless, ATT, China Telecom, Sprint, KDDI, Vodafone Netherlands, Vodafone Hutchinson, Bharti Airtel, Reliance Communications, Vodafone Germany, Turkcell, T-Mobile Czech, Vodafone Hungary, VimpelCom, SFR, Cricket, Bouygues, Telenor Norway, Vodafone Spain, Bell Mobility, MegaFon, Portugal Telecom, Magyar Telekom, dU and Telekom Austria Group.
- Cisco delivered the industry's first elastic packet core solution via Cisco ASR 5500. The Cisco ASR 5500 integrates signaling, data, in-line services, policy and charging control within a single platform.
- The Cisco ASR 5500 offers unmatched total cost of ownership (TCO) according to ACG Research.

Cisco Quantum is an integrated suite of network management tools allowing service providers to efficiently and effectively monetize and optimize their mobile networks in the face of ever-increasing demands.

- Quantum Policy Suite provides next-gen policy management to deliver customized user experiences.
- Quantum Analytics Suite provides business and network analytics to help enable real-time and near real-time decision making.
- Quantum Self-Optimizing Networks provide real-time intelligence into the Radio Access Network (RAN) for optimized performance.

- Quantum WAN Orchestration provides capacity/traffic management improving network economics.

The Cisco Quantum solution allows for increased service velocity, quickly facilitating multiple service scenarios, while also providing a platform for application developers to take full advantage of the mobile Internet network. The Cisco Quantum solution focuses on simple access to, and correlation of, intelligence from various points of the network for better monetization and optimization, and enhanced user experience as a result leveraging many of the 3GPP based SON solutions such as:

APO-U – Automatic Parameters Optimization for UMTS RAN networks - includes a powerful set of self-organization applications aimed to reducing various operational tasks' duration and eliminating network performance degradations, which are common to such operations.

ANR-U – Automatic Neighbors Relations for UMTS RAN networks - a powerful tool to lower dropped call rates, improve radio frequency quality in a cell area and maximize utilization of RAN resources.

DLB-U – Dynamic Load Balancing for UMTS RAN networks - provides near-real-time response to rapidly changing and unpredictable load demands on the network. The dynamic load balancing application modifies the radio frequency (RF) footprint of the loaded and surrounding cells in real time to fit the current usage demand and match the subscriber distribution to the available resources. Using RF shaping, increases efficiency of the network and utilization of existing infrastructure.

ICLB-U – Inter Carrier Load Balancing for UMTS RAN networks - provides a near-real time response to the unpredictable load challenges on the network using carrier re-selection to balance the most congested radio resource across all the different carriers.

MEH-U – Mass Events Handling for UMTS RAN networks - a real-time SON product that optimizes the RAN in a venue where a mass event, characterized by a large gathering of users, creates heavy volume of traffic in a small area with major changes in traffic on the scale of minutes.

APO-L – Automatic Parameters Organization for LTE RAN networks - identifies new LTE cells added to the network and creates the inter-technology (iRAT) relations between LTE and UMTS cells to allow optimal iRAT handover where required. APO-L also configures other parameters based on operator's policy profiles and to allow minimum errors, follows the configurations with periodic validity verification and enforcement.

Cisco Quantum Highlights

- Cisco Quantum is deployed in the AT&T network optimizing its UMTS RAN. In 2012, Cisco expanded its SON solution in AT&T to include LTE supporting products. Also in 2012, two other tier 1 service providers deployed the Cisco Quantum SON portfolio in their mobile Internet networks.
- At the end of 2012, Cisco Quantum is covering and optimizing nearly 800,000 sector-cells from a number of RAN equipment vendors.
- Cisco Quantum was also tested by five additional service providers with networks covering an additional 150,000 sector-cells. These trials are planned for commercial deployment during 2013.

Cisco Small Cell Solutions complement the aforementioned core network solutions, offering a full range of small cell solutions. Cisco defines small cells to encompass the full range of Wi-Fi, 3G and 4G/LTE access technologies. To simplify and ease customer deployment and integration, the Cisco Service Provider Wi-Fi (SP Wi-Fi) solution and Cisco Small Cell Licensed Radio (SCLR) solution are offered to accommodate the variety of needs of the cable and mobile service provider's mobile Internet network.

Each network is built on the same mobile Internet solution framework in order for a service provider to implement appropriate licensed radio access elements. Incorporated in each solution is proven integration and optional delivery of wired and wireless backhaul that are essential for RANs to be rapidly deployed across large geographies. Three key components that exist in the Cisco Small Cell solution are the Small cell base stations, Aggregating RAN gateways and RAN Management System.

The Cisco Universal Small Cell (USC) series of products are specially designed, cost-optimized, compact 3GPP compliant base stations designed to meet the needs of various end-user market segments. The Cisco USC delivers 3G, 4G, 3G+Wi-Fi, 3G+4G and is developing 3G+4G+Wi-Fi offers. These Cisco USC base stations target segments that span both indoor and outdoor deployments and support use cases per market segment requirements. Every Cisco USC small cell contains the Cisco distributed Self-Organizing Network (dSON) technology for simplification of the small cell deployment and macro network coexistence.

The Cisco dSON components and algorithms are field proven with large volumes of deployed base stations co-existing properly with the macro-network, simplifying complex configuration including neighbor list management for handover optimization, handling large numbers of users and complex call models. For Wi-Fi elements, the Cisco USC components are combined with the Cisco SP Wi-Fi solution.

The aggregating RAN gateway is the Cisco HNB-GW (Home NodeB Gateway) for 3G deployments, the Cisco HeNB-GW (Home eNodeB Gateway) for LTE deployments and the SP Wi-Fi Gateway for unlicensed radio deployments. These 3GPP standards compliant network elements exist as software configurations on the Cisco ASR 5000 Series. The Cisco HeNB-GW elements aggregate the high-volumes of small cell base stations and shield the core network from excessive signaling loads, mobility events and complex configurations necessary for mobility management. Security of the core network is assured since the Cisco HeNB-GW includes a Cisco Security Gateway to aggregate high-fan-out of IPSec tunnels to each small cell. For SP Wi-Fi, the Cisco ASR 5000 Series is used as the 3GPP standards-based anchor service node and entry gateway to the service provider's network.

The Cisco Universal Small Cell RAN management system (RMS) is a complementary operational support system suite to enable rapid small cell deployment and small cell system management. The Cisco Universal Small Cell RAN Management System solution enables a base station to configure via out-of-band secure link that scales with the volumes of small cells deployed.

The Cisco Universal Small Cell RAN Management System solution extends the standards based HMS (or TR-069 configuration server) with components to interact with the gateway for service management, to the higher layers within the service providers' operational support system for simple network activation and device/service management and to the adjacent element management system for traditional network management services used by the service provider network operations departments.

The Cisco Universal Small Cell RAN Management System also allows for true "zero-touch" deployment without a specialized technician at each deployment site. The Cisco USC CloudBase allows cloud delivery of 3G SW and parameters. The Cisco USC CloudBase facilitates the service provider's ability to simplify the complete supply chain, reduce deployment cost, recover from faults and secure the end-points.

Cisco Small Cell Highlights

- Cisco Small Cell solutions have been deployed in more than 200 service provider's networks including Cox Communications, Time-Warner Cable, Comcast, Telkom PT, BT, T-Mobile and large public space venues such as airports, stadium, shopping malls and convention centers.

- Cisco has enjoyed global success with licensed radio deployments and has more than 20 customers via our direct and OEM channel partners NEC and NSN.

- Notable deployments are the world's largest Iuh network with AT&T in the USA with more than one million deployed units, SFR in France and SoftBank Mobile in Japan.

- Cisco addresses all the key small cell markets and segments including the Cisco USC 9000 for outdoor, Cisco USC 7000 for public space/venue, Cisco USC 5000 for enterprise and Cisco USC 3000 for home and SoHo markets.
- The Cisco USC 5310 is offered as a unique “3G module” for the Cisco award-winning Aironet Access Point 3600 to upgrade and include 3G capability without additional site, power and backhaul upgrades, thus reducing the cost of creating 3G overlays.
- Cisco RAN gateways power the world’s first LTE small cell deployments in Korea.

COMMSCOPE

For the carrier market, ***CommScope**,* through its Andrew Solutions portfolio, is a global leader for wireless network infrastructure, including all the integral building blocks for base station sites such as air interface access (antennas), RF conditioning (filters, amplifiers and diplexers), air interface backhaul, installation (mounts and towers), design and installation services, inter-connectivity (feeder cabling), energy conservation, power and power backup, and monitoring and control. CommScope is also a leading global provider of solutions that enhance and extend coverage, capacity and energy-efficiency of wireless networks and network planning and optimization products and services. They are a leader in integrated outdoor electronics, power and power backup solutions for both wired and wireless networks.

CommScope’s solutions address all areas of RF path and coverage needs for UMTS and LTE. The company’s RF solutions enable operators to synchronize investments with revenue using scalable deployment strategies and technologies, accelerate payback by expanding macro and small cell coverage effectively and manage coverage, capacity and interference in key areas such as urban settings, indoors and along transportation corridors.

CommScope products support current 3GPP releases and product roadmaps and will continue to be developed to ensure future compliance to 3GPP specifications. CommScope solutions specifically address the unique needs of wireless operators deploying UMTS/LTE networks in the following ways:

Rapid development of a focused outdoor UMTS-LTE footprint – In 2013, CommScope introduced a family of equipment-integrated, factory-tested, modular solutions called Metro Cell Concealment Solutions to help operators as they offload macro network traffic onto smaller, denser cell sites, particularly in congested urban areas to address surging mobile data consumption rates. In addition, CommScope accelerates dense urban builds with small footprint rooftop deployments, supplements macro coverage with microcell-based capacity for outdoor hotspots, simplifies greenfield site builds with kits and bundles, and broadens effective cell coverage with tower-mounted amplifiers, multi-carrier power amplifiers and Node-based interference cancelling repeaters. CommScope provides turnkey coverage and distributed capacity for outdoor venues such as urban streets, urban canyons, road tunnels and railways with multi-operator, multi-standard ION® optical distribution networks and RADIAX® radiating cable.

The Andrew SiteRise® tower solution, also introduced in 2013, is believed to be the world’s first pre-assembled tower top for remote radio unit site architectures. Andrew SiteRise provides pre-assembly and pre-testing of all RF equipment prior to hoisting up the tower. Through this unique approach to site construction, Andrew SiteRise offers standardization that will improve installation quality and on-going network performance and reduce deployment times.

HELIAX® 3.0 cable and connector products—including FiberFeed® hybrid power and fiber optic cable—have best-in-class RF performance coupled with ease of deployment. The FTTA Turnkey Solution™, introduced in 2013, standardizes remote radio unit (RRU) installation while bringing simplicity, consistency and performance assurance to a technologically and logistically complex application. The FTTA Turnkey Solution enables wireless operators to create and maintain a future-ready wireless network that can be implemented with any major radio technology. It is a comprehensive, flexible platform capable of supporting multiple RF technologies and frequencies while boosting network capacity.

CommScope also innovates at the top of the tower to help operators maximize efficiency, coverage and spectrum usage in their networks through the concept of sector sculpting, a creative approach to antenna pattern shaping that carves out more capacity, improves coverage and limits interference. Sector sculpting boosts network performance and better controls interference between sectors while increasing the number of accessible subscriber channels. These sector sculpting antennas can radiate multiple, tightly defined RF patterns from one antenna unit. For example, the Six Sector Solution, introduced in 2013, is a comprehensive antenna solution that enables wireless operators to significantly increase capacity at the cell site. It utilizes advanced antenna technology that can make site acquisition and installation easier by enabling the use of three antennas where six were previously needed. Implementation of the Six Sector Solution provides almost twice the capacity, increases the gain of each sector by 3 dB for better building penetration and mitigates interference for higher data throughput.

Other Andrew sector sculpting offerings include the Five Beam, 18-Beam, UltraBand™ and SmartBeam® base station antennas. In addition, the Andrew Sentinel™ microwave backhaul antenna uses a similar pattern shaping approach to boost capacity between microwave links.

Cost-effective capacity and coverage – CommScope also helps operators extend the reach and capacity of networks with its ION distributed antenna system (DAS), which distributes coverage and capacity in a cost-effective, homogenous, future proof fashion. The ION-U system, introduced in 2013, features integrated guidance and intelligence, enabling wireless network operators to design, plan, deploy and optimize a DAS more quickly and efficiently and at a lower total cost of ownership. The Node A indoor or outdoor all-digital repeater provides a low cost coverage extension solution, supporting up to four simultaneous frequency bands in 400, 700, 800, 850, 900, 1700, 1800, 1900, 2100 or 2600 MHz.

Energy and Environment – CommScope's energy conservation initiative supports the industry's global efforts in reducing power consumption, greenhouse gas emissions and operating costs. To achieve many of these "green" goals, wireless operators can invest in clean and reliable backup power generators, amplifier upgrades, shelter cooling and hybrid cooling systems through CommScope's initiative. It is estimated that the operation of telecommunications networks is responsible for 0.5 percent of all carbon dioxide emissions worldwide. CommScope believes that its energy solutions can help wireless operators save an average of $5,000 per site and per year on energy consumption.

ERICSSON

Ericsson is a world-leading provider of communications technology and services. They enable the Networked Society with efficient real-time solutions that allow us all to study, work and live our lives more freely, in sustainable societies around the world.

Ericsson offers services, software and infrastructure within Information and Communications Technology for telecom operators and other industries. Today, 40 percent of the world's mobile traffic goes through Ericsson networks which services more than 2.5 billion subscriptions.

Ericsson is a company with more than 110,000 employees working with customers in more than 180 countries. Founded in 1876, Ericsson is headquartered in Stockholm, Sweden. In 2012, the company's net sales were SEK 227.8 billion (USD 33.8 billion).

Ericsson is the world's leading provider of technology and services to telecom operators. They are the leader in 2G, 3G and 4G mobile technologies, providing support for networks with over 2 billion subscribers and demonstrating a leadership position in managed services.

- An important key to the quick deployment potential of commercial LTE networks is Ericsson's Self Organizing Networks (SON) solution, offering customers standardized "plug and play" networks with a high degree of automation, saving time and improving performance.

- Ericsson has signed LTE contracts with nine of the top ten ranked operators by global revenue 2012. A number of these contracts include radio access, evolved packet core and mobile backhaul and VoLTE.

- Ericsson continues its leadership in the Magic Quadrant for LTE Infrastructure 2013 according to Gartner, Inc., the world's leading information technology research and advisory company. Ericsson was named a leader for a 4th year in a row in the Gartner Magic Quadrant report for LTE Network Infrastructure in August 2013.

- Ericsson is the undisputed leader in development and standardization of LTE and offers end-to-end networks with superior performance when it comes to stability, throughput, and latency – the most important key factors for end-users of LTE.

- Ericsson has had the highest impact on the released LTE specification and expects to hold 25 percent of all essential patents in LTE.

- Ericsson is the global leader in telecom services and has won the world's first Managed Services deal for LTE.

- Ericsson's core network solutions include industry-leading soft switches, IP infrastructure for edge and core routing (Ericsson's Smart Service Routers), IP-based Multimedia Subsystem (IMS) and gateways. GSM and WCDMA/HSPA share a common core network, therefore; operators' previous investments are preserved as they migrate from voice-centric to multimedia networks. Ericsson's switching products have industry-leading scalability and capacity.

- Ericsson's MINI-LINK microwave system is one of the world's most widely deployed mobile backhaul solutions. Transport networks (e.g. MINI-LINK and metro optical networks) are essential elements of our end-to-end solutions.

GEMALTO

Gemalto: Leveraging on strong investments and powerful R&D expertise, Gemalto is the indisputable leader on HTTP-enabled OTA platforms. This market acceptance is highlighted with:

- A field proven experience with 230 OTA platforms deployed worldwide.

- A long story of award recognition from the early start of LTE.

A total of 6 LTE awards from LTE World:, "*Best Contribution to R&D for LTE*", "*Best contribution to LTE standards*", "*Best enabling technology*", "*Most Innovative Network Deployment*", "*Most innovative LTE Application / Service"* and *"Best LTE Security product*" from LTE Telecom Awards 2013.

The wireless ecosystem is changing and becoming ever more open and connected. Mobile network operators (MNOs) need to dynamically manage devices, UICCs and secure elements across all networks, including 2G, 3G, 4G, Wi-FI and CDMA, to guarantee the best end-user experience and enable new high-potential use cases such as M2M, NFC and multimedia.

To respond to the changing needs of mobile network operators, Gemalto has developed the Gemalto's Advanced Connectivity Offer, which includes the *LinqUs™ Advanced OTA* platform and the *UpTeq™ LTE* UICC. This offer enables MNOs to become more efficient and to offer a wider range of innovative services to their customers:

- Deploy NFC applications and ensure mobile applications such as mobile payment, loyalty and transport really take off thanks to the security and large update capabilities of the Advanced Connectivity Offer. Gemalto is uniquely positioned to successfully support our customers with NFC initiatives. Gemalto's unmatched track record includes more than 50 major NFC projects worldwide with many of the world's leading MNOs, banks and Service Providers, including all commercial NFC deployments worldwide in 2011 and 2012.

- Manage subscriptions and securely deliver and activate subscriptions on demand, in an optimized way to address mobile broadband consumer devices and the emerging M2M market.

- Deploy multimedia services and allow seamless activation of ISIMs for automatic and secured access to IMS networks, easy identification for video calls, VoIP or new use cases such as multiple multimedia identities.

- Optimize networks with end-user Quality of Experience (QoE) measurement, enable national network offloading to Wi-Fi and femtocell and ensure service continuity in roaming situations.

The *LinQus™ Advanced OTA* is the result of Gemalto's years of experience and world leadership in OTA platforms. It embeds advanced technology and features, such as:

- Security: with HTTPS, PSK/TLS and Global Platform SCP03, all sensitive information can be protected with the upmost level of security.

- Polling: with the polling feature, the UICC is always up to date without performing any campaigns—the card initiates its own update when it is appropriate.

- LTE ready: with the HTTP support, it is now possible to download large applications, maximize download efficiency and address IP only devices.

- Architecture: with the latest software technologies, the *LinQus™* Advanced OTA is easily scalable to adapt to the investment as performances grow, and to enable efficient and reliable architecture (Geo Active High Availability solution).

The carrier grade efficiency of the *LinqUs™ Advanced OTA* has already been field-proven through a number of high-profile commercial LTE deployments, notably with Verizon Wireless, Sprint, US Cellular, Cricket and Metro PCS in the U.S., and as of September 2013, in a SaaS mode (Software as a Service) with US Operator Nex-Tech Wireless.

On the top of Gemalto's Advanced Connectivity Offer, the following modules can be deployed to take advantage of the strength of the OTA stack:

- MNO-TSM module, called the Business Enabler, automates and simplifies the whole process of implementing partnerships with different service providers via their preferred SP-TSM. It provides a secure channel between partners and mobile subscribers over which the operator has full control to deploy third-party NFC-applications on the secure element.

- Advanced Subscription Manager for M2M subscription management as well as for voice/data enable devices, allows downloading and managing subscriptions over the air, either by SMS or by HTTPs.

NOKIA SOLUTIONS AND NETWORKS

Nokia Solutions and Networks (NSN) is the world's specialist in mobile broadband. From the first ever call on GSM, to the first call on LTE; NSN operates at the forefront of each generation of mobile technology. NSN global experts invent the new capabilities their customers need in their networks. They provide the world's most efficient mobile networks, the intelligence to maximize the value of those networks and the services to make it all work seamlessly.

A leader in the commercialization and innovation of LTE, NSN serves millions of LTE subscribers in commercial FDD-LTE and TD-LTE networks worldwide. NSN has a total of 92 contracts on six continents (as of Sept. 2013), underscoring its global leadership position in LTE commercial references and live network performance. NSN is a supplier to close to 60 commercial LTE operators which account for 45% of all LTE subscribers. Their unique track record is based on award-winning platforms like the multi-technology, compact, modular and weatherproof Flexi Multiradio 10 Base Station and the ingenious Liquid Radio LTE Software Suite and Smart Scheduler to maximize performance and optimize the use of radio spectrum.

NSN's Global Services enable operators to safely move towards LTE with the highest quality possible and ensure fast and reliable network rollouts with end-to-end network integration to Customer Experience Management. Our industry-leading Security solutions enable operators to provide secure subscriber services while our Network Planning and Optimization services support a smooth transition with Refarming Services, LTE Planning, iSon Services, LTE Optimization and Services for VoLTE.

NSN LTE achievements:

- NSN supplies all six of the "Big Six" operators in Japan and Korea (DOCOMO, KDDI, SoftBank, SK Telecom, LG U+ and Korea Telecom), representing more than 29.4 million LTE subscribers during 1Q 2013.
- NSN has brought the benefits of LTE-Advanced carrier aggregation to SK Telecom, LG U+ and Korea Telecom, helping them reach up to 150 Mbps throughput.
- The NSN LTE solution comprises 3GPP standardized solutions introduced in different releases and subsequent updates, including: Single RAN Advanced and small cells (Rel-10), Evolved Packet Core (Rel-8), VoLTE (Rel-9) and professional services.
- NSN is the driving force behind TD-LTE innovation and commercialization, with many world firsts since 2009. These include five recent unprecedented speed records such as 1.6 Gbps (Rel-10) throughput using the commercial Flexi Multiradio 10 Base Station. NSN has won 11 TD-LTE contracts (seven of which have been commercially launched), including the first 4G/TD-LTE network in Latin America, the first TD-LTE network in Russia and the first TD-LTE network in Saudi Arabia.
- During Mobile World Congress 2013, NSN received the Global TD-LTE Initiative (GTI) Market Development Award, the first ever infrastructure vendor to win this category.
- In China, NSN has been working on a multi-city TD-LTE deployment with China Mobile and recently enabled the world's first live TV broadcast via TD-LTE.
- ABI Research ranked NSN number 1 in its Macrocell Basestation Vendors competitive assessment, giving NSN high scores in Innovation and Implementation.
- NSN is ranked as a Leader in IDC's MarketScape: Worldwide LTE Radio Infrastructure 2013 Vendor Analysis.
- NSN has been positioned by Gartner, Inc. in the "Leaders" quadrant of its "Magic Quadrant for LTE Network Infrastructure 2013."

QUALCOMM

Qualcomm Incorporated is the leader in next-generation mobile technologies, developing some of the industry's most advanced chipsets, software and services. The Company's R&D efforts and intellectual property portfolio in the areas of LTE and HSPA+ have catalyzed the evolution of mobile broadband, helping to make wireless devices and services more personal, affordable and accessible to people everywhere.

Qualcomm foresees and solves impossible wireless challenges. Their key wireless initiative is to solve the 1000x data challenge to cost efficiently enable 1000x more mobile data capacity. Qualcomm is working on small cells solutions and new deployment models such as neighborhood small cells, innovative spectrum solutions, such as ASA to bring more spectrum, and are leveraging their unique end-to-end capability to make the networks more efficient at all levels, including the evolution of HSPA+ and LTE.

Qualcomm is committed to LTE and HSPA+ and is a leader in both standards development and chipset commercialization of 3GPP technologies. Qualcomm's contributions to the advancement of HSPA+ and LTE are reflected in a variety of key industry milestones, including:

- The world's first HSPA+ Rel-7 chipset was launched early 2009. Qualcomm's introduction of the MDM8200 Gobi™ chipset set the stage for the world's first HSPA+ network launch in early 2009 and the continued global successes HSPA+ Rel-7 launches worldwide.
- The world's first dual-carrier HSPA+ chipset was launched in August 2010. Qualcomm's data-optimized Gobi™ chipset (MDM8220) and handset-optimized chipset (MSM8270) supported HSPA+ Rel-8 and the multicarrier feature with 42 Mbps peak data rates.
- The world's s first multi-mode 3G/LTE Gobi™ chipsets launched in December 2010. The MDM 9x00 chipsets support both LTE FDD and LTE TDD including integrated support for Rel-8 DC-HSPA+ and EV-DO Rev B – helping to provide the user with a seamless mobile broadband experience.
- The world's first mobile platform with integrated LTE/3G World Mode. Snapdragon™ S4 (8960) with integrated application processor and second generation Gobi™ LTE/3G Multimode Modem was launched March 2012. We expanded our multimode support with integrated TD-SCDMA and support for VoLTE with SR-VCC.
- The world's first LTE Advanced chipsets supporting carrier aggregation was launched June 2013 using industry-leading Qualcomm Snapdragon™ 800 chipsets, integrated with Qualcomm's third-generation Gobi™ LTE World Mode modems. As a first step, the launch supported aggregation of two 10 MHz carriers enabling peak data rates of 150 Mbps (Cat 4).
- The world's first announcement of LTE/LTE Advanced chipsets for the volume smartphone segment tier using Snapdragon™ 400 (8926) chipsets with integrated third-generation Gobi™ LTE World Mode modems.

Qualcomm continues to serve as a leading contributor to 3GPP for the continued HSPA+ and LTE Advanced evolution to bring further enhanced user experience and capacity solutions required to solve the 1000x mobile data challenge in areas such as:

- Heterogeneous network (HetNet) and small cells enhancements for both HSPA+ and LTE. Qualcomm was instrumental in the effort to specify the enabling LTE Advanced features for time-domain resource partitioning (inter-cell interference coordination eICIC) and advanced receivers with interference cancellation.
- Continued carrier aggregation evolution to better leverage all spectrum assets. One example is multiflow which Qualcomm spearheaded for HSPA+ and is now being developed for LTE Advanced.
- New innovative use of LTE such as LTE-Direct, a direct device-to-device technology that enables and discovers thousands of devices and their services in the proximity, in a privacy sensitive and battery efficient way.

T-MOBILE USA

T-Mobile USA: Based in Bellevue, Wash., T-Mobile USA operates its wireless network under the flagship brands, T-Mobile and MetroPCS. As America's "Un-carrier", T-Mobile USA is redefining the way consumers and businesses buy wireless services through leading product and service innovation. The company's advanced nationwide 4G and 4G LTE network delivers outstanding wireless experiences for customers who are unwilling to compromise on quality and value.

Network Modernization

In February 2012, T-Mobile announced a $4 billion plan to drastically rework its network by refarming its spectrum holdings to free up spectrum for LTE and make its HSPA+ technology compatible with more mobile devices and networks. T-Mobile shifted its HSPA+ from the 1700 MHz AWS band to its 1900 MHz spectrum thus opening up its 1700 MHz spectrum open for LTE deployment. A small amount of 2GSM was retained in the 1900 MHz band to accommodate legacy devices. In May 2012, T-Mobile named Ericsson and Nokia Siemens Networks as the primary infrastructure suppliers for the modernization effort.

By September 2012, T-Mobile launched HSPA+ service at 1900 MHz in Las Vegas and was starting to turn up HSPA+ service in the 1900 MHz band in other cities committing to have a "material" footprint of refarmed 1900 MHz spectrum by year-end.

LTE Roll Out

In September 2012 Deutsche Telekom appointed John Legere as chief executive of the of T-Mobile USA operations and also budgeted for significant network upgrades, including the move to LTE.

In October 2012, T-Mobile USA announced a plan to combine with MetroPCS to create a publicly-traded company to form a premier challenger in the U.S. wireless marketplace. The two companies share a commitment to innovation and customer service. Each owned PCS and AWS spectrum and their respective 3G mobile networks were both on migration paths to LTE.

The plan combined T-Mobile and MetroPCS' complementary spectrum to provide greater network coverage, a deeper LTE network deployment and a path to at least 20x20 MHz of 4G LTE in many metro areas. The single, national network will deliver LTE Services to a broader subscriber base, including better LTE network density in key metropolitan areas such as New York, Los Angeles and Dallas, as well as improved in-building coverage. The new company's network plans are aligned with and will enhance the $4 billion network modernization plan already have underway. By the end of 2012, T-Mobile USA successfully surpassed its goal of launching 100 million POPs of modernization coverage.

In the first quarter of 2013, T-Mobile had modernized sites covering over 142 million people and was on track to coveting 200 million POPs by the end of the year. They announced the launch of its first LTE (in addition to HSPA+ 42) markets in Baltimore, Houston, Kansas City, Las Vegas, Phoenix, San Jose, and Washington DC. T-Mobile also announced the availability of new LTE devices including the iPhone 4 in April.

T-Mobile and MetroPCS officially merged on May 1, 2013 and began migrating MetroPCS LTE customers to TMUS LTE to refarm the spectrum for double or quadruple LTE capacity, installing HSPA+ technology on some MetroPCS sites to ensure coverage parity for MetroPCS customers and increase overall network capacity, and providing roaming to MetroPCS LTE customers in TMUS LTE markets to improve their data roaming experience and reduce the company's roaming costs.

Also in May 2013, T-Mobile successfully migrated all MetroPCS LTE traffic to the TMUS LTE network by deploying the first Multi Operator Core Network (MOCN) in the U.S. This enabled the refarming of MetroPCS spectrum doubling capacity from 5+5 MHz to 10+10 MHz. T-Mobile will be replicating this process in each of the MetroPCS LTE markets to free up key spectrum for greater spectrum depth for the combined company's LTE network with a path to 20+20 MHz deployment in 90% of the top 25 markets in 2014 and beyond.

By July 2013, T-Mobile announced that it had deployed LTE covering nearly 160M POPs in 116 metro areas (73% of the top 100 metros).

At the completion of the 3Q 2013, T-Mobile offered nationwide 4G LTE network coverage available to 203 million people in 254 metro areas and served more than 45 million subscribers and began providing the iPhone 5s and 5c.

In October 2013, the company completed the previously announced acquisition of 10 MHz of AWS spectrum from U.S. Cellular for $308 million in cash. The purchased AWS spectrum covers a total of 32 million people in 29 markets in the Mississippi Valley region, including St. Louis, Nashville, Kansas City, Memphis, Lexington, Little Rock, Birmingham, New Orleans and Louisville.

APPENDIX D: ACRONYM LIST

2G	Second Generation
3G	Third Generation
3GP-DASH	3GPP Dynamic Adaptive Streaming over HTTP
3GPP	3rd Generation Partnership Project
4C-HSDPA	Four Carrier HSDPA
4G	Fourth Generation
AA	Antenna Array
AAA	Authentication, Authorization and Accounting
AAS	Active Antenna Systems
ABC	Application Based Charging
ABS	Almost Blank Subframes
AC	Access Class
ACB	Access Control Barring
ACK/NACK	Acknowledgement/Negative Acknowledgement
ACLR	Adjacent Channel Leakage Ratio
ADC	Application Detection and Control
AF	Application Function
AMBR	Aggregate Maximum Bit Rate
AMR	Adaptive Multi-rate
AMR-WB	Adaptive Multi-rate WideBand
ANDSF	Access Network Discovery and Selection Function
ANI	Access Network Information
ANR	Automatic Neighbor Relation
APN	Access Point Name
APT	Asia Pacific Telecommunity
ARP	Allocation and Retention Priority
ARPU	Average Revenue Per User
AS	Application Server
ATCF	Access Transfer Control Function
AVC	Advanced Video Coding
AVP	Attribute Value Pair
AWS	Advanced Wireless Spectrum
BB	Baseband
BBERF	Bearer Binding and Event Reporting Function
BF	Beamforming
BLER	Bit Error Rate
BM-SC	Broadcast Multicast Service Center
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BSSID	Base Station Subsystem ID
BTS	Base Transceiver Station
CA	Carrier Aggregation
CAPEX	Capital Expenses
CAT	Customer Alerting Tones
CB	Coordinated Beamforming
CBC	Cell Broadcast Center
CC	Component Carrier
CCO	Capacity and Coverage Optimization
CDF	Charging Data Function

CDMA	Code Division Multiple Access
CDR	Call Detail Record
Cell_DCH	Cell Dedicated Channel
CELL_FACH	Forward Access Channel
CELL_PCH	UTRAN RRC state where UE has no dedicated resources are allocated
CGF	Charging Gateway Function
CIO	Cell Individual Offset
CM	Configuration Management
CMS	Communication and Media Solutions
CN	Core Network
CO2	Carbon Dioxide
CoMP	Coordinated Multi-Point Transmission and Reception
CPC	Continuous Packet Connectivity
CQI	Channel Quality Indications
CR	Change Request
CRS	Cell Specific Reference Symbols
CS	Circuit Switched
CSFB	Circuit Switched Fall Back
CSG	Closed Subscriber Group
CSI	Channel State Information
CSI-IM	Channel-State Information – Interference Measurement
CSI-RS	Channel-State Information Reference Symbol
CT	Core Network and Terminals
CT3	Core Network and Terminals WG3
CT4	Core Network and Terminals WG4
CTIA	Cellular Telecommunication Industry Association
DB-DC	Dual Band Dual Cell
DCH	Dedicated Channel
DC-HSPA	Dual Carrier-High Speed Packet Access
DIME WG	Diameter Maintenance and Extensions Working Group
DL	Downlink
DLM	Diameter Load Managers
DMB	Digital Multimedia Broadcasting
DMRS	Demodulation Reference Signal
DNS	Domain Name Server
DPCCH	Dedicated Physical Control Channel
DPS	Dynamic Point Selection
DRX	Discontinuous Reception
DSAC	Domain Specific Access Control
DSMIPv6	Dual Stack-Mobile Internet Protocol version 6
E911	Enhanced 911
EAB	Extended Access Barring
EAP-AKA	Extensible Authentication Protocol Method - Authentication and Key Agreement
Eb/No	Energy per Bit over Noise Spectral Density
ECCE	Enhanced Control Channel Element
ECGI	E-UTRAN Cell Global Identifier
ECM-IDLE	EPS Connection Management IDLE
E-DCH	Enhanced Dedicated Channel (also known as HSUPA)
EDGE	Enhanced Data rates for GSM Evolution
E-DPCCH	Enhanced Dedicated Physical Control Channel
eIMTA	Enhanced International Mobile Telecommunications Advanced
eICIC	Enhanced Inter-Cell Interference Coordination

eMBMS	Evolved Multimedia Broadcast Multicast Service
eMPS	Enhancements for Multimedia Priority Service
eNB	Evolved NodeB, E-UTRAN NodeB
eNodeB	Evolved NodeB
EPC	Evolved Packet Core also known as System Architecture Evolution (SAE)
EPDCCH	Enhanced Physical Downlink Control Channel
EPLMN	Equivalent Public Land Mobile Network?
EPS	Evolved Packet System
E-RAB	Enhanced Radio Access Bearer
EREG	Enhanced Resource Element Group
ERF	Event Reporting Function
ESM	Energy Savings Management
ETSI	European Telecommunications Standards Institute
EUL	Enhanced Uplink
E-UTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
EV-DO	Evolution Data Optimized or Data Only
EVM	Error Vector Magnitude
EVS	Enhanced Voice Services
FACH	Fast Access Channel
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FD-LTE	Frequency Division LTE
FDM	Frequency Division Multiplex
FEC	Forward Error Correcting
feICIC	Further Enhanced Inter-Cell Interference Coordination
FET	Frame Early Termination
FFS	For Further Study
FGI	Feature Group Indicator
FirstNet	First Responder Network Authority
FOMA	Freedom of Mobile Multimedia Access
FPI	Flow Priority Indicator
FQDN	Fully Qualified Domain Names
FS_CNO	Study on Core Network Overload
FS_DOCME	Study on Diameter Overload Control Mechanisms
FS_GOCME	Study on GTP-C overload control mechanisms
GB	Gigabyte
Gbps	Gigabit per second
GCSE_LTE	Group Call System Enablers for LTE
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GHz	Gigahertz
Gi	Interface between GPRS and external data network
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GTP-C	GPRS Tunneling Protocol - Control
GTP-U	GPRS Tunneling Protocol User Plane
GTPv2	GPRS Tunneling Protocol version 2
GTT	Global Text Telephony
GW	Gateway
Gyn/Gzn	Interfaces between the TDF and the OCS/Offline Charging System (OFCS)

HARQ	Hybrid Automatic Retransmission Request
HARQ-ACK	Hybrid Automatic Repeat Request Acknowledgement
HetNet	Heterogeneous Network
HEVC	High Efficiency Video Coding
HLR	Home Location Register
HNB/HeNB	Home NodeB/Home eNodeB
HO	Handover
HOM	Higher Order Modulation
HPLMN	Home Public Land Mobile Network
HPSIM	HP Systems Insight Manager
HSDPA	High Speed Downlink Packet Access
HS-DPCCH	High Speed-Dedicated Physical Control Channel
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
HS-PDSCH	High Speed Physical Downlink Shared Channel
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
I/Q	In-phase Quadrature referring to the COMPONENTS used in quadrature amplitude modulation
IC	Inter-Cell
ICIC	Inter-Cell Interference Coordination
ICS	IMS Centralized Services
ICT	Information and Communication Technology
ID	Identification
IDC	In-Device Coexistence
IETF RFC	Internet Engineering Task Force Request for Comments
IFOM	Internet Protocol Flow Mobility and seamless WLAN Offload
IKEv2	Internet Key Exchange version 2
IMEI-SV	International Mobile Equipment Identity
IMS	Internet Protocol Multimedia Subsystem
IMS MES	IMS Multimedia Emergency Session
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IP-CAN	Internet Protocol Connectivity Access Network
IPsec	Internet Protocol Security
IRP	Integration Reference Point
ISM	Industrial, Scientific and Medical
ISO/IEC	International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC)
ISRP	Inter-System Routing Policies
Itf-N	Interface N
ITU	International Telecommunications Union
I-WLAN	Internet Wireless Local Area Network
JCT-VC	Joint Collaboration Team on Video Coding
JP	Joint Processing
JT	Joint Transmission
LAI	Location Area Identification
LCS	Location Service

LHN	Local Home Network
LIPA	Local Internet Protocol Access
LMR	Land Mobile Radio
LOBSTER	LOcation Based Selection of gaTEways foR WLAN
LPN	Low Power Nodes
LTE	Long Term Evolution
M2 Interface	Interface between the Multi-cell/multicast Coordination Entity and the eNodeB
M2M	Machine-to-Machine
M3AP	M3 Application Protocol
MAC	Media Access Control
MAP	Mobile Application Part
MAPCON	Multi-Access PDN Connectivity
MBMS	Multimedia Broadcast/Multicast Services
Mbps	Megabits per second
MBSFN	Multicast Broadcast Single Frequency Networks
MCE	Multi-cell/Multicast Coordination Entity
MDT	Minimizing Drive Tests
MeNB	Macro Evolved NodeB
MGCF	Media Gateway Control Function
MHz	Megahertz
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MMES	Multimedia Emergency Services
MMSE-IRC	Minimum Mean Square Error Interference Rejection Combining
MNO	Mobile Network Operator
MOS	Mean Opinion Score
MO-SMS	Mobile Originated Short Message Service
MPS	Multimedia Priority Service
MSC	Mobile Switching Center
MSISDN	Mobile Subscriber Integrated Services Digital Network Number
MT	Mobile Terminated
MTC	Machine Type Communications
MTC-AAA	MTC Authentication, Authorization and Accounting
MTCe-SDDTE	Small Data and Device Triggering Enhancements
MTCe-UEPCOP	UE Power Consumptions Optimizations
MTC-IWF	MTC Interworking Function
MTSI	Multimedia Telephony Service for IMS
MT-SMS	Mobile Terminated-Short Message Service
MU-MIMO	Multi-User Multiple-Input Multiple-Output
MWC	Mobile World Congress
NAI	Network Access Identifier
NAIC	Network Assisted Interference Cancellation
NAS	Non Access Stratum
NB	Narrowband
NCL	Neighbor Cell List
NFC	Near Field Communications
NOC	Network Operation Centers
NPSBN	National Public Safety Broadband Network
NPSTC	National Public Safety Telecommunications Council
NR	Neighbor Relation
NSWO	Non-seamless WLAN offload
NTIA	National Telecommunications and Information Administration

NW	Network
O&M	Operation and Maintenance
OAM	Operations, Administration and Maintenance
OC	Overload Control
OCS	Online Charging System
OEM	Original Equipment Manufacturer
OFCS	Offline Charging System
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
OMA	Open Mobile Alliance
OMA-DM	Open Mobile Alliance - Device Management
OPEX	Operating Expenses
OTT	Over-the-Top
PBCH	Primary Broadcast Channel
PCAP	Packet Capture
PCC	Policy and Charging Control
PCEF	Policy and Charging Enforcement Function
PCFICH	Physical Control Format Indicator Channel
P-CPICH	Primary Common Pilot Channel
PCRF	Policy and Charging Rule Function
PCS	Personal Communications System
P-CSCF	Proxy Call Session Control Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Public Data Network
PDP	Packet Data Protocol
PDSCH	Physical Downlink Shared Channel
PDU	Packet Data Unit
P-GW	Public Data Network Gateway
PHICH	Physical Hybrid ARQ Indicator Channel
PLMN	Public Land Mobile Network
PMCH	Physical Multicast Channel
PMI	Precoding Matrix Index
PMIPv6	Proxy Mobile IPv6
PoC	Push-to-Talk Over Cellular
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
ProSe	Proximity Services
PRS	Positioning Reference Channel
PS	Packet Switched
PSC	Packet Scheduling
PSD	Power Spectral Density
PSNR	Peak Signal to Noise Ration
PSS/SSS	Primary Synchronization Signal/Secondary Synchronization Signal
PSTN	Public Switched Telephone Network
pTAG	Primary Timing Advance Group
PTT	Push-to-Talk
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
PWS	Public Warning System
QAM	Quadrature Amplitude Modulation
QCI	Quality of Service Class Index
QoS	Quality of Service

QoS_SSL	QoS Subscriber Spending Limits
RA	Routing Area
RAB	Radio Access Bearer
RACH	Random Access Channel
RADIUS AAA	Remote Authentication Dial In User Service for Authentication, Authorization, and Accounting management for computers to connect and use a network service
RAM	Remote Application Management
RAN	Radio Access Network
RA-RNTI	Random Access Radio Network Temporary Identifier
RAT	Radio Access Technology
RAU	Routing Area Update
RCAF	RAN Congestion Awareness Function
RCI	RAN User Plane Congestion Information
RDN	Radio Distribution Network
RE	Resource Element
RF	Radio Frequency
Rf/Ga	GPRS/Web services interface to record data for offline charging
RFI	Request for Information
RFM	Remote File Management
RI	Rank Indicator
RLC	Radio Link Control Layer
RLF	Radio Link Failure
RNC	Radio Network Controller
RNL	Radio Network Layer
ROT	Rise-Over-Thermal
RRC	Radio Resource Control
RRM	Radio Resource Management
RRU	Radio Remote Units
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
rSRVCC	Reverse Single Radio Voice Call Continuity
RSSI	Received Signal Strength Indicator
Rx	Receive
RXU	Receiver Units
S1-U	S1 Interface User Plane
SAE	System Architecture Evolution also known as Evolved Packet Core (EPC)
SAI	Service Area Identifier
SaMOG	S2a Mobility based on GTP
SAPP	Service Awareness and Privacy Policies
SAS	Standalone Serving Mobile Location Center
SC	Service Continuity
SCCP	Signaling Connection Control Part
SC-FDMA	Synchronization Channel-Frequency Division Multiple Access
SCS	Services Capability Server
SDDTE	Small Data and Device Triggering Enhancements
SeNB	Serving eNB
SFN	Single Frequency Network
SG	Serving Gateway
SGi	Reference point between the PDN-GW and the packet data network
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway

S-GW	Serving Gateway
SIB-1	System Information Block Type 1
SIMTC	System Improvements for Machine Type Communication
SINR	Signal-to-Interference plus Noise Ratio
SIP	Session Initiated Protocol
SIPTO	Selected Internet Protocol Traffic Offload
SIR	Signal-to-Interference Ratio
SM	Spatial Multiplexing
SME	Short Message Entity
SMS	Short Message Service
SMSC	Short Message Service Center
SNR	Signal to Noise Ratio
SON	Self-Optimizing or Self-Organizing Network
SORTD	Spatial Orthogonal-Resource Transmit Diversity
SPR	Subscription Profile Repository
SRNS	Serving Radio Network Subsystem
SRS	Sounding Reference Signal
SRVCC	Single Radio Voice Call Continuity
SS7	Signalling System No.7
sTAG	Secondary Timing Advance Group
SU-MIMO	Single-User Multiple-Input Multiple-Output
SWB	Super-wideband
T5	Control plane interface between MTC-IWF and serving nodes (SGSN/MME)
TA	Timing Advance
TAG	Multiple Timing Adjustment Groups
TAI	Tracking Area Identity
TAU	Target Acquisition and Tracking Unit
TAU	Target Acquisition and Tracking Unit
TBD	To Be Determined
TBS	Tranport Block Size
TCAP	Transaction Capabilities Application Part
TCCA	The Tetra and Critical Communications Association
TDD	Time Division Duplex
TDF	Traffic Detection Function
TD-LTE	Time Division LTE
TDM	Time Division Multiplexing
TD-SCDMA	Time Division Synchronous CDMA
TETRA	Terrestrial Trunked Radio
TFCI	Tranport Format Combination Index
TFT	Traffic Flow Template
TMSI	Temporary Mobile Subscriber Identity
TR	Technical Report
TS	Technical Specification
TSG-SA	Technical Specification Group - Services and System Aspects
TSMS	Interface between the Short Message Entity and the Short Message Service Center
Tsp	Reference point between the Service Capability Server (SCS) and Machine Type Communication Inter-Working Function
TTI	Transmission Time Interval
TWAG	Trusted WLAN Access Gateway
TWAN	Trusted WLAN
Tx	Transmit

TXRU	Transceiver Units
TXRUA	Transceiver Unit Array
TXU	Transmitter Units
UE	User Equipment
UEPCOP	UE Power Consumptions Optimizations
uFI	Designation for hotspot
UICC	A physically secure device, an Integrated Circuit Card (or Smart Card), that can be inserted and removed from the terminal. It may contain one or more applications. One of the applications may be a USIM.
UL	Uplink
ULI	User Location Information
UMTS	Universal Mobile Telecommunication System (also known as WCDMA)
UP	User Plane
UPCON	User Plane Congestion
UpPTS	Uplink Pilot Time Slot
URA_PCH	UTRAN Registration Area_Paging Channel
URI	Uniform Resource Identifiers
URN	Uniform Resource Names
URNTI	User Radio Network Temporary Identifier
USAT	USIM Application Toolkit
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
USIM	Universal SIM
UTRAN	Universal Terrestrial Radio Access Network
VCC	Voice Call Continuity
VoIP	Voice and Video over Internet Protocol
VoLTE	Voice-over-LTE
VPLMN	Visiting Public Land Mobile Network
WB	Wideband
WCDMA	Wideband Code Division Multiple Access
WebRTC	Web Real-Time Communication
Wi-Fi	Wireless Internet or IEEE 802.11 standards
WiMAX	Worldwide Interoperability for Microwave Access based on IEEE 802.16 standard
WLAN	Wireless Local Area Network
WLCP	WLAN control protocol
X2	Interface between eNBs
X2GW	X2 Gateway

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