Meeting the 1000x Challenge:

The Need for Spectrum, Technology and Policy Innovation

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EXECUTIVE SUMMARY

Global mobile data traffic has been approximately doubling during each of the last few years, and this growth is projected to continue unabated. Thus, the mobile industry needs to prepare for the challenge to meet an increase in mobile data demand by a staggering 1000X over the next few years. This white paper reviews a set of innovative approaches and technologies as building blocks to address this challenge.

There are various opportunities and avenues to enhance the network capacity and coverage of current macro cell deployments by, for example, exploiting advanced receivers, cooperative multipoint transmissions and advanced antenna solutions. Heterogeneous Networks (Het-Nets), another innovation that is commercial today, is expected to evolve further to offer enhanced capacity growth via network densification through widespread deployment of small cells.

Technological innovation, coupled with massive investment, is necessary, but not sufficient to reach the 1000x goal. The need for additional spectrum is vital to support mobile broadband growth. The industry needs a fast track access to as much premium spectrum as possible for mobile broadband use and therefore, innovation in spectrum regulation must occur.

While traditional tools of clearing and auctioning exclusive use licensed spectrum for mobile broadband must continue as a priority, some spectrum bands cannot be cleared 24/7 nationwide and in a reasonable time frame. Policy makers will have to consider each and every sliver of under-utilized spectrum for licensed use, using new policy tools available in their arsenal. In this context, it is important to adopt what is known as Authorized/Licensed Shared Access (ASA/LSA), a complementary method of licensing spectrum to enable fast-track availability and using harmonized spectrum for mobile cellular use. ASA/LSA allows some incumbents' underutilized spectrum (either in time, geography and/or frequency) to be used more efficiently.

In the US, there are new initiatives to release 500 MHz of Federal and non-Federal Spectrum and the Federal Communications Commission (FCC) is working to repurpose 3.5 GHz spectrum, particularly for small cell deployments, and leveraging the ASA/LSA regulatory concept in an effort to explore innovative spectrum policy options. Two other spectrum bands are also currently under study leveraging ASA/LSA, the 1755-1780 MHz and 1695-1710 MHz bands, in view of the fact that these bands are currently occupied.

Other examples of these innovative regulatory developments exist beyond the U.S. This white paper explains these examples for the benefit of achieving global harmonization and economies of scale across the Americas and beyond (e.g., ASA/LSA is currently under study in Europe for 2.3 GHz – within regulatory bodies European Conference of Postal and Telecommunications Administrations (CEPT), Radio Spectrum Policy Group (RSPG) and standardization organization European Telecommunications Standards Institute (ETSI).

This paper demonstrates that the merits of increased spectral availability are an important means to bridge the gaps between 1000x data demand and capacity performance that technology evolution provides.

Specifically, here is a brief outline and summary of the sections presented in this paper:

Section 1: Introduction

Section 1 provides a description of the 1000x challenge and introduces the need for new technological innovations and policy changes to meet the 1000x challenge.

Technologically, meeting the 1000x challenge is a combination of increasing the end-to-end system efficiency of existing and future wireless networks and deploying more resources in the form of small cells and spectrum.

Achieving a 1000x traffic gain will clearly require availability of more spectrum. Given that most spectrum is already allocated to multiple services, making more spectrum available for mobile services will require new innovative policies for the licensing assignments of spectrum and sharing among the users. Policy innovation such as ASA/LSA is needed to make use of various under-utilized bands and make the quality of service that consumers demand, predictable.

Section 2: Why 1000x Capacity?

Section 2 provides a detailed picture of the traffic growth in the recent years and the estimated growth in the foreseeable future.

Widespread adoption of wireless broadband and smartphones has resulted in tremendous growth in traffic volumes in mobile networks in recent years. With the introduction of the smartphone and tablets, mobile devices have evolved from being used predominantly for talking into a versatile communication companion. People spend more and more time on being connected to the internet over a mobile device. More than 133 million people in the U.S.

already own a smartphone and that number is growing. The traffic growth will be further driven by larger-screen devices and video rich tablets, machine-to-machine applications and soon, the connected vehicle and home.

Research predicts that mobile data traffic will grow exponentially and video traffic will drive that growth. Not only does the video content consume more resources than many other applications, faster and bigger smart devices coupled with advanced wireless networks have led to increasing adoption of video content. According to Cisco Visual Networking Index (VNI), mobile video traffic is already over 50 percent of mobile data traffic, and is expected to account for 66 percent of global mobile data demand by 2017. According to Cisco VNI, the global mobile data traffic grew 70 percent in 2012 and is expected to grow steadily at CAGR of 66 percent from 2012 to 2017. This means there will be a 13-fold increase by the end of 2017. Ericsson Mobility Report shows that mobile data traffic already exceeded mobile voice traffic already in 2009 and that data traffic is growing at a steady rate whereas voice traffic growth remains moderate. In fact, the Ericsson report shows that mobile data traffic doubled in 2012 and is expected to grow with a CAGR of around 50 percent between 2012 and 2018. This entails growth of about 12 times by the end of 2018. Qualcomm and Nokia Solutions and Networks have both talked about a '1000x' increase in data traffic, driven by increases in the number of mobile broadband users as well as an increase in the average data consumption by users.

All traffic growth predictions are suggesting that demand for mobile data could overwhelm wireless network resources due to finite and limited spectrum availability, even though technology evolution is improving the efficiency and capacity of the wireless networks. To be ready to accommodate this growth, the wireless industry needs additional spectrum and associated policy innovation.

The need for additional spectrum is recognized internationally. The International Telecommunication Union (ITU), an internationally recognized entity chartered to define the next generation wireless technologies, has established a recommendation on the amount of spectrum that will be needed to support mobile data growth. Report ITU-R M.2078 estimated spectrum bandwidth requirements for mobile operators' needs to allow for the proper future development of International Mobile Telecommunications IMT-2000 and IMT-Advanced while taking into account a mobile data dominated world.

Report ITU-R M. 2078 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 1. Predicted spectrum requirements for IMT and IMT-Advanced Technologies.[1]

Market Setting	Spectum Requirement for RATG 1 (MHz)			Spectum 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.

Section 3: Technology Enhancements to Meet 1000x Challenge

Section 3 presents the various technology enhancements that will help to meet the 1000x data challenge. This section provides the details of the several technological innovations that have been developed to drive macro cell efficiencies, to tap into small cell potential, and to explore avenues to provide high data performance.

There are several untapped opportunities to enhance the network capacity and coverage of current macro cell deployment. The first step towards meeting the 1000x challenge will be to derive most of the efficiencies from macro cells with new innovations so that operators can leverage their existing macro cellular network infrastructure network in a cost effective manner to increase capacity. There are several efforts currently underway in further enhancing the performance of 3G, 4G and Wi-Fi technologies in delivering higher capacity, data rates and user experience.

As part of the HSPA Evolution, the Multi-Carrier HSPA (MC-HSPA) feature introduced in the latest 3GPP releases 8, 9, 10, 11 and 12, allows users to simultaneously receive data in both the Downlink (DL) and Uplink (UL) with an aggregation of up to 40 MHz in multiple carriers. MC-HSPA allows for MIMO 4x4 features for downlink and 2x2 for uplink while providing operators a

[1] Source: International Telecommunications Union (Report ITU-R M. 2078)

[2] [Ref 1-1] Qualcomm CTIA 2013: http://www.qualcomm.com/media/documents/ctia-2013-qualcomm-1000x-mobile-data

means to offer higher data rates and especially improving performance for users at the edge of the cell. MC-HSPA in a combined eight 5 MHz carriers in Rel-11 will provide peak data rates of 336 Mbps in the downlink and 69 Mbps in uplink. MC-HSPA also provides significantly increased sector throughput and serves a greater number of users with better burst rates compared to single carrier systems in equivalent spectrum.

As for 4G, the LTE technology that is currently commercial in several operators' networks is deployed in FDD up to 2x10 MHz bandwidth and 20 MHz in TDD. The LTE-Advanced technology allows deployment in much wider bandwidth with carrier aggregation across bands providing enhanced spectral efficiencies, sector throughput and user experiences.

The LTE-Advanced technology is designed to provide peak rates of more than 1 Gbps downlink in 100 MHz and over 375 Mbps for the uplink using higher order DL and UL Multiple-Input Multiple-Output (MIMO) antenna systems. The main objective for LTE-Advanced, however, is to provide better coverage and user experience for cell edge users. The evolution of LTE-Advanced is focused on providing the requisite interference and mobility management features for heterogeneous networks.

The Wi-Fi access points and networks are expected to play a vital role in meeting the 1000x data capacity challenge. For Wi-Fi evolution, 802.11ac is the next-gen Wi-Fi technology that provides significant enhancements in data capacity. 802.11ac provides three times the capacity compared to 802.11n. In the next phase of evolution, 802.11ac extends the MIMO feature to include multi-user MIMO and provides 3 times the capacity of the first phase. The Wi-Fi evolution features 802.11ad technology that uses bandwidth rich 60 GHz spectrum. The 802.11ad provides multi-gigabit data rates especially suited for short range applications.

The next step in the evolution of 3G and 4G technologies is to incorporate smart network techniques to improve network efficiency and user experience and especially address the challenge of improving cell-edge data rates which continue to be lower than average. Multipoint HSPA is a new feature currently under study in 3GPP with an objective to address the imbalance of loading between adjacent sectors/cells and improve the cell-edge data rates while leveraging existing transceiver capabilities of the network and UEs.

The smart network techniques essentially leverage MC User Equipment (UE) capabilities to deliver a more uniform experience across the network. There are multiple types of multi-flow depending on the frequency carriers that are in used in the deployment. The Single Frequency Dual Carrier (SFDC) HSPA multi-flow feature essentially improves 5 MHz deployments. The Dual

Frequency Dual Carrier (DFDC) and Dual Frequency, Four Carrier (DF4C) HSPA systems optimize 10 MHz and 20 MHz systems.

Another important source of performance improvements comes from antenna enhancements which in the near future are going play a key role in enhancing coverage, system capacity and user data rates without additional power or bandwidth. A MIMO system, irrespective of the technology (3G or 4G), consists of multiple transmit and receive antennas plus signal processing at both transmitter and receiver.

Another source of dramatic improvements in network performance is possible with evolving 3G/4G/Wi-Fi networks and devices to intelligently select the best mode of access among a myriad of possible options—3G/4G, Wi-Fi, small/macrocells etc.—in licensed and unlicensed spectrum. For example, the data pipe needs to determine if 3G/4G or Wi-Fi or a LTE Broadcast service or a device-to-device communication is a better fit for the application/data that is being transferred.

With radio link performance fast approaching theoretical limits, the next performance and capacity leap is now expected to come from an evolution of network topology by using a mix of macro cells and small cells in a co-channel deployment. Capacity gains of macrocells from using more spectrum and optimization and improved efficiency are unlikely to be enough to keep up with the traffic demand increase, so extreme cell densification will be needed too.

The introduction of heterogeneous network (HetNet) techniques in LTE-Advanced and HSPA, including intelligent interference coordination methods in the network, offers a more promising and yet scalable path to achieve tremendous growth in spectrum efficiency per unit area. Enhancements such as small cell "Range Expansion" introduced in LTE-Advanced are also possible with HSPA+ today, providing the much needed traffic offload from macro networks and improving the overall network capacity more so than merely adding small cells.

The evolved HetNets, while adopting innovative interference management techniques, will include new kinds of cells such as relays besides low power miniature base stations, utilizing higher spectrum bands such as 3.5 GHz.

The huge increase in indoor data usage combined with the relatively small size and cost of small cells opens doors for new ways to complement traditional macro networks with low-cost indoor small cells. This paper explores new deployment models that can reduce the network costs and enable hyper-dense deployment. A new innovation in small cell technology is

currently being proposed that allows simple plug-and-play deployment in indoor locations enabling orders of magnitude increase in overall network capacity.

The new deployment concept referred to as "Neighborhood Small Cells" (NSC), uses densely deployed open-access small cells and leverages existing premises and backhaul to greatly reduce capital and operational expenses for the operator. This deployment model is expected to provide huge capacity gains where a 10 percent penetration level of NSCs, a DL median throughput gain of ~25x to 55x can be achieved with an additional 10 MHz NSC carrier. NSC deployment can provide gains in the order of 10-100x when a single 10 MHz carrier is dedicated to NSCs. With additional spectrum, NSCs can conceivably provide a solution to meet the 1000x data demand.

Carrier Aggregation (CA) has been identified as a key technology that is crucial for LTE-Advanced in meeting IMT-Advanced requirements. The need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than those currently supported in LTE (up to 20 MHz) while at the same time ensuring backward compatibility with LTE. Consequently, in order to support bandwidths larger than 20 MHz, two or more component carriers are aggregated together in LTE-Advanced.

Even though LTE Rel-8 can support bandwidths up to 20 MHz, most American wireless operators don't have that much contiguous spectrum. In spectrum below 2 GHz most operators have between 5-15 MHz of contiguous spectrum in a single frequency band. Also many operators own the rights to use spectrum in many different bands. So from a practical perspective, carrier aggregation offers operators a path to combine spectrum assets within the bands they operate in and to combine assets across multiple frequency bands.

Under light network load conditions Carrier Aggregation devices can better utilize resources of the aggregated component carriers, rather than being restricted to a single carrier block of spectrum.

Supplemental Downlink (DL) is a form of asymmetric CA that can be utilized to improve the DL performance by combining paired DL and UL spectrum with spectrum that is assigned for DL only transmission. This is an attractive technology for assigning more radio resources in the downlink to improve the performance so that the radio resource capacity is more in accordance with the traffic payload demands.

New technology enhancements incorporated in user's mobile devices (i.e., user equipment "UE") are a double-edged sword. Technology enhancements to the devices improve spectrum efficiency and as well as help to address the 1000x traffic challenge. However the same

enhancements also act to encourage usage and thus foster demand for additional communications and feeding the 1000x traffic expansion. Improved screen sizes and resolution, for example, increase the demand for data communications to detail the higher quality images on the devices. The technological advancements planned for the mobile networks to enhance system performance will also be reflected in the future mobile devices. These include accessing additional spectrum, new methods of coding, advanced air interfaces, small cell deployments, heterogeneous networks and multiple antenna techniques. For each of these techniques there is a corresponding implementation within the mobile devices to improve the user experience and the system's capacity. The ability of the mobile devices to automatically adapt to a multiplicity of local network facilities and provide the user with a seamless experience is the fundamental basis for the networks to grow and evolve to deliver the 1000x traffic capacity.

The mobile device is the focal point of the 1000x environment as it must understand and adapt to the local network capabilities which may vary significantly from basic speech-services to multimedia data or from very large to very small cells, depending on the facilities of the local networks. The mobile devices are faced with the unique challenge of not only adopting the new technology features but also continuing to support the previous generations. Such a multiversity of modes and flexibility for operation across bands, radio access technologies and networks in support of the 1000x traffic challenge will be the major factor in the development of future mobile devices and the associated user service.

Section 4: Spectrum and Policy Innovation

This section explores spectrum considerations and some of the policy innovations that are required to meet the 1000x challenge. First, the section provides the current changing landscape and allocation of new spectrum, both licensed and unlicensed, and then explores the new policy initiatives in the Americas.

More spectrum, particularly more licensed spectrum, is essential to achieve the 1000x traffic requirements capacity. In fact, more contiguous spectrum, including for small cells deployment in higher bands and greater efficiency across the system, are all essential to reach this difficult, but critical, goal.

With regard to spectrum requirements, this section discusses in detail key initiatives, both long term and shorter term. While both licensed and unlicensed spectrum both play important roles in meeting the capacity needs, there is no substitute for licensed spectrum to deliver a predictable quality of service. However, it is increasingly difficult for governments to clear

additional spectrum in order to make it available for licensed mobile broadband. For that reason, spectrum policy innovation is important.

Moreover, as discussed in section 4.4 (spectrum harmonization), at the root of the phenomenal success and ubiquity of the global mobile communications services are the basic elements of "wide harmonized spectrum", "harmonized technical regulations" and "harmonized international standards." These elements have been, and will continue to be, the keys to reaping the economies of scale for global mobile services, the manufacturing of globally interoperable equipment and ensuring that all users can communicate with each other. The continuing growth of mobile communication services, at prices users can afford, will be predicated on the expanding global availability, or at least regionally availability, of harmonized spectrum assignments and common technical standards and communication protocols across multiple frequency bands. Although for example, the ITU spectrum allocation tables identify frequency bands internationally for IMT, differences in technical regulations between regions have led to there being more than forty different band plans defined for the mobile radio access standards. As the users of the mobile devices expect to roam among service providers with different bands, and globally across different regions, the number of band plan combinations from the choice of over forty standardized bands is rapidly increasing, which presents challenges for implementation in the small personal portable devices.

New spectrum assignments, if they are to take advantage of global economies of scale, must rely on technical regulations that are harmonized as much as possible. Meeting the 1000x data traffic challenge while continuing to reap the global economies of scale for newly designated mobile spectrum assignments, will only be possible if there is a concerted effort for harmonization at all levels of spectrum assignment, technical regulations and interoperability communications standards. The real advantage is for consumers to be able to enjoy the same breed of innovation and technological advancements in their devices, independent from the economic development of a certain country of residence. Since these new devices are not only voice centric, consumers are able to enjoy these innovations faster, creating new growth opportunities as it boosts the demand for higher speed networks. As the internet goes mobile and multiple markets increasingly use the same harmonized frequencies, buyers of the devices in multiple markets can gain important benefits from the economies of scale and scope.

As mentioned above and explained in greater detail in section 4.3 (new policy initiatives), new innovative spectrum policy will be crucial to sustain the exponential growth of mobile data traffic economically and efficiently at a time when policy makers are facing challenges in finding more cleared spectrum for mobile broadband. Policy makers will need to balance the different

approaches described above. The industry has understood the necessity to find alternative spectrum policy approaches in addition to cleared licensed spectrum (which often takes too long and is too costly) and to unlicensed spectrum (which is difficult to monetize as based on "best effort") but also to attain more "good" internationally harmonized spectrum.

Authorized/Licensed Shared Access (ASA/LSA) is a novel authorization scheme designed to help meet the 1000x mobile data challenge. It complements the two traditional authorization models – exclusive/cleared licensed and unlicensed – while enhancing spectrum harmonization on a regional and global level. That is, ASA/LSA can be used to unlock an underutilized spectrum band that would otherwise not be made available for a decade or more, if ever. ASA/LSA is an innovative spectrum sharing policy approach in the form of a binary framework granting individual exclusive spectrum rights of use for mobile broadband operations with the so-called "vertical" incumbent, defined as a current holder of spectrum rights of use which has not been granted through an award procedure for commercial use. It is not light licensing, secondary trading, TV white spaces or a 3-tiered priority approach model as proposed by the PCAST report. ASA/LSA allows sharing of underutilized spectrum on a non-interference basis with incumbents while permitting commercial offering of mobile broadband services with predictable quality of service.

As noted in particular in this section, the process of establishing an ASA/LSA regime is much more advanced in Europe, where both regulators/governments and industry (ETSI, Digital Europe, GSMA) have been working together to develop a stable and clear definition of ASA/LSA as predictability is key for investments in technologies and innovation.

Another example of policy innovation is Supplemental Downlink (SDL). In the past, relatively small unpaired blocks of spectrum could not be used for mobile broadband due to the size of the band, channelization and compatibility with other services, among other factors. However, these bands can be used in a highly efficient manner for mobile broadband through SDL. The 600 MHz, Lower 700 MHz, and L-band are all examples of bands that could be well suited for SDL.

Finally, the industry is committed to continue investing in the development of mobile broadband technologies to ensure that innovation will support consumer usage of mobile broadband in the most cost efficient way. In particular, and as an example, leveraging ASA/LSA in higher frequencies and using these spectrum bands with the new technology innovations described in the first section of the document (especially small cells, Self Organizing Networks (SON)/interference management, along with TDD technology and/or SDL) will meet the growing market demand for mobile broadband while ensuring sustainable long term investments.

Thus, technological innovation, coupled with massive investment, is necessary but not sufficient to reach the 1000x goal. The need for additional spectrum is vital to support mobile broadband growth. The industry needs fast track access to as much premium spectrum as possible for mobile broadband use and therefore, innovation in spectrum regulation must occur and ASA will be an essential regulatory instrument to alleviate this challenge. Additionally, as networks continue to evolve and expand, multi-vendor deployments will become common, and cells from multiple vendors will be required to self-configure and self-optimize jointly to meet the 1000x goal.

1. INTRODUCTION

1.1 1000X CHALLENGE AND NEED FOR ADDITIONAL CAPACITY

Globally, mobile data traffic has been approximately doubling each year during the last few years. The mobile communications industry is now working to meet a need for an estimated 1000x increase in traffic capacity for mobile access networks[2]. Of course, it cannot be predicted when the 1000x traffic growth will happen, however the wireless industry is currently experiencing a tremendous growth in mobile data traffic. For instance, China Mobile saw its data traffic more than double in the first half of this year[3]. Wireless data traffic jumped 129 percent in the first six months to 891.4 billion megabytes, up from 389.2 billion megabytes in the same period last year. Additionally, this steep growth for China Mobile in 2013 followed an increase of 187 percent in 2012. In Feb 2012, AT&T indicated, that mobile data traffic on their network grew more than 20,000 percent over the previous five years, more than doubling in 2011[4].

The traffic growth is happening as a consequence of the increase in the number of mobile network users together with the increase in the amount of information communicated by each user. The amount of information is affected both by the amount of data exchanged as well as the duration of sessions and the average data rate. The 1000x traffic growth challenge thus entails a combination of delivering more data bits, more quickly to many more users.

For instance, the data utilization per device has increased significantly[5] – the average amount of traffic per smartphone nearly tripled in 2011, 150 MB/month versus 55 MB/month in 2010. The average smartphone usage grew 81 percent in 2012, to 342 MB per month from 189 MB

[2] [Ref 1.1] Qualcomm CTIA 2013: http://www.qualcomm.com/media/documents/ctia-2013-qualcomm-1000x-mobile-data-challenge

[Ref 1.2] NSN blog: Beyond 4G networks carry 1000 times more traffic by 2020: http://blogs.nokiasiemensnetworks.com/mobile-networks/2011/08/24/beyond-4g-networks/

[3] [Ref 1.3] China Mobile data growth Aug 2013: http://www.china.org.cn/business/2013-08/16/content_29734856.htm

[4] [Ref 1.4] AT&T, Feb 2012: http://www.att.com/Common/about_us/files/pdf/ar2011_annual_report.pdf

[5] [Ref 1.5] Cisco white paper http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

per month in 2011. The mobile network connection speeds also more than doubled in 2012. Globally the average mobile network downlink speed in 2012 was 526 kbps up from 248 kbps in 2012. The average mobile network connection speed for smartphones in 2012 was 2.064 Mbps up from 1.211 Mbps in 2011. For tablets, the average mobile network connection speed in 2012 was 3.683 Mbps, up from 2.030 Mbps in 2011.

There are many facets of wireless access technologies which can contribute solutions towards the 1000x capacity challenge. Some of these solutions are already in development and there is a robust roadmap for many more. Conceptually, meeting the 1000x challenge is a combination of increasing the end-to-end system efficiency of existing and future wireless networks, deploying more resources in the form of small cells, additional spectrum, as well as innovative ways of acquiring, deploying and managing the combined resources.

One of the most significant technological innovations includes deploying more small cells, both indoor and outdoor, to create hyper-dense Heterogeneous Networks (HetNets). Such HetNets combine interference management techniques and self-organizing deployment solutions to bring the network capacity closer to the user where it is needed, especially indoors.

Traditionally, allocations of mobile spectrum to meet traffic growth have always lagged the need highlighted by various wireless data growth forecasts and hence spectrum and policy innovations are required to meet the 1000x capacity challenge. These include exploiting more spectrum in low bands (e.g. around 700 MHz) to benefit from its improved building penetration properties and in higher bands, (e.g. around 3.5 GHz) which is especially suitable for the small cells of HetNets.

While traditional spectrum allocation will continue to be a priority (both licensed and unlicensed), government and regulators around the world are facing significant challenges in making available spectrum and there is still a lack of harmonization and therefore scale. The availability of exclusive use licensing for spectrum is still considered the preferred model. Yet, we cannot simply rely on the traditional tools to clear incumbents off spectrum bands in order to yield enough spectrum for mobile broadband to keep up with demand. In some cases, it will take far too long to clear incumbents, yet these incumbents do not fully utilize the spectrum. Policy innovation such as Authorized Shared Access/ASA is needed to make use of these bands. Without ASA, these bands, although underutilized, cannot be made available for mobile broadband with the predictable quality of service that consumers demand.

The purpose of this white paper is to discuss the technical and regulatory techniques necessary to enable 1000x more capacity in mobile access networks over the next decade. In the sections that follow, this paper highlights the solutions that would cost-effectively enable growing the mobile access network to achieve 1000x more capacity.

1.2 NEED FOR TECHNOLOGY ENHANCEMENTS

Small cells are already being used in various mobile networks today. But, to reach 1000x capacity we would need an extreme densification of the network using many small cells everywhere: (a) indoors and outdoors, on lampposts and at all possible venues, residences and enterprises, (b) supporting all technologies—3G, 4G, Wi-Fi, (c) in all types and sizes—referred to as femtos, enterprise, picos, metros, relays, remote radio heads, distributed antenna systems etc. and (d) deployed by operators as well as users.

The network densification begins with using existing spectrum and enhancement techniques possible today. For example, small cell 'Range Expansion (eICIC)' introduced in LTE Advanced, and possible with HSPA+ today, can increase the overall network capacity much more than what can be achieved by merely adding small cells. Studies have shown that the overall capacity of these dense HetNets scale with the degree of small cells densification, thanks to interference management and self-organizing network solutions.

To reach the 1000x capacity goal, we cannot only rely on deploying small cells in the traditional 'planned' manner. Extreme densification of networks using small cells warrants a new low cost, ad-hoc deployment model with viral, 'unplanned' 3G/4G small cells deployed more like Wi-Fi. This requires plug and play small cells that are self-organizing and easily-deployable, both indoors and outdoors. These could be user-installed, leveraging the existing backhaul and power, however, they are always managed by operators, ensuring coordination with the macros and other small cells. These 3G/4G small cells can also be deployed ad-hoc by operators or partners such as utility providers at lampposts, walls, basically anywhere, resulting in a much lower cost deployment model.

Traditionally, operators plan a cellular network initially for coverage with macro sites and then expand for capacity with cell splitting of macro sites and additional small cells. This is typically done by using an outside-to-in approach, providing the capacity from an outside location to users both outside as well as indoors.

All indications are that most of the mobile traffic will be indoors. Therefore, it is obvious that there has to be a lot of focus on indoor deployments of 3G/4G and Wi-Fi small cells, in addition

to traditional macro networks. The relatively smaller size and cost of small cells makes them even more compelling for an inside-out deployment, therefore, we can also provide coverage to some of the outside traffic from the inside.

Moreover, the end-user can also deploy these small cells virally wherever there is power and backhaul available. One example would be dense residential areas where residents could rapidly deploy inside-out small cells – a deployment model usually referred to as 'neighborhood small cells'. Even a moderate penetration forms a neighborhood network, providing a huge amount of capacity for indoor traffic as well as support all the outdoor traffic in the neighborhood. These indoor small cells can provide good outdoor coverage and seamless handoff between small cells as well as with the macro network. This deployment model has many benefits, but a prime benefit is the lower cost compared to a traditional 'planned' operator deployed small cell model.

When making this huge increase in capacity a reality, it is equally important to ensure the implementation of advanced interference management techniques that will enable the hyper dense HetNets and take their performance to a new level. One example is the next generation Wi-Fi - 802.11 ac, which provides more than three times higher efficiency with even more improvements planned in the roadmap, compared to today's Wi-Fi.

There are also some specific enhancements that address the changing landscape of mobile broadband usage. For example, HSPA+ Advanced has mechanisms that can achieve more than 10x increases in the capacity for large applications such as web browsing, machine-to-machine, etc. LTE broadcast can provide substantial capacity gains for mass media compared to unicast (normal video streaming). The industry is also working on solutions to dynamically switch to broadcast when multiple users desire to view the same content.

Smart devices and services can substantially increase performance and user experience; for example, selecting the most suitable radio access among all available options (3G/4G/Wi-Fi, small cell, Macro, etc.) based on the type of application/service being used.

However, as we will see in the next section and the rest of this white paper, technological solutions alone cannot get us to 1000x. We also need more spectrum and policy innovations in the way spectrum is provided.

1.3 NEED FOR POLICY INNOVATION

Reaching the goal of 1000x traffic capacity in future mobile access networks will make use of the many technology enhancements to increase the spectral efficiency, add more small cells

and make denser networks. However, achieving a 1000x traffic gain will also require availability of more spectrum. To date, the traditional policy approaches to commercial spectrum allocation and management have been the mainstream and will continue to be, especially since the mobile broadband industry continues to need cleared, exclusive, licensed spectrum as its highest priority. However, given that most spectrum is already allocated to multiple services, making more spectrum available for mobile services in a timely and affordable manner will need new innovative policies, which will be useful especially in situations where traditional approaches deem extremely difficult or impractical. There are three models for spectrum administration:

1) **Licensed approach for mobile broadband use** – Under this regulatory framework, stakeholders obtain access, through appropriate market-based licensing, to exclusive spectrum rights over a geographical region, resulting in quality of service and predictable performance. This is the traditional approach for spectrum assignment, and it requires that the spectrum be cleared of the previous service use before it is available to the new service users in a reasonable timeframe. For example, the 3G/4G mobile networks and the broadcast TV services are operated using the exclusive licensed model.

2) **Unlicensed approach for shared use (like Wi-Fi)** – Under this license-exempt approach, no single entity is assigned exclusive control over the spectrum and multiple services share the assignment (e.g. radars in the 5 GHz band or with ISM e.g. 2.4 GHz). Without a single controlling entity there may be interference among disparate systems and hence individual system performance may be unpredictable, and the use has to be more opportunistic. For example, Wi-Fi networks are typically deployed using the unlicensed model. For suitable traffic levels, they deliver very satisfactory services to the users.

3) **Authorized/Licensed Shared Access for mobile broadband** — ASA/LSA is a third complementary way of authorizing spectrum when incumbent spectrum is underutilized and not able to be cleared at all locations and times in a reasonable timeframe. ASA framework is binary as an ASA licensee enjoys exclusive spectrum rights where and when the spectrum is not used and when the incumbent grants the ASA license use of the spectrum at a given place and time ensuring interference protection, quality of service and predictability. ASA applies for under-utilized spectrum of incumbents which has not been granted rights of use under a competitive assessment. The key benefits of ASA are to unlock globally harmonized mobile bands.

In the licensing of new spectrum for mobile access services, policy innovations are needed to permit the licensing of spectrum in higher frequency bands (such as 2.3, 3.4, 3.5 and 3.8 GHz bands), as well as in the ranges of the existing bands. The higher frequency bands are ideal for small cell deployments and authorized shared access because of the smaller coverage of these bands. Moreover, small cells are well suited for ASA because of their lower transmit power. For example, small cells can be deployed geographically closer to incumbent spectrum holders, but macro cell deployments are also possible farther away. Policy innovations are required to enable the authorised sharing model and establish expectations among the sharing partners.

The initial focus of ASA is to target globally harmonized bands for which commercial devices are either already available in the market (for other regions) or will soon be available. Examples of these bands include the 2.3 GHz band in Europe and the 3.5 GHz band in the USA.

To further facilitate the offloading of mobile traffic to smaller cells, policy innovations may be required to make available additional unlicensed spectrum. Unlicensed spectrum dedicated to Wi-Fi, especially for next generation Wi-Fi, is a key technology to enable high density and high traffic access within buildings. For example, there is an effort ongoing in the USA to allocate an additional 195 MHz of spectrum in the 5 GHz bands. Policy innovations may be required to ensure the unlicensed sharing model will continue to meet access service expectations among the users.

2. WHY 1000X CAPACITY?

2.1 TRAFFIC GROWTH DURING THIS DECADE

Widespread adoption of wireless broadband, fuelled by success of the smartphones has resulted in tremendous growth in traffic volumes in mobile networks in recent years. With the introduction of smartphones and tablets, mobile devices have evolved from being used predominantly for talking into a versatile communication companion. We spend more and more time being connected to the internet over a mobile device and today the U.S. consumer spends an average of 2 hours and 38 minutes per day on smartphones and tablets[6].

[6] [Ref 2.1] Flurry Five-Year Report, April 2013: http://blog.flurry.com/bid/95723/Flurry-Five-Year-Report-It-s-an-App-World-The-Web-Just-Lives-in-It

More than 133 million people in the US already own a smartphone[7] and that number is growing. The traffic growth will be further driven by larger-screen devices and video rich tablets, Machine-to-Machine (M2M) applications and soon also the connected vehicle and home.

Although the smart devices are used in multiple ways, video traffic drives the growth. Not only does the video content consume more resources than many other applications, faster and bigger smart devices coupled with advanced wireless networks have led to increasing adoption of video content. According to Cisco Visual Networking Index (VNI), mobile video traffic is already over 50 percent of mobile data traffic, and is expected to account for 66 percent of global mobile data demand by 2017[8].

According to Cisco VNI, the global mobile data traffic grew 70 percent in 2012 with strongest growth in countries such as Japan and Korea where 4G penetration is high. According to this Cisco report, the global mobile data traffic is expected to grow steadily at CAGR of 66 percent from 2012 to 2017, which means a 13-fold increase over 2012 and over 11.2 exabytes per month by the end of 2017.

[7] [Ref 2.2] comScore Reports, February 2013: http://www.comscore.com/Insights/Press_Releases/2013/4/comScore_Reports_February_2013_U.S._Smartphone_Subscriber_Market_Share

[8] [Ref 2.3] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017, February 2013 http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf

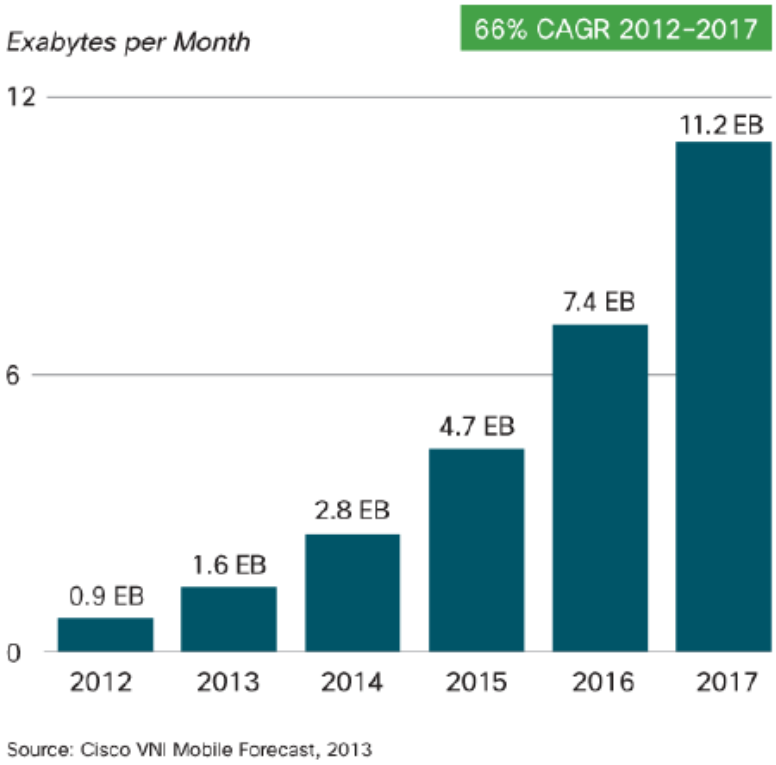


Figure 2.1. Global Mobile Data Traffic growth 2012 to 2017.[9]

Other companies have provided similar evidence on the expected data traffic growth. For example Ericsson Mobility Report[10] shows that mobile data traffic exceeded mobile voice traffic already in 2009 and that data is growing at a steady rate whereas voice traffic growth remains at moderate single digit growth per annum. In fact, this Ericsson report shows that mobile data traffic doubled in 2012 and is expected to grow with a CAGR of around 50 percent between 2012 and 2018, which entails growth of around 12 times by the end of 2018. Qualcomm[11] and Nokia Solutions and Networks[12] have both advocated a '1000x' increase in data traffic, driven

[9] Cisco VNI

[10] [Ref 2.4] Ericsson Mobility Report, June 2013: http://www.ericsson.com/ericsson-mobility-report

[11] [Ref 2.5] Qualcomm The 1000x Data Challenge: http://www.qualcomm.com/solutions/wireless-networks/technologies/1000x-data

[12] [Ref 2.6] NSN blog: Beyond 4G networks carry 1000 times more traffic by 2020: http://blogs.nokiasiemensnetworks.com/mobile-networks/2011/08/24/beyond-4g-networks/

by the increase in number of mobile broadband users as well as increase in the average data consumption by a user.

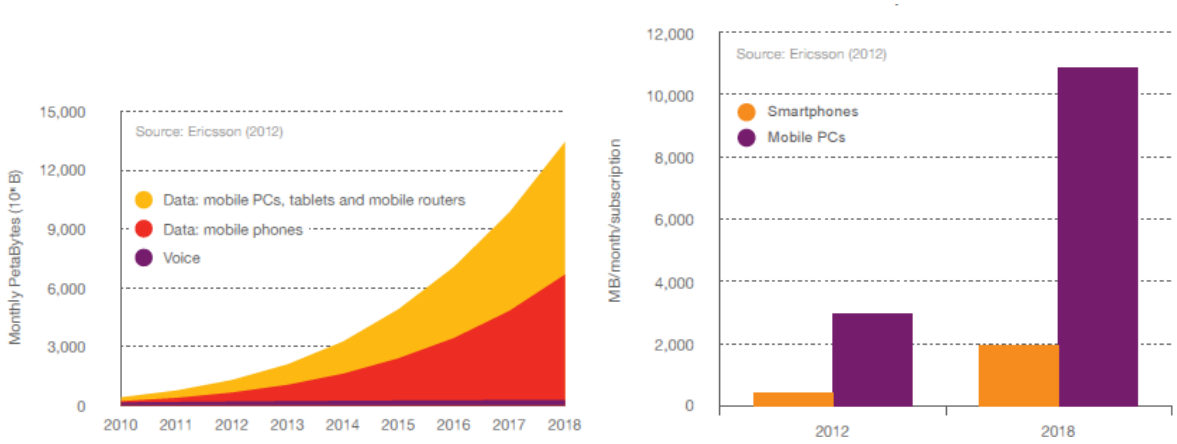


Figure 2.2. Global mobile traffic (voice and data) 2012-2018 and average traffic per smartphone and mobile PC in 2012 and 2018. [13]

All the information and traffic growth predictions are showing demand for data that could overwhelm the wireless network resources due to finite and limited spectrum availability even though technology evolution is improving the efficiency and capacity of the wireless networks. To be ready to accommodate the growth, the wireless industry needs additional spectrum and associated policy innovation.

2.2 NEED FOR 1000X DATA DEMAND

The need for additional spectrum is also recognized internationally. The International Telecommunication Union (ITU) is the internationally recognized entity chartered to produce an official definition of the next generation of wireless technologies. Its Radio Communication Sector (ITU-R) has established an agreed and globally accepted definition of 4G wireless systems that is inclusive of the current multi-dimensioned and diverse stakeholder universe. Another important aspect is the establishment of the spectrum needs that mobile data growth would require, and ITU has worked extensively on this. The methodology for calculating the spectrum requirements for future development includes a mix of services, radio access techniques and complementary systems. These inputs are used to create a complex multi-dimensional model accommodating a diversity of services and market demand scenarios with

[13] Ericsson Mobility Report

forward-looking technology aspects. The results are not only global, but also show the variance on a regional basis.

The ITU-R report M.2078 on estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced, establishes recommendations for the allocation of sufficient radio spectrum to allow for the proper development of IMT-2000 and IMT-Advanced while taking into account the mobile operator needs for additional spectrum in a mobile data dominated world.

Report ITU-R M. 2078 recognizes the regional differences and outlines the need for a minimum amount of spectrum allocated for IMT-2000 and IMT-Advanced, for the years 2010, 2015 and 2020 depending on the market development status. For simplicity's sake, the markets are categorized as either lower market setting or higher market setting. The ITU report also classifies the spectrum requirements by Radio Access Technology Group (RATG). RATG 1 covers pre-IMT and IMT, as well as enhancements to IMT, and RATG 2 is comprised of IMT-Advanced.

Table 2. Predicted spectrum requirements for IMT and IMT-Advanced Technologies.[14]

Market Setting	Spectum Requirement for RATG 1 (MHz)			Spectum 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. North America is an example of a higher market setting, and the 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.

[14] International Telecommunications Union (Report ITU-R M. 2078)

3. TECHNOLOGY ENHANCEMENTS TO MEET 1000X CHALLENGE

3.1 TECHNOLOGY INNOVATIONS TO DRIVE MACRO CELL PERFORMANCE EFFICIENCY

3.1.1 EVOLUTION OF HSPA, LTE AND WI-FI

Deriving increased efficiencies from macro cells with new innovations will be the first step in addressing the 1000x challenge. This will allow the operators to leverage their existing macro cellular infrastructure network in a cost effective manner to increase capacity. There are several efforts currently underway to make the data pipe even more efficient, by evolving 3G, 4G and Wi-Fi. 3G, 4G and Wi-Fi have well established and strong evolution paths, successively increasing capacity, data rates and user experience. An overview of the upcoming enhancements in 3G, 4G and Wi-Fi technologies is given in the sections below:

HSPA Evolution:

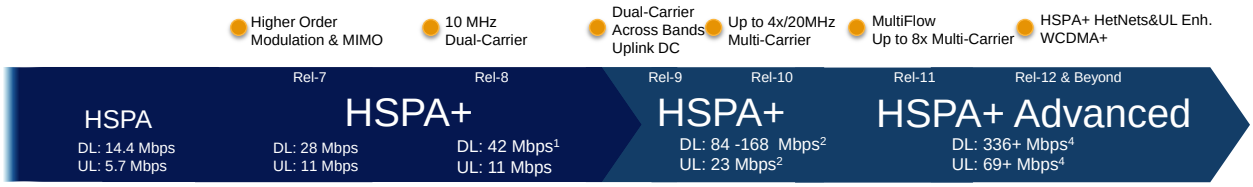


Figure 3.1. Evolution Roadmap of 3G Technologies.[15]

One of the latest enhancements to HSPA technologies is Dual Cell HSDPA (DC-HSDPA) introduced in Release 8 of the 3GPP specifications which enables the User Equipment (UE) to receive downlink data on two adjacent carriers simultaneously. While the uplink aggregation is added in Rel-9; Releases 10, 11 and 12 have standardized 3G systems to be available in swaths of 40 MHz spectrum for both downlink and uplink[16]. The Multi-Carrier HSPA (MC-HSPA) technology combined with MIMO 4x4 features for downlink and 2x2 for uplink provides operators the means to offer higher data rates to all users in the cell, and thus providing an

[15] Source: Qualcomm.

[16] [Ref 3.1] The Evolution of HSPA: The 3GPP Standards Progress for Fast Mobile Broadband Using HSPA+ by 4G Americas, October 2011; http://www.4gamericas.org/documents/4G%20Americas%20White%20Paper_The%20Evolution%20of%20HSPA_October%202011x.pdf

enhanced mobile broadband experience. The following Figure 3.2 shows the increased peak data rates HSPA+ technology is positioned to offer over the upcoming releases.

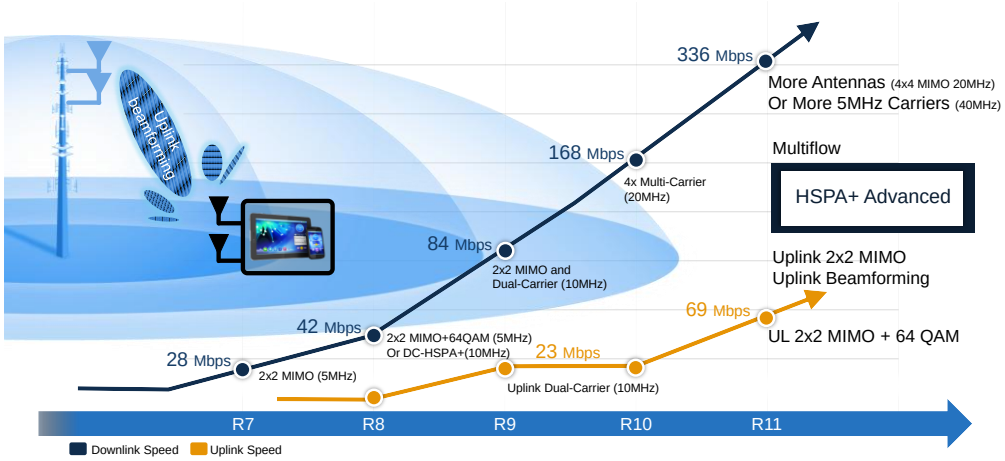


Figure 3.2. Downlink and uplink data rate evolution for various releases of 3GPP HSPA+.[17]

MC-HSPA in a combined eight 5 MHz carriers in Rel-11 will provide peak data rates of 336 Mbps in the downlink and 69 Mbps in the uplink. The MC-HSPA also provides significantly increased sector throughput and serves a greater number of users with better burst rates compared to single carrier systems in equivalent spectrum.

[17] Source: Qualcomm.

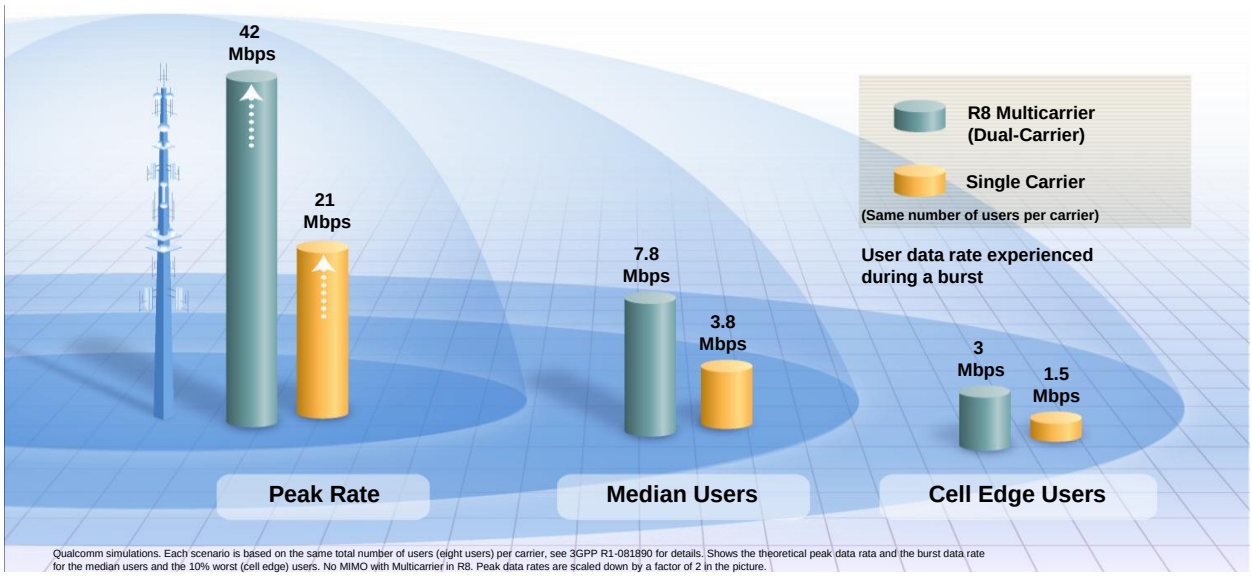


Figure 3.3. Simulation results showing the DC-HSPA+ performance benefits in comparison with Single Carrier HSPA+ for peak, median and cell edge users.[18]

MC-HSPA leverages the existing operator network resources and enables operators to offer customers a much higher quality mobile broadband experience. MC-HSPA also significantly increases the number of users that can be supported per carrier for a given user experience in the context of applications with bursty data.

[18] Source: Qualcomm.

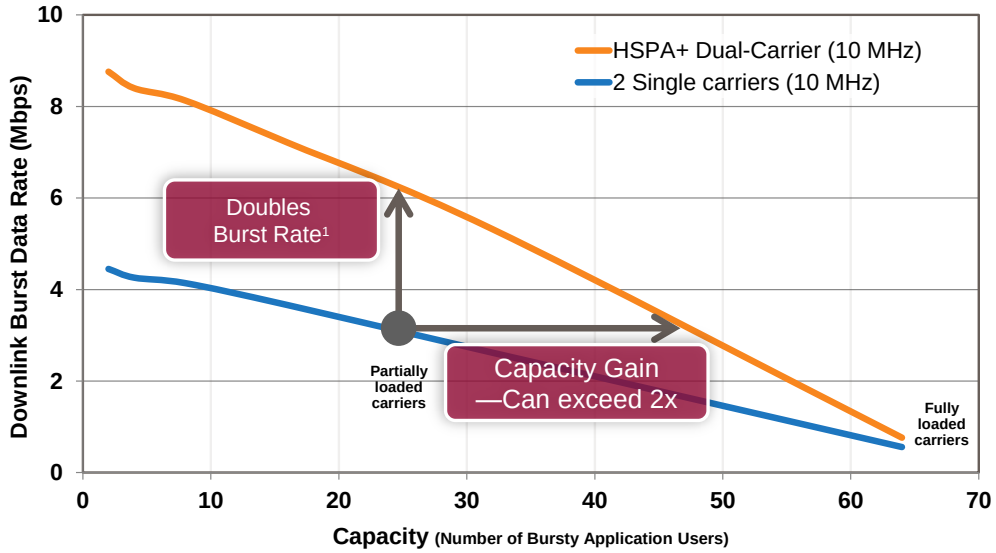


Figure 3.5. Performance results showing the benefits of DC-HSPA+ downlink burst data rates and user capacity in comparison with 2 single carriers of HSPA+.[19]

LTE Evolution

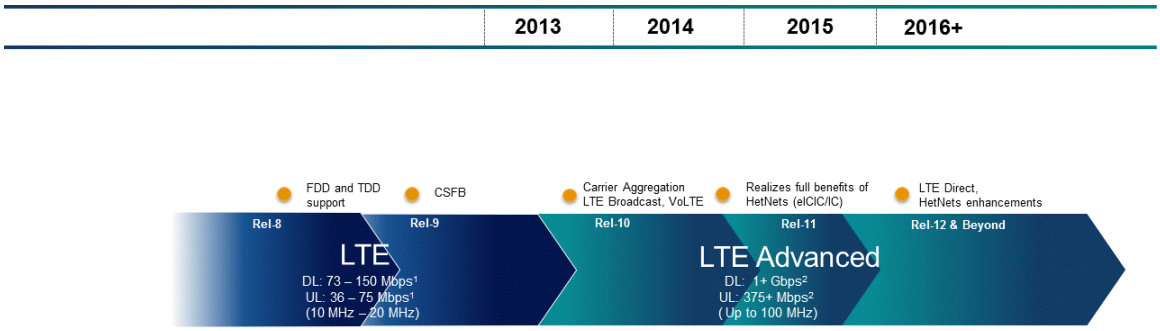


Figure 3.5. Evolution Roadmap of 4G Technologies.[20]

[19] Source: Qualcomm.

[20] Source: Qualcomm.

The LTE technology that is currently commercial in several operators' networks is deployed in FDD up to 10 MHz bandwidth and 20 MHz in TDD. The LTE-Advanced technology is geared towards providing greater flexibility with wideband deployment in much wider bandwidth with carrier aggregation across bands providing enhanced spectral efficiencies, sector throughput and user experience. The LTE-Advanced technology is designed to provide higher peak rates of more than 1 Gbps downlink in 100 MHz and over 375 Mbps for the uplink using higher order DL and UL MIMO.

Section 3.4 provides an in depth discussion of the details of LTE carrier aggregation. However, the evolution of LTE-Advanced is primarily about flexible and faster deployment using heterogeneous networks using a mix of macro, pico, relay, femto, RRH. Fundamental to LTE-Advanced is providing a robust interference management for improved fairness. An important goal for LTE-Advanced is providing better coverage and user experience for cell edge users. A more in depth discussion on the evolution of 3G and 4G technologies can be found in Ref 3.2[21].

Wi-Fi Evolution

The Wi-Fi access points and networks which have been a major source of data offloading from the cellular networks are expected to play a vital role in meeting the 1000x data capacity challenge. The Wi-Fi evolution as depicted in Figure 3.6 shows 802.11ac is the next-gen Wi-Fi technology that provides significant enhancements in data capacity. 802.11ac provides ~3 times higher capacity per stream compared to 802.11n. 802.11ac uses the relatively interference free 5 GHz band and wider channels to provide user data rates over Gbps. In the next phase of evolution, 802.11ac extends the MIMO feature to include multi-user MIMO and provides 3 times the capacity of the first phase by simultaneously serving multiple, but spatially separated users, using the same resources[22].

[21] [Ref 3.2] Mobile Broadband Explosion: The 3GPP Wireless Evolution, by Rysavy Research for 4G Americas, August 2012;
http://www.4gamericas.org/documents/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%2020121.pdf

[22] [Ref 3.3] IEEE802.11ac: The Next Evolution of Wi-Fi by Qualcomm, May 2012;
http://www.qualcomm.com/media/documents/ieee80211ac-next-evolution-Wi-Fi

The Wi-Fi "Family" also has a strong evolution path in 802.11ad which is being promoted by WiGig Alliance and which uses bandwidth rich 60 GHz spectrum. 802.11ad provides multi-gigabit data rates and is especially suited for short range applications. It is worthwhile noting that 60 GHz is a globally harmonized band with up to 9 GHz of spectrum available in many countries. The initial targets for application are wireless docking, followed by wireless display, in-room wireless audio and video in the coming future. The 802.11ah technology is still in its infancy. The standard is still being conceived and developed by the industry, and is slated for the sub- GHz bands, targeting home/building applications with multi-year battery life.

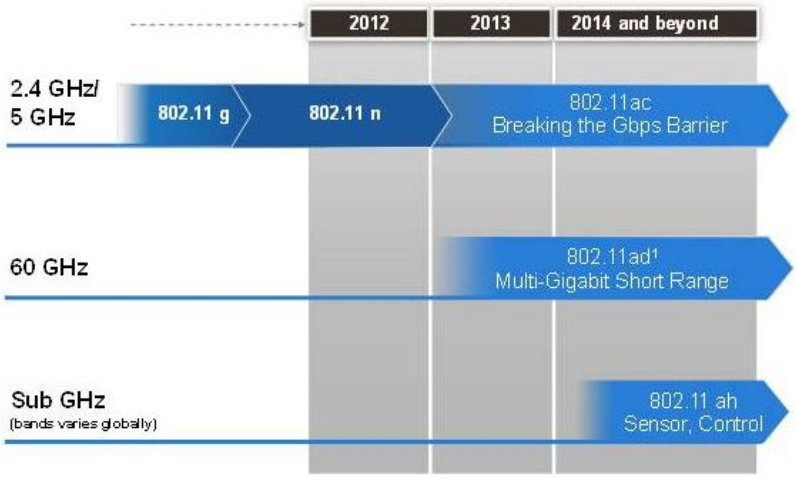


Figure 3.6. Evolution Roadmap of Wi-Fi Technologies.[23]

3.1.2 MULTIFLOW AND SMART NETWORKS

One of the important challenges that must be addressed for macro cellular networks is the cell-edge data rates that continues to be significantly lower than average. Many cellular networks today are plagued with issues of capacity saturation and inadequate cell edge performance. However, neither the capacity nor the quality potential of the network as a whole is fully reached. Adjacent sectors and frequency carriers are often unevenly loaded; different

[23] Source: Qualcomm

topological layers in the network (e.g. macro, pico, femto) are sometimes unevenly loaded as well.

Most UEs with poor serving cell data rates can often receive signals from other cells which are yet fully exploited in HSPA+ and LTE networks. The next step in the evolution of 3G and 4G technologies must take all this into consideration. Multipoint HSPA is a new feature currently under study in 3GPP with the objective of addressing some of the aforementioned issues while leveraging existing transceiver capabilities of the network and UEs. The following are some of the benefits that are conceived of multipoint smart networks:

- Improved user experience at the cell edge
- Efficient and dynamic load balancing across sectors in single-carrier deployments
- Efficient and dynamic load balancing across sectors / carriers in multicarrier deployments
- Leverage DC-HSPA / MC-HSPA capabilities of the network and UEs by means of incremental hardware and software upgrades

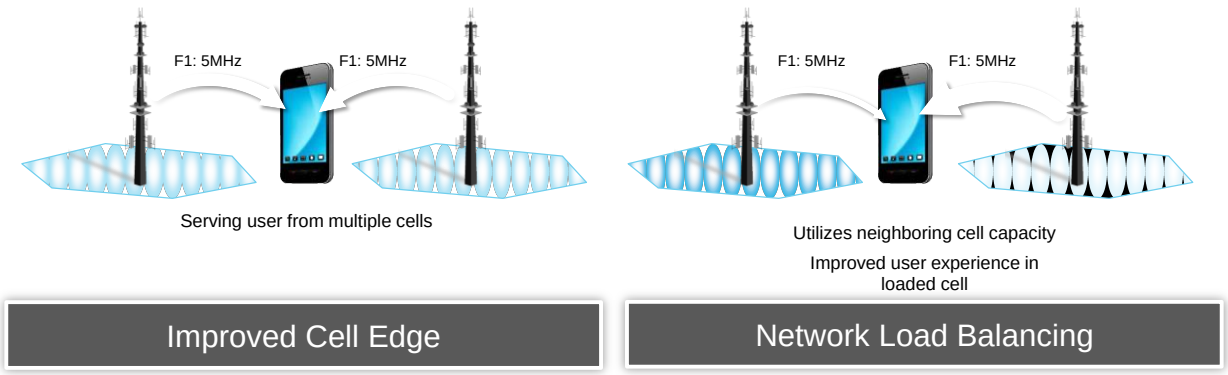


Figure 3.7. Illustration of Multipoint Multi-Flow Smart Networks.[24]

Smart Network Techniques improve network efficiency and user experience exploiting dynamic and uneven loading conditions across sectors, differential network topologies and differential UE capabilities. The smart network techniques essentially leverage MC UE capabilities to

[24] Source: Qualcomm

deliver a more uniform experience across the network. These techniques enable efficient and dynamic load balancing across sectors using inter-node and intra-nodeB multipoint transmission [Ref 3.4][25].

There are multiple types of multi-flow depending on the frequency carriers that are used in the deployment. The Single Frequency Dual Carrier (SFDC) HSPA multi-flow feature essentially improves 5 MHz Deployments. The Dual Frequency Dual Carrier (DFDC) and Dual Frequency Four Carrier (DF4C) HSPA systems optimize 10 MHz and 20 MHz Systems. DFDC allows UEs to aggregate carriers from Two Different Sectors. Depending on the load on each sector/carrier, UTRAN can decide on which combination of sector/carrier to serve UEs. Devices with 4 Rx chains could take advantage of multipoint transmission while still being served with two carriers (e.g., R9 UE with MIMO and DC or R10 UE with 4C-HSPA support) have similar chipset complexity that can be leveraged to enable tradeoff of MIMO or 4 carrier aggregation to multipoint.

There are multiple scenarios where Multipoint Smart Networks provide compelling gains:

- Rural/Sub-Urban One Carrier Deployments and 5 MHz Systems (e.g., 900 MHz, India)
- Voice Primarily On One Carrier and Second Carrier for Data

[25] [Ref 3.4] HSPA+ Advanced: Taking HSPA+ to the Next Level Whitepaper by Qualcomm, February 2012; http://www.qualcomm.com/media/documents/hspa-advanced-taking-hspa-next-level-0

The following figure shows the improvements in the throughput gains for UEs at a low geometry in cell-edge situations.

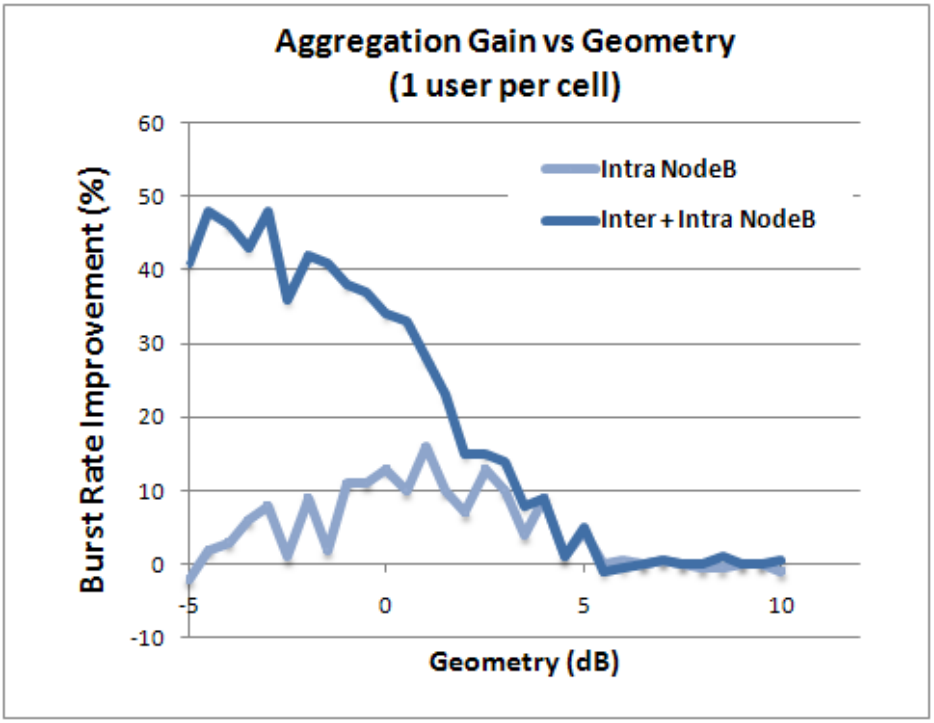


Figure 3.7. Simulation results showing the improvements in cell-edge data rates due to multi-point multi flow smart networks.[26]

It can be noted that low Geometry UEs see burst rate improvements by 30 percent - 50 percent with Inter + Intra -Node-B, whereas with Intra-Noted-B the improvements are between 0 percent - 15 percent.

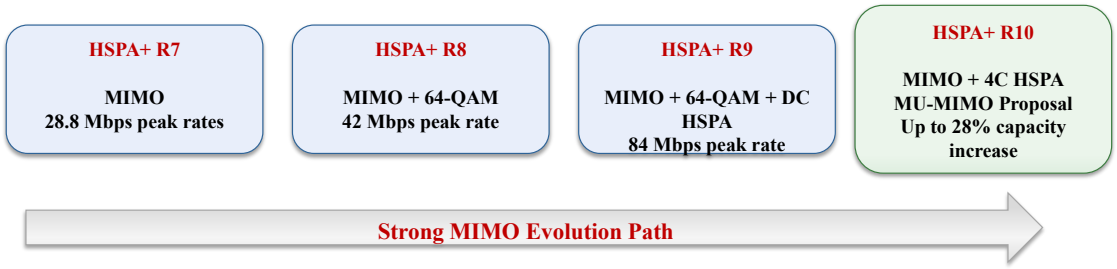
[26] Source: Qualcomm

This section particularly focused on the enhancements that are underway with HSPA+ technologies with multi-flow concepts, but similar efforts are underway in LTE-Advanced evolution.

3.1.3 ANTENNA ENHANCEMENTS

Antenna enhancements are going to play a key role in enhancing macro cellular efficiencies in the upcoming future. Multiple antennas can be used in a multitude of ways in a cellular system to increase coverage, system capacity and user data rates without additional power or bandwidth[27]. A MIMO system consists of multiple transmit and receive antennas plus signal processing at both transmitter and receiver – HSPA+ supports 2x2 DL MIMO. HSPA+ with MIMO provides high peak rates and system capacity. MIMO gains are strictly dependent on the user channel conditions. The following are various benefits of a MIMO enabled cellular technology:

- MIMO spatial multiplexing enables very high data rate transmissions to users close to the base station
- Beam forming increases user data rates for cell-edge users by focusing the transmit power to the direction of the user, enabling higher receive SINR at the terminal
- Beam forming along with spatial multiplexing in a cellular system provides higher user data rates at both high and low SINR regions.



[27] [Ref 3.5] MIMO and Smart Antennas for Mobile Broadband Networks By 4G Americas, October 2012, http://www.4gamericas.org/documents/MIMO%20and%20Smart%20Antennas%20for%20Mobile%20Broadband%20Systems%20Oct%202012x.pdf

Spatially separated users with orthogonal beams from Node B can benefit from MU-MIMO

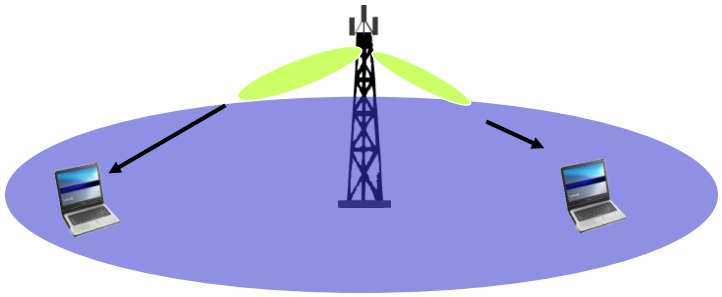


Figure 3.8. Evolution of MIMO implementation techniques in HSPA+ technologies.[28]

Further, using MU-MIMO, significant capacity increases over MIMO can be achieved with minimal network and UE changes. MU-MIMO increases DL system capacity by allowing spatially separated users to use the same code resources. MU-MIMO provides up to 28 percent capacity increase over SU-MIMO.

3.1.4 TRAFFIC MANAGEMENT

In the midst of multiple radios and in various available licensed and unlicensed spectrum, intelligent traffic management techniques are going to play a critical role in meeting the 1000x data challenge.

Making the pipe more intelligent helps to reap the efficiencies even further. It is about ensuring the pipe to be able to distinguish the type of data and the apps it is carrying, and thereby select the most optimal radio link and delivery channels among the options it has. For example, it is about the pipe determining whether 3G/4G or Wi-Fi or a LTE Broadcast service or a Device-to-device communication is a better fit for the app/data that is being transferred.

There is another important aspect to Traffic Management and that is the best utilization of the licensed and unlicensed spectrum. In a smart selection of 3G/4G or Wi-Fi technologies for service, a carrier can essentially utilize licensed spectrum for high value core data while opportunistically and seamlessly offloading lower-value traffic to un-licensed spectrum (Wi-Fi)[29]. However, this involves making the Wi-Fi network smarter and this will be primarily driven

[28] Source: Qualcomm

[29] [Ref 3.6] Traffic Management and Offload Strategies for Operators; (January 2011) By Qualcomm; http://www.qualcomm.com/media/documents/traffic-mgmt-and-offload-strategeies-operators

by standards enhancements, combined with device intelligence to achieve smart opportunistic Wi-Fi offload.

To make Wi-Fi smarter, one of the measures is to enable seamless discovery of Wi-Fi and authentication by using the 3G/4G SIM based credentials of the users, unlike what is being done today finding the Wi-Fi, providing user id/password, and connecting. Smarter Wi-Fi will enable devices to find usable Wi-Fi on its own and connect without user intervention.

Another measure is to implement operator mandated policies where operators decide a priority the apps/services/traffic that will go through 3G/4G and the ones through Wi-Fi. At the same time, it is also necessary to support seamless service continuity where services active during the transition between 3G/4G/Wi-Fi continue to operate without interruption. These standards enhancements are essential but it is necessary to incorporate intelligence in the devices to optimally select 3G/4G/W-Fi.

Meeting 1000x challenge requires all these enhancements in the sphere of traffic management and also features that make the selection even more refined allowing simultaneous connection to both 3G/4G and Wi-Fi data.

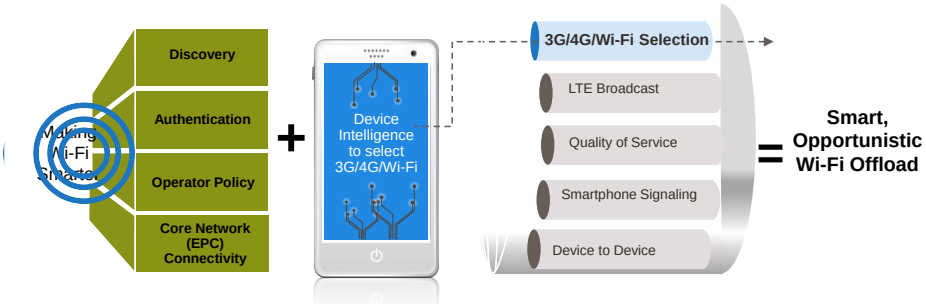


Figure 3.9. Illustration of techniques achieving smart opportunistic Wi-Fi offload.[30]

3.2 TAPPING INTO SMALL CELLS POTENTIAL

To meet the 1000x challenge, effective solutions are required to bring new data capacity at a much lower cost. In this regard, small cells will play a quintessential role in serving the data needs over the coming years. Radio link performance is fast approaching theoretical limits. The next performance and capacity leap is now expected to come from an evolution of network topology by using a mix of macro cells and small cells in a co-channel deployment.

[30] Source: Qualcomm

HetNet densification is clearly a way forward, i.e., many small cells are required and they will be deployed indoors, outdoors, at all possible venues such as residences, enterprises, in all technologies (3G, 4G, Wi-Fi), in all various mode such as indoor residential, enterprise, picos, relays, remote radio heads, distributed antenna systems, etc. The various types of small cells should complement the traditional macro networks, and allow denser use of spectrum.

The introduction of Heterogeneous Network (HetNet) techniques in LTE-Advanced and HSPA, including intelligent interference coordination methods in the network, offers a more promising and scalable path to achieve tremendous growth in spectrum efficiency per unit area.

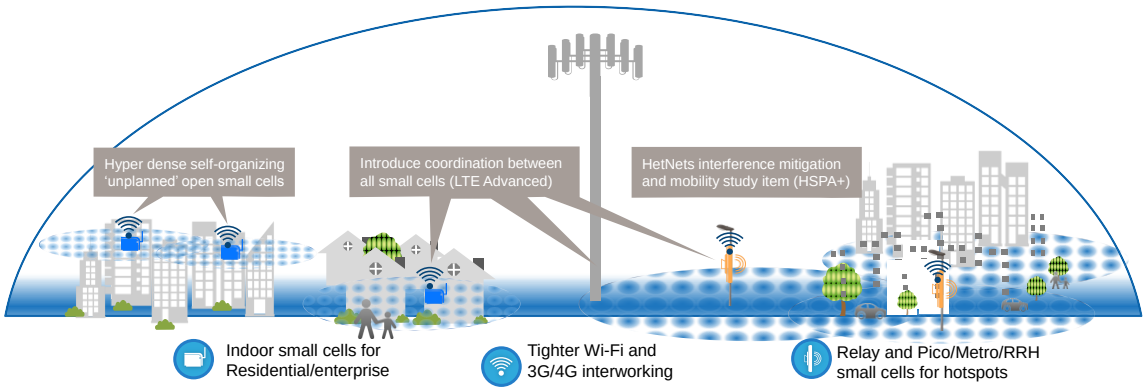


Figure 3.12. A typical heterogeneous network scenario in which various types of small cells and macro cells coexist to provide enhanced data capacity and user experience.[31]

The traditional way of building a cellular network is to use big macro cells, allowing good coverage of a particular area without the need for too many expensive cell sites. As the wireless data demand grows over the next decade, macro cell-splitting can become economically and logistically unfeasible as the cost of hardware, site acquisition and complexity of network planning can be beyond the practical limits. Operators are therefore looking to smaller form factor base stations which can be deployed in a wider range of locations.

With reducing size, lower RF transmit power and thus shorter ranges, self-organizing small cells will play an integral role in cellular networks and enable operators to meet the 1000x demand

[31] Source: Qualcomm

challenge. It is crucial to have small cells providing supplemental data by deploying them appropriately in a variety of venues[32] such as:

- Offices and residences (from single-family homes to high-rise buildings)
- Public hotspots (shopping malls, airports, train/subway stations, stadiums)
- Outdoor public areas sites (such as lamp posts)

A range of different Radio Access Technologies (RATs) and Wi-Fi will all co-exist, and macro cells will be complemented by a multitude of small cells, such as micro, pico and femto cells to fulfill the anticipated growth in capacity as discussed in the previous sections[33].

3.2.1 EXTREME DENSIFICATION OF SMALL CELLS

Capacity gains of macrocells from using more spectrum, optimization and improved efficiency are unlikely to be enough to keep up with the traffic demand increase, and so extreme cell densification will be needed too. Small cells are already accepted in the industry as a main stream solution. Enhancements such as small cell "Range Expansion" introduced in LTE-Advanced are even possible with HSPA+ today providing verily needed traffic offload from macro networks and improving the overall network capacity more than merely adding small cells.

However, to reach 1000x capacity, more small cells, indoor and outdoor, basically everywhere, are needed to create hyper-dense HetNets. However to get to 1000x cost effectively, we also need to evolve to a lower cost viral, ad-hoc viral plug-and-play deployment model for 1000x. We also need to put more small cells indoors—more inside-out-deployments—that could even be deployed by the end-user. Extremely dense deployment of small cells essentially brings the network closer to the user and provides capacity where needed. These networks are called hyper-dense HetNets which in turn has its own system level challenges requiring more sophisticated interference management and self-organizing network solutions.

[32] [Ref 3.7] Nokia Siemens Networks Small Cells Brochure @ http://us.nokiasiemensnetworks.com/downloads

[33] [Ref 3.8] Nokia Siemens Networks Flexi Zone @ http://us.nokiasiemensnetworks.com/portfolio/solutions/heterogeneous-networks/flexi-zone

3.2.2 SMALL CELLS FOR OUTDOORS AND INDOORS

Outdoor small cells today are deployed primarily in dense urban areas, with deployment levels dictated mainly by the service level that operators need to provide to their customers at given locations. An outdoor street level small cell network can help operators provide indoor penetration through up to three interior walls in the customer trading floor area of the shops, restaurants and cafes, etc. in that street.

The outdoor solution would in such cases need to be complemented by a significant amount of in-building wireless installations like femtos or Distributed Antenna Systems (DAS) as traffic grows much beyond ten times the base value. When indoor traffic in dense areas is well-defined and fully-confined, operators may in some cases be able to progress directly to deploying in-building wireless systems like femtos or DAS, supplemented only by macro-level outdoor upgrades and later, outdoor small cells.

Adding further capacity using indoor small cells seems to be inevitable, especially for larger indoor locations such as malls, tube/train stations and enterprises which would require a dedicated indoor small cell deployment. Although outdoor small cells are important for hot spot and hot zone areas, they may be insufficient as a stand-alone solution for provisioning very high capacity and QoS to indoor users, especially when deep in-building penetration is needed.

Further, it is widely known and understood that most of the mobile traffic will be indoors. Thus, there is a need to focus on indoor deployments with 3G/4G and Wi-Fi small cells, in addition to traditional macro networks. There is also an added benefit that wireless traffic coverage can be extended outside from the inside, a reversal of what we have witnessed so far.

A new innovation in small cell technology is currently being proposed that allows simple plug-and-play deployment in indoor locations enabling orders of magnitude increase in overall network capacity [Ref 3.9][34]. The new deployment concept, referred to as "Neighborhood Small Cells" (NSC), uses densely deployed open-access small cells and leverages existing premises and backhaul to greatly reduce Capital Expenditure (CapEx) and Operational Expenditure (OpEx).

[34] [Ref 3.9]Neighborhood Small Cells for Hyper-Dense Deployments: Taking HetNets to the Next Level; by Qualcomm, February 2013; http://www.qualcomm.com/media/documents/neighborhood-small-cell-deployment-model

A Neighborhood Small Cell network consists of small cells deployed by the end user or an operator with no or minimal RF planning in a variety of places including user residences, small offices, enterprise buildings, public places, lamp posts, cable junction boxes at street corners, etc. Unlike a traditional "closed" access small cells (aka femtocells) deployment model, NSCs have "open/hybrid" access to serve all subscribers belonging to an operator.

Open access small cell deployment has the advantage that users can be served on the best downlink providing the best performance. Whether located indoors or outdoors, an open access NSC provides coverage and capacity for both indoor and outdoor users and thus serves the entire neighborhood. More details and an illustration of Neighborhood Small Cells are provided in Appendix I.

Figure 3.11 show NSC performance evaluated in terms of improvement in UE DL throughput or equivalently DL capacity in a deployment of 10 MHz macro + 10 MHz NSC relative to baseline macro-only (10 MHz) deployment. Performance is evaluated for different NSC penetrations {2,5,10,20,30,50} percent that correspond to {14,36,72,144,216,360} NSCs per macrocell, respectively. The gain shown is for the DL median throughput for 25 and 200 active UEs simultaneously per macrocell. At 10 percent penetration level of NSCs, a DL median throughput gain of ~25x to 55x is achieved with an additional 10 MHz NSC carrier. Gains are attributed to cell splitting as well as improvement in SINR compared to macro deployment as users get closer to their serving NSC.

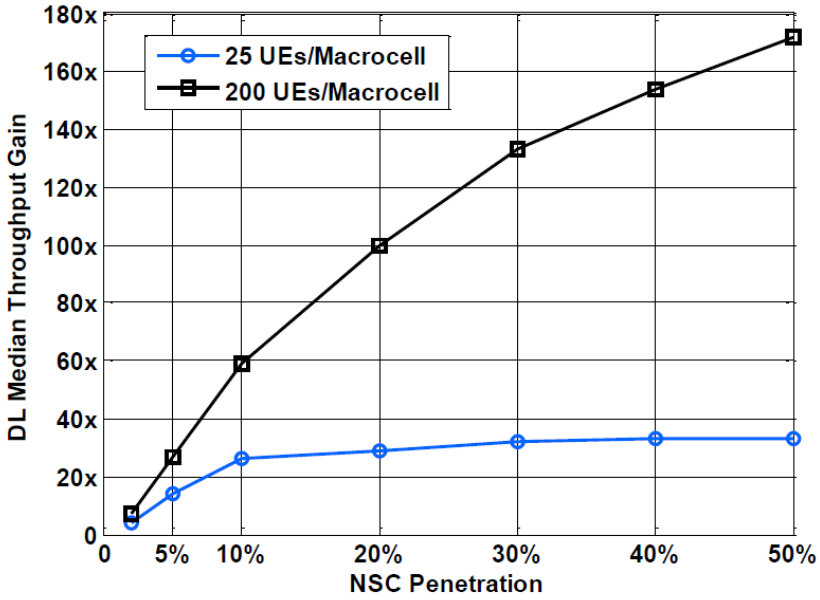


Figure 3.11. DL user throughput gains for a (10 + 10) MHz NSC deployment relative to 10 MHz macro carrier baseline for 25 or 200 active users per macrocell area.[35]

As shown through these results, NSC deployment can provide gains in the order of 10-100x when a single 10 MHz carrier is dedicated to NSCs. With additional spectrum, NSCs can provide a solution to meet the1000x data demand.

3.2.3 INNOVATIONS IN SMALL CELL DEPLOYMENT

A number of innovations will be in order with increased densification of small cells and to ensure operation in complex heterogeneous systems with a variety of access points, both small and big. Operating and optimizing complex heterogeneous systems presents several key challenges, such as how to distribute traffic efficiently between cells, RATs and layers while guaranteeing seamless user mobility, how to alleviate the impact of interference and how to adapt the system efficiently to meet changing traffic demand[36].

[35] Source: Qualcomm

[36] [Ref 3.10] 3GPP TR 36.872 V0.21.0 (2013-05), "Small Cell Enhancements for E-UTRA and E-UTRAN, Physical Layer Aspects, (Release 12)"

Here are some of the key focus areas:

Traffic steering and mobility management

Traffic steering allows operators to optimize their resources, improve the way users experience services and minimize power consumption by directing the traffic to a particular RAT or layer. Traffic steering is a tool for reducing OPEX and limiting or postponing CAPEX, especially in complex heterogeneous systems. Traffic steering works hand-in-hand with mobility management to ensure a reasonable number of handovers and avoid radio link failures. It also needs to consider other factors such as the capabilities of the terminals and network, the delivery of services and quality of service (QoS), the load in different RATs and layers and power consumption.

Interference management

Inter-cell interference is already one of the limiting factors in today's mobile communications systems, especially in dense, urban deployments. The problem is even worse in the context of multi-layer networks. If both the macro cell and the smaller cell are using the same radio resources (so-called co-channel deployment), interference problems can occur. Interference can be attenuated or increased if the cell border is shifted towards the larger or smaller cell, for example, by traffic steering or mobility management. Smart resource reuse is required when interference cannot be avoided by physical means. It may be better to split interfering entities onto orthogonal resources (divided by time or frequency). An optimal scheme would let adjacent cells cooperatively decide upon resource usage, requiring complex signaling between cells. A more pragmatic approach is to employ static resource reuse concepts:

Reserve some resources for macro-only, small-cell-only or constrained usage - so-called fractional frequency reuse. Escape carrier concepts are a good example, where dedicated carriers are reserved for macro usage only. LTE Release 10 includes a feature that allows recurring time slots to be reserved for some layers, referred to as enhanced inter-cell interference coordination (eICIC). eICIC only works if base stations can be time synchronized and terminals have good measurement capabilities.

Certain layers may be allowed to access some resources only with a reduced transmission power. This is called soft frequency reuse. Power control parameters can be adjusted to either define a power offset to be used by all the elements in a particular layer and/or to apply power capping. This is an effective way to trade the performance of some layers against others, for example, by improving macro cell-edge performance at the price of small cell performance.

Co-Channel Deployments: Another important consideration for small cell densification in existing spectrum is sharing the spectrum with the macro network in a so called 'co-channel' deployment. The need is to provide a uniform user experience to users anywhere inside a cell — by changing the topology of traditional networks.

Traffic Offload to Small Cells: One key example is small cell range expansion, which effectively increases the utilization of the small cell such that more users can reach higher data rates and enjoy enhanced user experience. For the operator, this means more value out of the small cell investment.

Energy saving

Energy efficiency is increasingly important in terms of reducing both CO2 emissions and costs. Since the base stations consume the lion's share of energy in a typical network, efficiency is particularly crucial in dense heterogeneous systems.

While replacing old base stations with more power-efficient single-RAN equipment is the most intuitive option, major savings can also result from enabling systems to turn off access points when they are not needed. In a homogeneous network of cells, all but a certain pattern of cells might be turned off, reducing the cell density and increasing the size of the remaining cells. In multi-layer deployments, operators may switch off the smaller layer of cells in off-peak situations, so that the larger cells can take over without changing the coverage area.

3.2.4 SON ENHANCEMENTS

Growing demand for low-cost mobile broadband connectivity is driving the development of heterogeneous cellular networks. Projections point to rapidly growing numbers of small cells such as micro, femto and picocells (in order to drive greater coverage and/or offload capacity from macrocells), plus increasing prevalence of multi-technology networks (2G, 3G, 4G, plus Wi-Fi). These trends pose potentially significant operational and network complexity regarding macro/femto and inter-technology handover, as well as management of macro/femto and macro/pico interference.

To enable plug-and-play deployment of small cells and provide the above mentioned benefits, it is essential to incorporate specialized SON features to small cells[37]. As small cells are deployed in an unplanned manner, in the same frequency channel as the macro carrier, several challenges must be addressed: 1) how to minimize downlink interference to macro users, 2) how to reduce or eliminate uplink noise that might affect neighboring small cells and macro cells, and 3) how to provide seamless mobility for users in idle and connected modes.

Taken together, these trends place ever-increasing demands upon service providers' networks and their operational staff. Ensuring quality user experience requires more complex Quality of Service (QoS) and policy implementations while they simultaneously must increase network throughput in response to the rapid growth in wireless data. As networks continue to evolve and expand, multi-vendor deployments will become common and cells from multiple vendors will be required to self-configure and self-optimize jointly to meet the 1000x goal.

There are several innovations made in this arena of SON basically to mitigate these problems with automated solutions in the following areas:

- **Self Configuration:** Small cells need to self configure in such a way so that they seamlessly integrate and operate satisfactorily with the existing small cell macro network and provide excellent performance, regardless of their location within a residence or an enterprise within the macro network.

- **Mobility Management** Small cells need to discover neighbors autonomously to facilitate UE handover to neighbors. When handover happens, the source small cell can help maintain robustness by streamlining the handover to the target cell. Dense deployment of small cells creates many cell boundaries and leads to potentially more handovers. Frequent handovers can be mitigated by first identifying the cause. If the user is stationary and ping-ponging between small cells, handover parameter adjustments can be done to slow down the handovers. If the user is classified as a fast moving UE, transmissions can be handed over to the macro cell layer.

[37] [Ref 3.11] Self-Optimizing Networks - The Benefits of SON in LTE, by 4G Americas, July 2011; http://www.4gamericas.org/documents/Self-Optimizing%20Networks-Benefits%20of%20SON%20in%20LTE-July%202011.pdf

- **Tx power Management** The RF environment is constantly changing and each small cell needs to adapt its transmit power as small cells are being added, relocated or removed to maintain continuous coverage and avoid pilot pollution.

- **Resource and Interference Management** Small cells deployed in the same channel as macro cells need to coordinate with macro cells to determine the optimal resource partitioning and maximize traffic offloading to small cells. Load balancing and resource partitioning among different small cells is also crucial to improving the user experience.

- **Backhaul Management** Bandwidth of customer-grade backhaul cannot be guaranteed. When small cells experience limit in backhaul bandwidth, they should prioritize user classes as needed.

3.2.5 ADOPTING NEW KINDS OF SMALL CELLS

Deploying tens or hundreds of thousands of small cells brings significant new challenges. For example, the extra control traffic generated in these heterogeneous networks could swamp the transport and core networks, creating substantial interference between the macro- and small-cell networks and thus backhaul bottlenecks must be avoided. Therefore, with a storm of data heading their way, network operators are looking for new approaches to ease the traffic load on their existing infrastructure. One such innovative approach consists of setting up a zone covered by a cluster of low-power access points connected to a local controller. This configuration enables operators to provide a remarkably rich user experience while offloading unwanted data traffic from their macro and core networks.

3.2.6 RELAYS FOR WIRELESS BACKHAUL SOLUTIONS

Small cell transport is a key area to address to ensure viable small cell deployment. Mass deployment of small cells will be gated by the availability of cost-effective backhaul solutions. Wired transport solutions include fiber to the "x" (FTTx) and hybrid fiber-coaxial (HFC) installations. Wired backhaul cannot always be an option if good fiber access conditions are not present in the small cell deployment area. For such cases, wireless transport is the only solution for deployment of small cells[38].

[38] [Ref 3.12] "Small Cell Backhaul Requirements", A White Paper by the NGMN Alliance, 4th June 2012

Additionally, even in cases where both transport options may be viable, wireless backhaul may be preferable due to its higher flexibility for small cell installations and elimination of time-consuming construction or planning work. Even a change of the site location will not lead to big cost deltas for relocation of wireless hops.

For small cell sites deployed at the street level, Line of Sight (LOS) approaches will become challenging, especially as small cells become densely deployed and given a high presence of dynamic obstacles such as trucks, vegetation, etc. New transport topologies are emerging to support deployment of small cells. In many cases, near LOS (nLOS) or Non-LOS (NLOS) wireless backhaul solutions will be required. Such technologies may be deployed as point to point (P2P) wireless interworking (e.g. pole to pole).

Alternatively, small cell connectivity may be provided to a street cluster from a high roof top site (referred to as Street-Egress) as either P2P or point to multi-point (P2MP). Street Egress deployments may be suitable for higher frequency LOS transport technologies. In addition, mesh topologies can be used to provide path protection and as a way to circumvent obstacles, essentially providing a NLOS path even though there is no LOS from end-to-end. Mesh systems are not yet common in transport, but they constitute one promising future small-cell technique.

One of the key market requirements for small cell backhaul interconnect is the ability to connect the cluster of APs to the controller via wireless backhaul links. Wireless backhaul solutions are necessary to ease network installation requirements. Unlike the traditional LOS microwave backhaul that has been widely used for macro cellular backhaul, small cell wireless backhaul comes with its own unique challenges and limitations:

- Deployment is on the street level where trees, buildings, other clutters and foot/vehicle traffic can impact the wireless backhaul link performance in many ways unforeseen in the traditional tower level microwave backhaul deployment.
- The wireless backhaul technology has to be very cost-effective, maybe an order of magnitude more cost effective that the traditional microwave wireless backhaul.
- There is no one-size-fits-all small cell wireless backhaul radio that can be deployed in LOS, nLOS and NLOS environment.
- Street level deployment has to support aesthetic enclosure options to meet village zoning requirements.
- It needs to assist in support of a variety of synchronization options for dense urban under-ground deployments where the GPS signal is either too weak or not available.
- An integrated wireless backhaul solution with the AP is preferred to minimize the number of boxes on a lamppost or utility post. Some municipal regulation places

restriction on the number of boxes that can be installed on lamppost and street fixture alike.

- Preferred small cell wireless backhaul should support Self-Discovering, Self-Aligning and Self-Healing to minimize installation time and truck-rolls.
- 1-touch rollout with plug-and-play operation:
    - Post Physical Installation and power-up, the node must automatically discover its peers, establish backhaul connectivity and download its personality and operation information from network servers.

Relays are mobile network base stations, which connect to the network via an in-band wireless backhaul link instead of using a dedicated wired or microwave backhaul link as regular base stations do. In-band relaying means that the same radio resources are used both by relays and by customer user equipment (UE) such as mobile terminals. On the access side, in-band relay serves those subscribers in a coverage hole due to building penetration losses, or due to extreme shadowing by buildings or foliage, or may be due to extreme path loss into underground railway facilities.

On the backhaul side, relays can use advantaged antenna locations or elevated antennas or directional antennas for superior wireless backhaul performance[39]. However, one drawback of relays is that they consume prime spectrum which could otherwise have been used for access. Therefore relays are best used to fill coverage holes in areas which do not have a high amount of traffic. If the coverage hole does have a high amount of traffic, then a traditional backhaul solution should instead be used.

Another variant of relay for wireless backhaul solution is the out-of-band relay which basically allows the wireless backhaul to "zigzag" through urban clutters to compensate for the lack of direct line of sight (LOS). It can also be used to extend the range of the small cell wireless backhaul link for hard-to-reach sites located in, e.g., underground, street canyons, etc. An out-of-band small cell wireless backhaul relay operating as a PtP/PtMP extension in the urban clutter is typically achieved by putting together one or two backhaul units on a lamppost to

[39] [Ref 3.13] "On Backhauling of Relay Enhanced Networks in LTE-Advanced", "Ömer Bulakci, Aalto University School of Electrical Engineering, Espoo, Finland, Licentiate Seminar, Department of Communications and Networking, Aalto University, 2010

extend the connectivity and penetrate deep into urban clutter locations that do not have direct line of sight[40].

3.2.7 LEVERAGING HIGHER BAND SPECTRUM

All other things being equal under the free space line of sight condition, a signal propagating at higher frequencies would be expected to decay faster than a signal in lower frequency bands. For instance, based on the simple free space path loss model 3.5 GHz band is expected to yield approximately 29 percent reduced range compared to Broadband Radio Service/Educational Broadband Service (2.5 GHz), 45 percent compared to Personal Communications Service (1.9 GHz), and 75 percent compared to the Cellular bands (850 MHz). These range limitations would be even greater in attenuated environments, where higher frequency signals are less prone to penetrate building materials.

The 3.5 GHz band, considered purely from a radio propagation standpoint, holds great potential for small cell applications and is the subject of an FCC Notice of Proposed Rulemaking and Order. Small cell use could turn some of the perceived disadvantages of the band into advantages. Small cell deployments inherently require less range to meet users' needs than macrocell networks. Moreover, limited signal propagation can facilitate dense deployment of small cells with a reduced risk of harmful interference to geographically or spectrally adjacent users, greatly increasing frequency reuse and available network capacity.

On the other hand, the signal propagation at 3.5 GHz is still viable for non-line-of-site use, allowing for flexible network topologies. In short, given the characteristics of the band, the 3.5 GHz Band appears to be a good candidate for small cell uses[41]. Additionally, the band's characteristics make it well-suited to spectrum sharing, particularly geographic sharing.

The limited propagation – especially in combination with low-power operation – should allow disparate radio systems to operate in closer proximity than lower frequency bands. This feature of the band should enable greater sharing opportunities with incumbent systems (such as radars and satellite communications networks) with appropriate geographic separation and

[40] [Ref 3.14] "LTE Relay Node Self-Configuration", Péter Szilágyi, Henning Sanneck, Nokia Siemens Networks Research, 12th IFIP/IEEE IM 2011: Application Session

[41] [Ref 3.15] FCC NOTICE OF PROPOSED RULEMAKING "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band", FCC Docket No. 12-354

other mitigation techniques such as resilient and flexible technologies. It also raises the possibility of greater sharing between disparate commercial systems in the band.

As mentioned before, wireless backhaul is a key component of small cells deployment. Higher bands can also be used for wireless backhaul as explained in the table presented in Appendix I.

3.3 HETNET EVOLUTION

One important requirement for the existence of future hyper dense HetNets is interference coordination and mitigation to improve overall capacity, and enhanced mobility and user experience. Several techniques are considered in LTE-Advanced and HSPA+ technologies to coordinate the transmission resources between small cells as well as macrocells. For HSPA+, a study item has been introduced in the 3GPPstandards to find solutions to improve mobility and mitigate interference in HetNet.

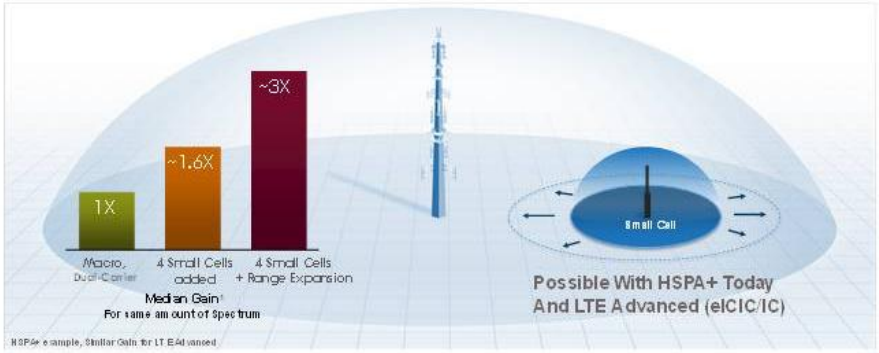


Figure 3.13. HSPA+ DL average and cell edge user throughput improvement with advanced HetNet techniques in a macro + 4 pico cell scenario.[42]

The above HSPA+ example shows that data capacity can be more than doubled on top of the gain by just adding four small cells and applying range expansion on a small cells deployment which shares the spectrum with the macro base station. This is possible with HSPA+ today, so no new standards or devices are necessary, we just need to tweak some network parameters

[42] Source: Qualcomm

and adjust base station transmit power levels. LTE-Advanced will provide similar gains utilizing interference management features referred to as eICIC in the standards (enhanced Inter Cell Interference Coordination), combined with Advanced Receivers with interference Cancellation (IC).

3.3.1 INTELLIGENT HETNETS

Heterogeneous networks, utilizing a diverse set of base stations, can be deployed to improve spectral efficiency per unit area. A typical heterogeneous cellular system consists of regular (planned) placement of macro base stations that transmit at high power level (~5W - 40W), overlaid with several pico base stations, femto base stations and relay base stations, which transmit at substantially lower power levels (~100mW - 2W) and are generally deployed in a relatively unplanned manner.

In a homogeneous network, each mobile terminal is served by the base stations with the strongest signal strength, while the unwanted signals received from other base stations are usually treated as interference. In a heterogeneous network, such principles can lead to significantly suboptimal performance. In such systems, smarter resource coordination among base stations, better server selection strategies and more advanced techniques for efficient interference management can provide substantial gains in throughput and user experience as compared to a conventional approach of deploying cellular network infrastructure.

LTE-Advanced Heterogeneous Networks (HetNets) use a mix of macro, pico, femto and relay base stations, effectively bringing the network closer to the user. To deliver high spectral efficiency per unit area, advanced techniques are applied to manage and control interference when low power small cells are added to macro cells in the same channel. Two techniques: enhanced Inter-cell Interference Coordination and advanced terminal receivers with interference cancellation (eICIC/IC) are paramount to provide a performance leap for heterogeneous networks in LTE-Advanced[43].

LTE-Advanced HetNets will support Range Expansion and Resource Partitioning with an eICIC software upgrade to a LTE network. Range Expansion allows more user terminals to benefit directly from low-power base stations such as picos, femtos and relays.

[43] [Ref 3.16] LTE Advanced: Heterogeneous Networks by Qualcomm, January 2011; http://www.qualcomm.com/media/documents/lte-heterogeneous-networks

Adaptive inter-cell interference coordination uses Almost-Blank Subframes (ABS) to provide smart resource allocation amongst interfering cells and improves inter-cell load balancing in heterogeneous networks. Advanced terminal receivers cancel interference of legacy overhead channels in ABS from interfering cells to enable full Range Expansion of low-power small cells. Adaptive inter-cell interference coordination provides smart resource allocation amongst interfering cells and improves inter-cell "fairness" in a heterogeneous network.

The LTE-Advanced eICIC feature has been standardized in 3GPP Rel. 10 while the device requirements for interference cancellation receivers have been specified in Further enhanced ICIC (FeICIC) of Rel. 11.

3.3.2 RANGE EXPANSION ENHANCEMENTS

Range expansion allows more user terminals to benefit directly from low-power small cells such as picos, femtos and relays.

A pico base station is generally characterized by a substantially lower transmit power as compared to a macro base station, and a mostly ad hoc placement in the network. Because of unplanned deployment, most cellular networks with pico base stations can be expected to have large areas with low signal-to-interference conditions, resulting in a challenging RF environment for control channel transmissions to users on the cell edge. More importantly, the potentially large disparity (e.g., 20dB) between the transmit power levels of macro and pico base stations implies that in a mixed macro/pico deployment, the downlink coverage of a pico base station is much smaller than that of a macro base station.

This is not the case for the uplink; where the strength of the signal received from a user terminal depends on the terminal transmit power, which is the same for all uplinks from the terminal to different base stations. Hence, the uplink coverage of all the base stations is similar and the uplink handover boundaries are determined based on channel gains. This can create a mismatch between downlink and uplink handover boundaries, and make the base station-to-user terminal association (or server selection) more difficult in heterogeneous networks, compared to homogenous networks, where downlink and uplink handover boundaries are more closely matched.

If server selection is predominantly based on downlink signal strength, as in today's typical cellular networks, the usefulness of pico base stations will be greatly diminished. In this scenario, the larger coverage of high-power base stations limits the benefits of cell splitting by attracting most user terminals towards macro base stations based on signal strength without

having enough macro base station resources to efficiently serve these user terminals. Lower power base-stations may not be serving any user terminals.

Even if all the low-power base stations can use available spectrum to serve at least one user terminal, the difference between the loadings of different base stations can result in an unfair distribution of data rates and uneven user experiences among the user terminals in the network. Therefore, from the point of view of network capacity, it is desirable to balance the load between macro and pico base stations by expanding the coverage of pico base stations and subsequently increasing cell splitting gains. This concept is called range expansion, and a detailed overview is presented in reference [3.16].

3.3.3 INTERFERENCE MANAGEMENT: ENHANCED INTERFERENCE COORDINATION AND CANCELLATION

In a heterogeneous network with range expansion, in order for a user terminal to obtain service from a low-power base station in the presence of macro base stations with stronger downlink signal strength, the pico base station needs to perform both control channel and data channel interference coordination with the dominant macro interferers and the user terminals need to support advanced receivers for interference cancellation. In the case of femto base stations, only the owner or subscribers of the femto base-station may be allowed to access the femto base stations.

For user terminals that are close to these femto base stations but yet barred from accessing them, the interference caused by the femto base stations to the user terminals can be particularly severe, making it difficult to establish a reliable downlink communication to these user terminals. Hence, as opposed to homogeneous networks, where resource reuse one (with minor adjustments) is a good transmission scheme, femto networks necessitate more coordination via resource partitioning across base stations to manage inter-cell interference.

As a result, Inter-cell Interference Coordination (ICIC) is critical to heterogeneous network deployment. A basic ICIC technique involves resource coordination amongst interfering base stations, where an interfering base station gives up use of some resources in order to enable control and data transmissions to the victim user terminal. More generally, interfering base stations can coordinate on transmission powers and/or spatial beams with each other in order to enable control and data transmissions to their corresponding user terminals.

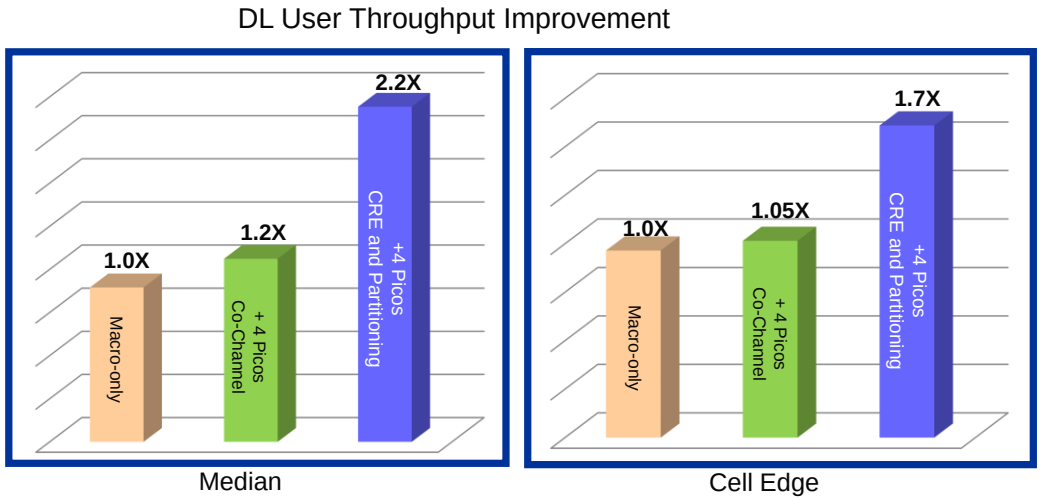
The resource partitioning can be performed in the time domain, frequency domain, or spatial domain. Time domain partitioning can better adapt to user distribution and traffic load changes and is the most attractive method for spectrum-constrained markets. For example, a macro base station can choose to reserve some of the sub frames in each radio frame for use by pico stations based on the number of user terminals served by pico and macro base stations and/or based on the data rate requirements of the user terminals.

For time-domain resource partitioning, a macro base-station can use almost blank sub frames (ABSF) to reserve some sub frames for picos. The macro base-station keeps transmitting legacy common control channels during ABSFs to enable full backward compatibility with legacy user terminals. The user terminals can cancel interference on common control channels of ABSF caused either by higher power macro stations or by close-by femto stations that the user terminals are prohibited to access.

The function of the advanced receiver is illustrated in Ref [3, 9]. The interference cancellation receiver fully handles colliding and non-colliding Reference Signal (RS) scenarios and removes the need for cell planning of heterogeneous deployment.

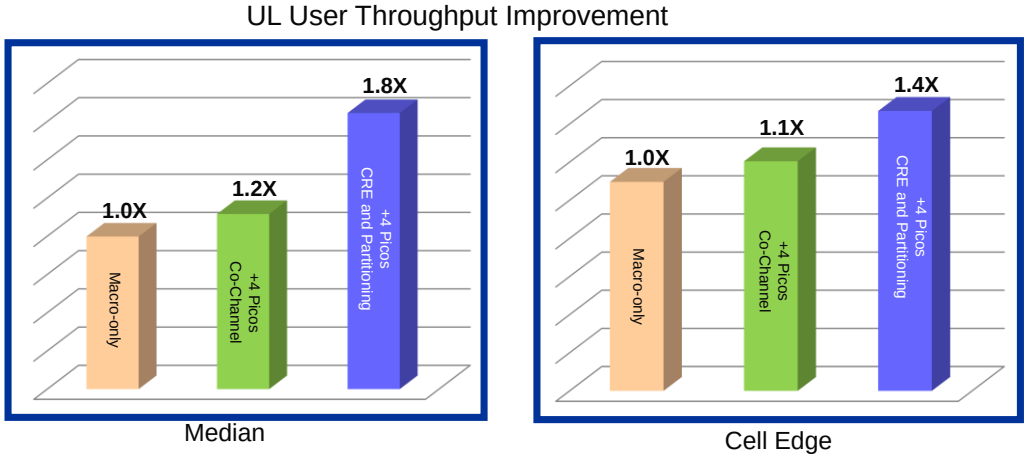
The potential performance improvement from LTE-Advanced heterogeneous networks can be demonstrated in an example with mixed macro/pico deployment. The 3GPP evaluation methodology specified in [2] is used with configuration 1 (uniform layout). The network consists of macro base-stations (with 46dBm transmit power and 16dB antenna gain) and pico base-stations (with 30dB transmit power and 5dB antenna gain), with and without heterogeneous network enhancements.

Figure 3.14 shows the user data rate improvement using heterogeneous network features for downlink while Figure 3.15 shows the same improvement for uplink, both with macro inter-site distance (ISD) of 500 meters and 4 pico cells per macro base station. As seen in the figures, both cell-edge and median user rates are improved significantly as the result of the intelligent server selection and advanced interference management techniques described in the following sections.



Simulation results based on Qualcomm prototype implementation and 3GPP evaluation methodology TR 36.814
Macro ISD = 500m, 2GHz carrier frequency, full-buffer traffic, 10 degree antenna downtilt, cell edge user is defined as 5 percentile rate user
4 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, 10 MHz FDD, 2x2 MIMO, TU3 channel, NLOS, local partitioning algorithm

Figure 3.14. DL average and cell edge user throughput improvement with advanced HetNet techniques in a macro + 4 pico cell scenario.[44]

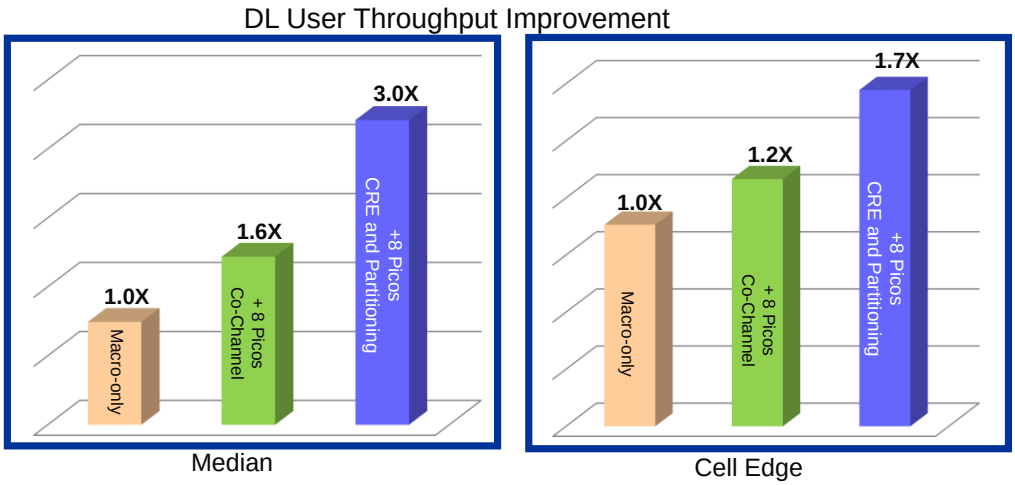


Simulation results based on Qualcomm prototype implementation and 3GPP evaluation methodology TR 36.814
Macro ISD = 500m, 2GHz carrier frequency, full-buffer traffic, 10 degree antenna downtilt, cell edge user is defined as 5 percentile rate user
4 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, 10 MHz FDD, TU3 channel, NLOS, local partitioning algorithm.

Figure 3.15. UL average and cell edge user throughput improvement with advanced HetNet techniques in a macro + 4 pico cell scenario.[45]

[44] Source: Qualcomm

[45] Source: Qualcomm



Simulation results based on Qualcomm prototype implementation and 3GPP evaluation methodology TR 36.814
Macro ISD = 1.7km, 700MHz carrier frequency, full-buffer traffic, 6 degree antenna downtilt, cell edge user is defined as 5 percentile rate user
8 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, 10 MHz FDD, 2x2 MIMO, TU3 channel, NLOS, local partitioning algorithm

Figure 3.16. DL average and cell edge user throughput improvement with advanced HetNet techniques in a macro + 8 pico cell scenario.[46]

3.3.4 OPPORTUNISTIC SMALL CELLS FOR DENSE HETNETS

With hyper dense HetNets, it is envisioned that there will be more small cells and therefore fewer users per cell, when comparing with a macro cell. For the indoor deployed residential smaller cells, it is conceivable there can be one user per small cell.

As more small cells are added to the HetNets, there will be cells not serving any active user at a given time. Even though no traffic is carried in these cells, the downlink common channels and signals will still be transmitted, generating unnecessary interference to neighboring cells. Moreover, the PAs of these cells will be kept on all the time, consuming excessive energy.

An approach that is considered as part of intelligent HetNets is to opportunistically turn small cells "ON" when there are active users in the vicinity and turn them dormant when there are no active users in the vicinity. When there is no user in the serving area, opportunistic small cells will enter the dormant state and stop transmission on the downlink.

The PA will be shutdown to improve the energy efficiency and downlink interference to adjacent cells will be removed. In the meantime, the small cell will continue to monitor uplink signals in the dormant state. Upon detection of uplink signals of approaching terminals, the

[46] Source: Qualcomm

small cell will become active and restore downlink transmission. The terminal detection and activation are performed in advance to ensure IC-capable terminals detecting the weak signals from small cells with range expansion. Opportunistic small cells can be implemented today without standard changes. This approach, which is called Opportunistic small cells, will help address these issues and facilitate HetNets densification. Opportunistic small cell approach has multiple benefits:

- Achieve reduction in energy consumption by only using the small cell when necessary. Lowering energy consumption would be even more beneficial during off-peak hours where it is less likely we will have users around.
- Provide capacity when needed and turn dormant otherwise and therefore not interfere unnecessarily by transmitting overhead information when there are no users around. This will further improve the system capacity by reducing the interference seen by other users in the network.

Opportunistic small cells can be implemented today by having the small cell monitor the uplink signals to detect an active user in the vicinity.

One key consideration for small cell deployment is the backhaul. Wireline backhauls such as fiber and Ethernet are not always available at the desired locations. Wireless backhauls using microwave and millimeter-wave require line-of-sight (LOS) to the aggregation point which may be a challenge in urban areas with high-rise buildings. Relays using NLOS wireless backhaul enable small cell deployment in backhaul constrained areas.

3.4 CARRIER AGGREGATION AND SUPPLEMENTAL DOWNLINK TECHNIQUES

Carrier Aggregation (CA) has been identified as a key technology that will be crucial for LTE-Advanced in meeting IMT-Advanced requirements. The need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than those currently supported in LTE (up to 20 MHz) while at the same time ensuring backward compatibility with LTE. Consequently, in order to support bandwidths larger than 20 MHz, two or more component carriers are aggregated together in LTE-Advanced.

An LTE-Advanced terminal with reception capability beyond 20 MHz can simultaneously receive transmissions on multiple component carriers. An LTE Rel-8 terminal, on the other hand, can receive transmissions on a single component carrier (CC) only, provided that the structure of the component carrier follows the Rel-8 specifications.

The spectrum aggregation scenarios can be broadly classified into three categories[47]:

1. Intra-band contiguous CA
2. Intra-band non-contiguous CA
3. Inter-band CA

Examples of these scenarios are provided in Figure 3.17.

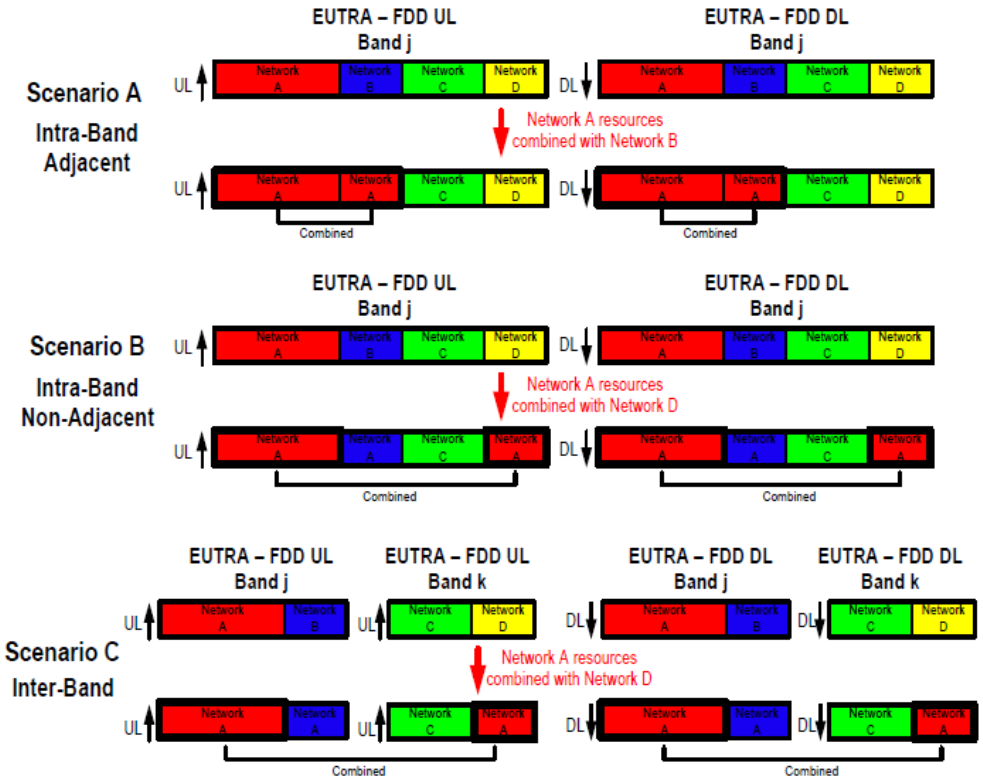


Figure 3.17. Spectrum Aggregation Scenarios for FDD.

For LTE Rel-10 CA, each component carrier aggregated together is a LTE Rel-8 carrier. Both contiguous component carriers and non-contiguous component carriers are supported. In LTE Rel-10, both symmetric as well as asymmetric CA is supported. In symmetric CA, the numbers

[47] [Ref 3.17] 4G Mobile Broadband Evolution: Rel-10, Rel-11 and Beyond, 4G Americas, October 2012

http://www.4gamericas.org/documents/4G%20Mobile%20Broadband%20EvolutionRel%2010%20Rel%2011%20and%20Beyond%20October%202012.pdf

of DL and UL component carriers are the same. In asymmetric CA, the number of DL and UL carriers is different. For simplicity, LTE Rel-10 only supports asymmetrical CA where the number of DL carriers is greater than or equal to the number of UL carriers. In TDD deployments, however, the number of component carriers in UL and DL is typically the same [Ref. 3.4.1].

Even though LTE Rel-8 can support bandwidths up to 20 MHz, most American wireless operators don't have that much contiguous spectrum. In spectrum below 2 GHz most operators have between 5-15 MHz of contiguous spectrum in a single frequency band. Also many operators own the rights to use spectrum in many different bands. So from a practical perspective carrier aggregation offers operators a path to combine spectrum assets within the bands they operate in and to combine assets across multiple frequency bands. Figure 3.18 show the enhanced user experience that can be provided with Carrier Aggregation by combining a single AWS carrier with a single 700 MHz carrier. Under lightly loaded conditions CA devices can better utilize resources on both component carriers, rather than being restricted to a single carrier block of spectrum. In this example two carriers of spectrum are combined together to nearly double the median end user throughput.

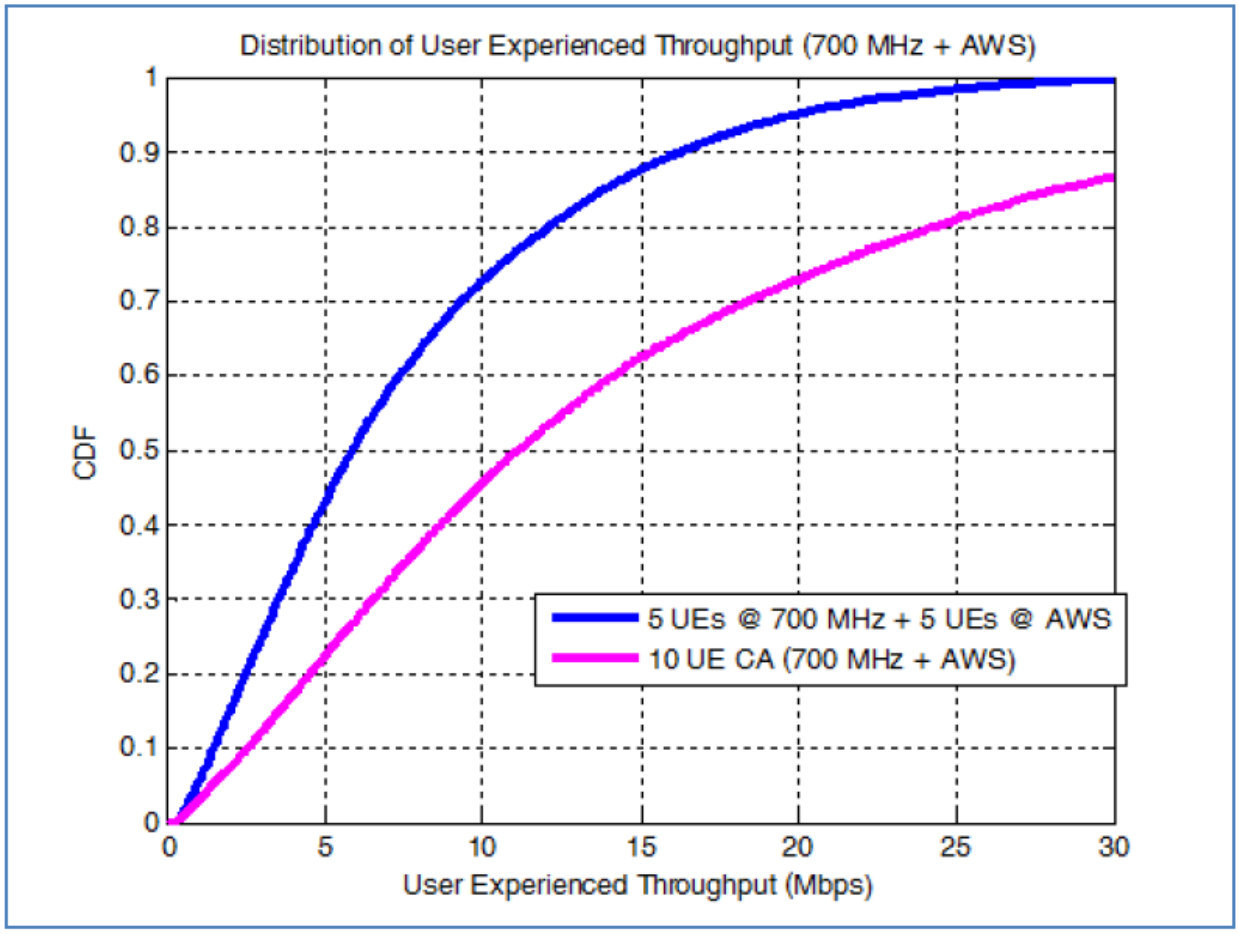


Figure 3.18 User Performance Benefits of CA [Ref 3.17]

In most networks today the DL payload is much higher than the UL payload. Over time as user behavior changes and new technologies like cloud computing evolves and matures, this ratio may change, but the current Mobile Broadband customer consumption is predominately driven by the DL. Supplemental Downlink is a form of asymmetric CA that can be utilized to improve the DL performance by combining paired DL and UL spectrum with spectrum that is assigned for DL only transmission. This is an attractive technology for assigning more radio resources in the downlink to improve the performance in the downlink so that the radio resource capacity is more in accordance with the traffic payload demands.

Asymmetric CA has been used successfully in commercial networks in the deployment of Rel-8 Dual Carrier HSPA+. In this implementation two adjacent 5 MHz DL carriers are combined with

one 5 MHz UL carrier. On the LTE side, 3GPP LTE Band 29 (716-728 MHz) was defined for DL only operation. Band 29 is intended to be used for LTE Asymmetric CA with one of the following existing band combinations such as Band 2, 4 or 5[48]. In the recent FCC Notice of Proposed Rulemaking (NPRM) adopted on Sept 28, 2012 regarding the TV incentive auction, the FCC has proposed that supplemental downlink could potentially be used with orphaned spectrum that is unable to be paired.

3.5 DEVICE AND OTHER ENHANCEMENTS

This section briefly discusses the technology advancements that are included in the mobile devices to meet the 1000x traffic capacity challenge for the future mobile networks.

New technology enhancements incorporated in mobile devices (i.e., the user equipment "UE") are a double-edged sword. Technology enhancements to the devices improve spectrum efficiency and hence help to address the 1000x capacity challenge, but the same enhancements also act to encourage usage and hence foster demand for additional spectrum feeding the 1000x traffic expansion.

Improved screen sizes and resolution, for example, increase the demand for data communications to detail the higher quality images on the devices. Better images may induce users to watch more mobile video and thus consume additional bandwidth. Improved batteries, as a further example, also enable more complex radio signal processing for spectrum efficiency, but also enable users to engage in mobile services for longer sessions. Thus, the many technology enhancements that increase the device's ability to improve and expand data services lead to an expanding demand for communications to serve new bandwidth-intensive applications.

The other sections of this document have discussed at length the technological advancements planned for the mobile networks to enhance system performance. These include additional spectrum, new methods of coding, advanced air interfaces, small cell deployments, heterogeneous networks and multiple antenna techniques. For each of these techniques there is a corresponding implementation within the mobile devices to improve the user experience and the system's capacity.

[48] [Ref 3.18] Overview of 3GPP Release 11 V0.1.4, 3GPP, March 2013

The ability of devices to automatically adapt to various local network facilities and so provide the user with a seamless experience is the fundamental basis for the networks to grow and evolve to deliver the 1000x capacity. The mobile device is the focal point of the 1000x environment as it must understand and adapt to the local network capabilities which may vary significantly from basic speech-services to multimedia data or from large to very small cells, depending on the facilities of the local networks. The mobile devices are thus faced with the unique challenge of not only adopting the new technology features but also continuing to support the previous generations. Such a multiversity of modes and flexibility for operation across bands, radio access technologies and networks in support of the 1000x challenge is a large factor in the development of future mobile devices.

3.5.1 INTELLIGENT CONNECTIVITY: 3G/4G/WI-FI ACCESS

Although, as noted above, the mobile devices must both support new technology and continue to support old technology to achieve the 1000x challenge, the fundamental aspects of intelligent connectivity include the following basic elements:

i. Interaction with multiple local network nodes (i.e. macro cells, small cells, home NodeB, Wi-Fi etc.);
ii. Channel aggregation (i.e. operating simultaneously on multiple radio channels); and
iii. Direct links (i.e. communicating directly with other devices within range).

(i) In many scenarios, devices are within the overlapping coverage zones of multiple networks of radio access technologies (e.g. LTE, small cells, home NodeB or Wi-Fi). The proper management to distribute traffic among these facilities can reduce the traffic demand for premium macro-cell spectrum and resources. Furthermore, usage of small cells may permit increased throughput and so engender an improved user experience. The use of small-cells provides significantly better spatial reuse. It is to be expected that increasing deployment of such small cells will be the principal means by which the 1000x challenge is met. Simple arithmetic suggests that 1000 cells will handle (about) 1000 times the traffic as one cell for a given amount of spectrum. However, a 1000 fold increase in the number of cells does increase the network complexity. In such an environment the user's device, for example, may be connected to multiple networks simultaneously. In some instances the traffic may be differentiated between multiple macro and small-cell networks. Delay tolerant traffic, for example, may be passed by the device through the Wi-Fi link while delay-intolerant

traffic may pass through the macro-cell mobile network. In other instances the device may communicate using the wide area macro cell network while in motion, but utilise the small cell network when stationary or moving slowly. The advent of small cells, heterogeneous networks, Wi-Fi etc. all lead to requirements for the UE to coordinate usage of a multitude of different cells and network arrangements and to manage them in a way that improves the user's experience and the spectrum utilisation.

(ii) Improved radio access link performance for mobile devices may be achieved through channel aggregation. In this scenario, additional radio channel resources are allocated to the mobile devices as their traffic grows (and removed when there is less traffic). In some cases the additional radio channel resources may be assigned from another radio band supplemental to the one used for basic connectivity of the mobile device. The additional capacity may be assigned in either the uplink or downlink direction. The downlink, for example, is most likely to be utilised for downloading large files or videos. However, with increasing reliance on "cloud computing" it is expected that there will also be a similar need to support uploads of large files and videos for processing in the cloud. Through the use of supplemental channels and channel aggregation, the overall radio access network capacity is shared among the peaks and troughs of the individual users' traffic needs. To the extent that the individual user's traffic is not uniform, this technique provides an effective means to provide improved efficiency in the use of spectrum, although at a cost of possible increased delay in data transfers and (of course) increased complexity (and cost) in the user equipment. The user equipment, for example must be capable of simultaneous operation on multiple bands and radio channels and hence sometimes requiring multiple antennas and separate transceivers for the different bands.

(iii) As the services provided by mobile communications expand, there are many common scenarios where the user's device is within range of the desired receiving terminal. While the desired receiver may be another user's terminal, in many future scenarios the receiving terminal may include, for example, a point-of-sale terminal, a vehicle or other machinery or local computer. In these cases the traffic may pass directly from the originator's device to the receiving device. It is not necessary, in these scenarios, for the user's traffic to pass up into the network and be rerouted back to another device that is nearby (and thereby occupying two access communications channels). Direct communications only requires a single radio channel. Enabling direct, "device-to-device", communication can have a significant reduction in the radio traffic for communication among devices that are within proximity range (i.e. a reduction factor of two in the number of radio channels may be achieved for the connections as only a

single radio channel is needed). As the future of mobile computing evolves from network-centric to user-centric (or device-centric), the occurrence of mobile device-to-device traffic will increase and direct routing will serve to help mitigate the increase in spectrum demand.

These are but some examples of evolving technology that will both increase the efficiency of the use of mobile communications spectrum, while at the same time encourage growth in services and traffic and thereby improving the user's experience. These basic intelligent connectivity implementations in the mobile devices will be the basis technologies for meeting the 1000x challenge.

3.5.2 ADVANCED RECEIVERS

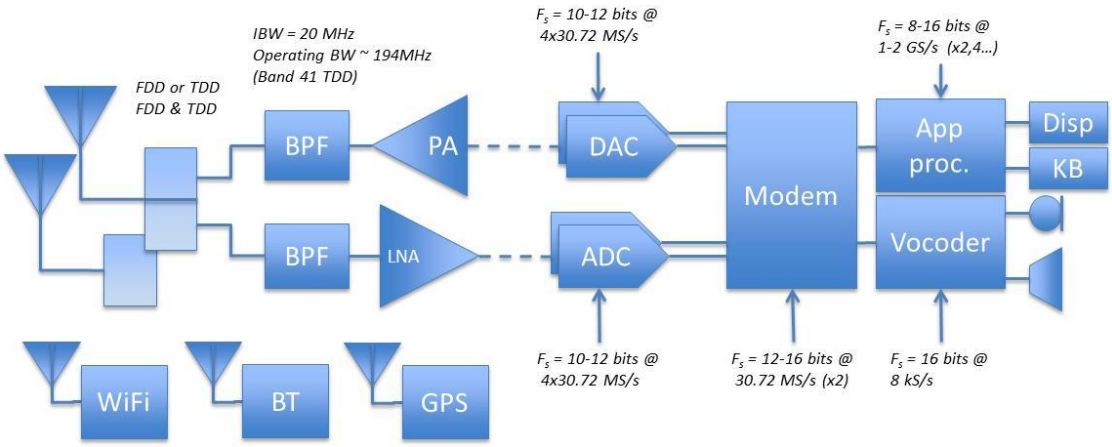


Figure 3.19. Radio receiver block diagram of mobile device (e.g. Rel-8).[49]

Figure 3.19 shows the system block diagram of a conceptual Release-8 LTE mobile device along with some typical sampling rates required at different points of the radio transceiver signal path. Future mobile devices are expected to support both FDD and TDD modes of operation with signal bandwidth of up to 20 MHz. The sampling rate of the receiver front-end analogue-to-digital converter (ADC) is typically around twice the maximum channel bandwidth required by the radio waveform (e.g., 4x30.72 million samples per second for LTE (if no filtering and decimation is performed at baseband). The LTE standard requires a 2x2 MIMO operating mode

[49] Source: Qualcomm

(Transmit Modes 2 to 4), and so requires the device to have two receiver chains up to the baseband combining point.

The required ADC or Digital-to-Analogue Converter (DAC) precision is set by the radio waveform signal profile and the dynamic range of the receiver. For current equipment, this is typically around 10 to 12 bits and about 80 dB of dynamic range. Among other factors, the higher bit-precision and higher sampling rates make additional demands on power consumption and complexity of the mobile device radios. The digital base band modem is also expected to run at higher sampling rates to support the 20 MHz signal bandwidth, and higher data throughputs. Additional sampling precision may be required to suppress strong adjacent channel signals, particularly if the channel is adjacent to a channel of another disparate service (e.g. a TV broadcast transmitter). In addition to the multiple transceiver functionality required for MIMO support, additional RF chains and transceivers are required to support the aggregation of channels across multiple bands and signal waveforms.

As is noted in Figure above, the macro- cellular LTE radio is but one of many within the mobile device. The device will typically also include a Wi-Fi system, Bluetooth local interface, GPS/GLONASS[50]/Galileo navigational system receiver, broadcast receiver (e.g., FM and TV) and a near-field communications unit. Each of these requires an antenna and suitable RF chains for their services and may be operated independently of the other radio system activity in other bands. While all of these RF units contribute to the mobile device's ability to adapt to various network arrangements, they also contribute cost and reduce battery life due to extra power consumption.

Within the other parts of the mobile device, the application processor ("App-proc"), used to interact with and to deliver services to the user, is evolving to utilise multi-core processors running at clock frequencies well in excess of 1 GHz. While these are key to delivering a satisfactory user experience, they must strike a balance with suitable battery lifetimes.

The advances in HD voice codecs ("Vocoder"), echo-cancellation systems for voice services and speech recognition have also placed additional signal processing and power consumption on modern devices.

While the challenge of increased processing load and power consumption of the evolving standards is met in current devices, continuing reduction in power consumption across the

[50] Globalnaya NavigAtsionnaya Sputnikovaya Sistema

breath of technology is needed to meet the new challenges posed by future releases of the radio systems. Some of the new features can be listed as:

(i) eICIC /IC control/data: Increased signal processing and power consumption
(ii) Carrier Aggregation and Multi-Flow: Increased IBW and number of transceivers and signal processing and power consumption
(iii) 8x8 MIMO (DL TM9): Increased number of receivers and signal processing and power consumption
(iv) 2x2 MIMO (Ul TM2): Increased number of transceivers and signal processing and power consumption
(v) Higher data rates (150 Mbps to 1.5 GB/s): Increased signal and application processing and power consumption
(vi) 802.11ac (Wi-Fi @ 1.7 GB/s): Increased IBW, signal processing and power consumption
(vii) Number of Antennas: Increased size and cost
(viii) Number of Operating Bands: Increased power consumption and size and cost

3.5.3 ANTENNA AND RF ENHANCEMENTS FOR DEVICES

The antennas become a more critical part of the RF chain in the mobile device as the number of RF channels and their bandwidth is increased to meet the 1000x challenge. Antennas are physically constrained by the wavelength of the radio signals[51]. The most efficient antennas are those that are of a size that is comparable to the wavelength of the RF signal. Typically antennas can be made reasonably efficient when they are at least ¼ wavelength in extent and there is a suitable ground plane. When antennas are less than ¼ wavelength in size, considered "electrically small", they become very inefficient at coupling to the radio signals. It should be noted also that the effectiveness of an antenna in a mobile device is also significantly affected by the effects of the user's hands and body. In some instances, for example, the user's hands may block the majority of the power radiated by the device, and in other conditions (depending on the band of operation) the user's body may act to detune the

[51] It can be observed that the development of technology for digital signal processing and applications in the mobile devices has generally followed "Moore's Law" of the doubling of processing power each couple of years. Thus it has been possible to squeeze ever more complex digital radio processing and services into smaller devices. However, the physics of antennas follow "Maxwell's Law" which stipulates that the size and efficiency of the antenna is irrevocably coupled to the wavelength of the radio signal. Lower frequency spectrum thus requires larger antennas than higher frequency spectrum and will continue to do so. When the antenna size becomes smaller than ¼ wavelength of the radio signals, its efficiency, and the efficiency of the radio system, becomes very poor. In simple terms, an antenna that is 1/8th wavelength will at best be 3 dB less efficient than one that is ¼ wavelength (in practice it may be much worse than this as the smaller antenna typically has a smaller associated ground plane and so has significant further loss of efficiency). The consequence being that to maintain and improve performance of the radio communications links, spectrum of higher frequencies will be required.

device's antenna. All of these external effects, as well as the need to pack multiple antennas into a handy size of the device, make the designer's challenges more severe.

As the number of bands to be supported in a single mobile device expands (e.g., ranging from 600 MHz through to 5.9 GHz including Wi-Fi) the free space wavelengths to be received range from about 500 mm to about 50 mm (the equivalent ¼ wavelength being about 125 mm and about 12.5 mm). Typically, when at least ¼ wavelength in size, an antenna is usable over a bandwidth of about 10 percent of its center frequency. An electrically small antenna, in addition to being a low efficiency collector of the radio signals will have a much narrower bandwidth (e.g. about 4 percent). No single antenna can span a range from 600 MHz to 6 GHz. Thus, devices are equipped with multiple antennas each designed for a specific operating band (or subset of bands). As additional bands are added to meet the 1000x challenge, additional antennas must somehow be incorporated into the mobile devices.

A typical size of a personal mobile device is on the order of 120x60 mm outside. For various practical reasons the main antenna is typically aligned along the bottom edge with a maximum possible extent of about 60 mm. Figure illustrates a placement of antennas within a device and an illustration of the relative size of ¼ wavelength for 600 MHz, 2 GHz and 5.9 GHz radio waves. Within the device the antennas are arranged around the perimeter with the central battery and display backplane providing the ground plane. In this example a main and diversity antenna are provided for two mobile bands in addition to antennas for the Wi-Fi, GPS and Bluetooth radios.

It should be noted that the improvement of the radio performance from the MIMO techniques (discussed at length elsewhere in this report) is predicated on the statistical independence of the radio signals at each antenna. Such independence becomes useful for antennas separated in space by more than about ½ wavelength. For devices operating at frequencies for which the device's size is much less than ½ wavelength, the full advantages of MIMO are yet to be demonstrated.

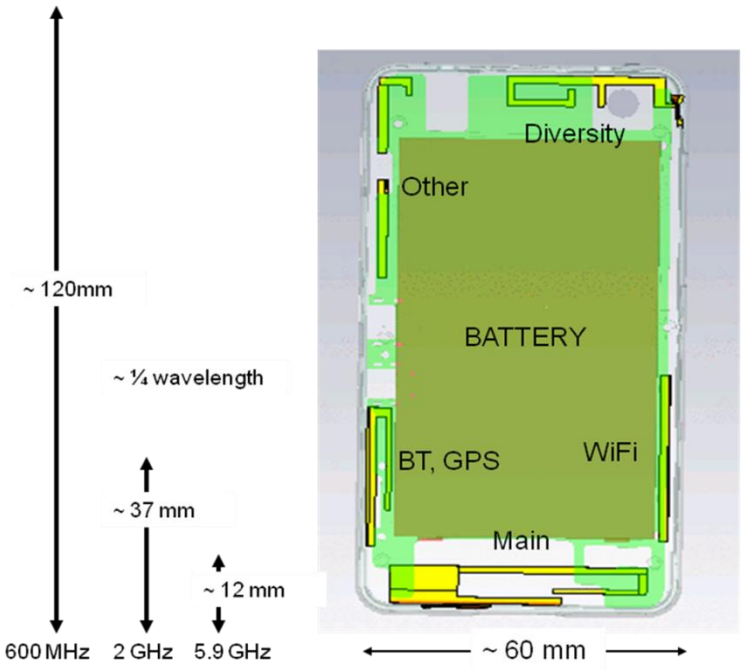


Figure 3.20. Illustration of relative sizes ¼ wavelength antenna and mobile device.

While antennas may be made physically small, such shrinkage comes at the price of reduced efficiency and narrower bandwidth. Electrically small antennas may have an efficiency of 30 percent or less (i.e., they receive less than 30 percent of the available RF signal power) and have a bandwidth of only a few percent (i.e. they achieve their efficiency only over a range of frequencies close to the center operating frequency). Electrically small antennas also are sensitive to their environment (i.e. nearby objects) and thus their performance can vary significantly when operated in the changing environment in close proximity to the user and their hands.

Together these physical constraints on the number and size of antennas are at odds with the increasing number of channels, increasing channel bandwidths and multiple-band channel aggregation techniques being planned for future mobile systems. The 1000x requirements for mobile devices to roam across multiple bands, the addition of new bands of operation and the aggregation of channels across multiple bands all contribute to the number and complexity of the antennas needed in the device.

New techniques of antenna design (some now in use) enables an individual antenna physical structure to be double (or multiple) tuned to multiple bands. This aids in extending device performance to accommodate multiple bands. Furthermore, technologies are under research

and development that enable the dynamic tuning of antennas across a band to better adapt to the bandwidths available. Such dynamic tuning is still subject to development to operate with suitable low levels of power to maintain battery lifetimes. Such new technology will be one way forward to enable the application of improved antenna systems with wider bandwidths and multiple bands to meet the 1000x challenge.

3.6 LEVERAGING EMBMS AND LTE-DIRECT ENHANCEMENTS

One of the technical solutions that can be used to mitigate the challenges of mobile video delivery is LTE broadcast, also known as Evolved Multimedia Broadcast Multicast Service (eMBMS). It is a Single Frequency Network (SFN) broadcast / multicast mode within LTE known as eMBMS which was defined in 3GPP Releases 8 and 9. Enhancements to certain aspects continue in Releases 10 and 11.

eMBMS is envisaged as supporting two primary use cases. The first use case is live streaming of video for high penetration applications; e.g., live sports. The second use case is to deliver other high attach rate content such as breaking news, and background file delivery.

For each of the use cases, efficiency is achieved if the content is of broad interest. When the video is of interest to a number of subscribers at the same time then multicasting the video over the air using eMBMS in LTE (or MBMS in 3G) is substantially more efficient than sending separate unicast transmissions to each client. This is because wireless is fundamentally a broadcast medium. Whatever is transmitted wirelessly can be received by multiple receivers in the range of the transmitter. Additionally the concept of single frequency network (SFN), where the same signal is transmitted by multiple adjacent base stations improves performance by eliminating out-of-cell interference. SFN can be employed when a number of users in multiple cells are watching the same content at the same time.

Traditionally, a number of users watch the same video in Linear TV. However, Linear TV is not commonly used on mobile devices. The real application for eMBMS delivery of video to smart phones and tablets is in stadia where specialized content such as action replays is watched by a large number of people at the same time. With a number of small cells covering the stadium, eMBMS with SFN could be substantially better than unicasting to different users.

There are two levels to eMBMS. There are a set of modifications to the radio physical layer that enable SFN operation within the already defined LTE operating modes and is implemented at the modem level. eMBMS is designed to operate within the mobile operators' LTE network infrastructure and dedicated LTE radio spectrum. There is also an upper layer eMBMS

framework that contains tools to enable services across the broadcast physical layer, often referred to as a broadcast service layer. The service layer includes support for file delivery and forward error correction (FEC).

The primary benefits of eMBMS relate to the increase in capacity that can be achieved via SFN operation, and the one to many aspect of broadcast distribution. These two aspects combined can provide a significant capacity lift for any content that is being viewed simultaneously by more than one user per cell / sector. The specific capacity numbers supported over eMBMS depend on sub-frames allocated for eMBMS configuration, and network configuration. Figure 3.21 shows a high level architecture for eMBMS.

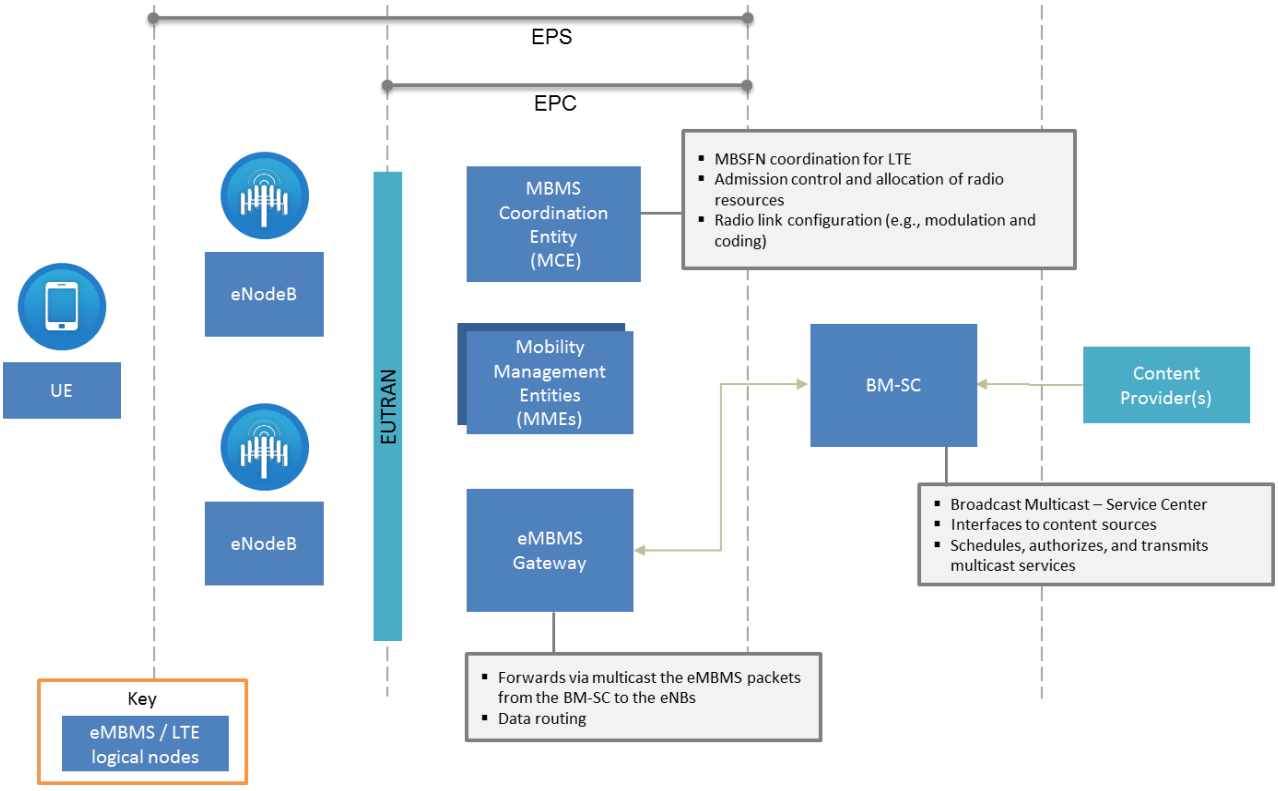


Figure 3.21. eMBMS Architecture. [52]

[52] Source: Qualcomm

The reader is referred to other papers that address the LTE broadcast issues in further detail including the three references [Ref 3.19] – [Ref 3.21][53].

In an increasingly hyper connected world with thousands of wireless devices around you, it is a challenge to quickly and efficiently discover the ones that are most relevant to you, especially in a privacy-sensitive and battery-efficient way. LTE Direct is a device-to-device (D2D) technology for proximate discovery giving the device the ability to passively and continuously search for relevant value in its physical proximity. One of the primary drivers for LTE Direct is to support the use cases for 700 MHz public safety users in the U.S. who require the ability to communicate device to device for the safety of first responders. LTE Direct is currently being considered by 3GPP to be part of 3GPP Release-12 enabling devices to directly discover each other using LTE spectrum, a feature also called operator-enabled proximity services. This enables mobile operators to offer a range of differentiated applications and in addition to the public safety use cases, may also have commercial use cases. LTE Direct also leverages the LTE network for timing, resource allocation as well as user authentication.

[53] [Ref 3.19] Qualcomm Commissioned White Paper by iGR, Content for All – The Potential for LTE Broadcast/eMBMS, January 2013

[Ref 3.20] Qualcomm White Paper, LTE Broadcast, A revenue enabler in the mobile media era, February 2013

[Ref 3.21] Supporting Wireless Video Growth and Trends, by 4G Americas, April 2013

4. SPECTRUM AND POLICY INNOVATION

4.1 THE CHANGING SPECTRUM LANDSCAPE

4.1.1 SPECTRUM POLICY INITIATIVES IN THE U.S.

In early 2009, the United States Congress directed the Federal Communications Commission (FCC) to develop a National Broadband Plan to ensure every American has access to broadband service. Bringing additional spectrum to the market is the heart of this plan as without it wireless broadband services would struggle to meet the huge growth in data demand. This is important as more efficient allocation and assignment of spectrum will not only bring broadband to everyone, but also reduce deployment costs, drive investment and benefit consumers through better performance and lower prices.

In its 2010 National Broadband Plan, the U.S. Federal Communications Commission (FCC), emphasized the importance of wireless spectrum. Spectrum is the enabler for providers of broadband service, and the National Broadband Plan targets to make 500 megahertz of spectrum newly available for broadband within 10 years, of which 300 megahertz should be made available for mobile use within five years. This reflects the Presidential Memorandum issued in June 2010, which directed the Department of Commerce and the National Telecommunications and Information Administration (NTIA), working with the Federal Communications Commission (FCC), to identify and make available 500 megahertz of spectrum over the next ten years for expanded wireless broadband use. The new spectrum should be suitable for both mobile and fixed wireless broadband use and will be made available from spectrum now used for other Federal and non-Federal services.

Two NTIA reports, the Ten-Year Plan and Timetable identified 2,200 megahertz of spectrum for evaluation, the process for evaluating these candidate bands, and the steps necessary to make the selected spectrum available for wireless broadband services. In addition, NTIA released the Fast Track Report identifying some spectrum reallocation opportunities that exist in the next five years – a total of 115 megahertz – contingent upon the allocation of resources for necessary reallocation activities.

The purpose of the Fast Track Report was to assess the Near-Term Viability of Accommodating Wireless Broadband Systems in various candidate spectrum bands. Band selection was limited to the 225 MHz to 4400 MHz frequency range since bands below 225 MHz have insufficient contiguous bandwidth necessary for wireless broadband and bands above 4400 MHz have

limited utility for mobile wireless broadband systems. The report contains a variety of electromagnetic compatibility assessments, using different models or analysis techniques. In collaboration with the FCC the NTIA released a Ten-Year Plan and Timetable to make 500 megahertz of Federal and non-Federal spectrum available for wireless broadband use by 2020, of which 115 MHz is within 5 years. The Plan and Timetable identify over 2200 MHz of spectrum that could potentially be repurposed for wireless broadband. Four candidate bands have been identified that could be repurposed by 2015. These are: (1) 1675-1710 MHz, (2) 3500-3650 MHz, (3) 4200-4220 MHz and 4380-4400 MHz, and (4) 1755-1780 MHz. The first three of these bands were selected based on an aggregation of factors such as the number and types of incumbent systems and geographic occupancy. NTIA selected the 1755-1780 MHz band for the Fast Track Evaluation based on recommendations from the wireless industry and because of a possible pairing with the 2155-2180 MHz band.

A major step towards bringing new spectrum to the market happened in early 2012 when the U.S. Congress, in passing the Middle Class Tax Relief and Job Creation Act of 2012 ("Spectrum Act")[54],, created a mandate for auctioning and licensing of new spectrum. The Spectrum Act gives the FCC authority to hold voluntary incentive auctions to repurpose some of the spectrum around 600 MHz that is used today for TV broadcasting, allocate 700 MHz D block spectrum for a nationwide interoperable broadband network for first responders and establish clearing and auction timelines for additional spectrum. The additional spectrum was further specified to be in 1915-1920 MHz and 1995-2000 MHz (the PCS H Block), 2155-2180 MHz (the AWS-3 block), and 15 MHz from the government spectrum at 1675-1710 MHz paired with 15 MHz to be determined by the FCC.

The 15 MHz from the 1675-1710 MHz was subsequently specified to be 1695-1710 by NTIA. The additional spectrum blocks shall be licensed within 3 years from passing the bill, in other words latest in February of 2015. FCC, as required by statute to notify NTIA at least 18 months in advance of any planned spectrum auction requiring relocations of federal users, gave the notice on to NTIA in March of 2013 indicating that the auctions for 1695-1710 MHz and 2155-2180 MHz with 1755-1780 MHz as preferred pairing could take place as early as September 2014. In turn, NTIA is required to notify the FCC of estimated relocation and sharing costs, as

[54] [Ref 4.1] Middle Class Tax Relief And Job Creation Act Of 2012 http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf

well as timelines for such relocation or sharing at least six months prior to the commencement of the auction.

4.2 NEW SPECTRUM ALLOCATIONS

4.2.1 THE 1755-1780 AND 1695-1710 BANDS

Every radio application works best within a certain range of frequencies. For mobile broadband application, this range is roughly from several hundred MHz to a few GHz. That is because radio waves in much higher frequencies do not propagate far through various clutter types and terrain environments, or penetrate deep into buildings. Lower frequencies are better in this regard, but they require large antennas for efficient transmission, which proves challenging in both handheld devices and network cell-site designs.

The 1755-1780 and 1695-1710 bands are right in the sweet range for mobile broadband application. These bands are particularly attractive to the wireless industry because they are immediately adjacent to the 1710-1755 MHz band, or the AWS-1 band, one of the bands most widely used for mobile broadband services in North America. Mobile handsets and base station receivers for this band already exist since 1755-1780 MHz is used in many parts of the world for cellular systems and has been identified by the ITU for use by IMT. The wireless industry has been advocating for pairing 1755-1780 MHz with 2155-2180 MHz as an extension to the AWS-1 band. For example, in a letter sent to NTIA on April 24, 2013[55], CTIA, 4G Americas, AT&T, T-Mobile, and Verizon, stated:

> *"Carriers around the world have plans to deploy LTE consistent with 3GPP band plans. The 1755-1780 MHz band, when paired with the 2155-2180 MHz band, aligns closely with 3GPP Band Class 10. Pairing the 1755–1780 MHz band with the 2155–2180 MHz band would allow this spectrum to be auctioned and licensed by February 2015..."*

[55] [Ref 4.2] CTIA Letter to NTIA on 1755-1780 MHz http://files.ctia.org/pdf/filings/CTIA_files_letter_with_NTIA_on_1755-1780_MHz_Band.pdf

In another letter sent to the FCC on February 22, 2013[56], 4G Americas expressed the industry's strong interest in having a cleared 1755-1780 MHz band paired in auction with 2155-2180 MHz.

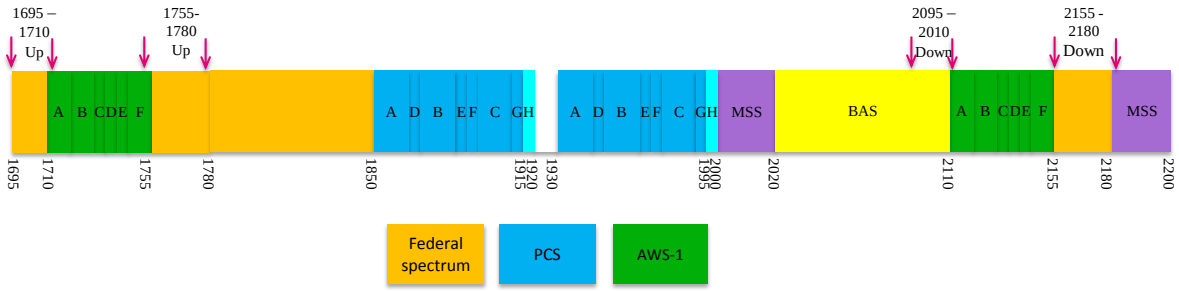


Figure 4.1. Spectrum chart for the 1755-1780 and 1695-1710 bands.

On March 5, 2013, CTIA-The Wireless Association and the Wireless Broadband Coalition released a global status report and map on the allocation of 1755-1780 MHz and 2155-2180 MHz spectrum, which showed a number of countries have or are in the process of allocating this internationally-harmonized spectrum for commercial purposes[57].

According to this CTIA report, these spectrum bands are already being used for commercial purposes by 43 countries, and 17 of the G-20 countries have allocated the bands for commercial use. The three countries that have not are the U.S., Canada and Argentina. If the U.S. follows the numerous international governments to allocate these bands, the wireless industry and users would benefit from the economies of scale, ranging from shorter time to deployment, lower cost for devices and networks, and better international roaming.

[56] [Ref 4.3] 4G Americas Letter to FCC on 1755-1780 MHz http://www.4gamericas.org/UserFiles/file/News/4G%20Americas%201755%20auction%20notification%202-22.pdf

[57] [Ref 4.4] CTIA & WBC Report on International Harmonization Status of 1755-1780 MHz and 2155-2180 MHz, February 2013 http://files.ctia.org/pdf/1302.Harmonization_Status_Report.Country-by-Country_Data.pdf

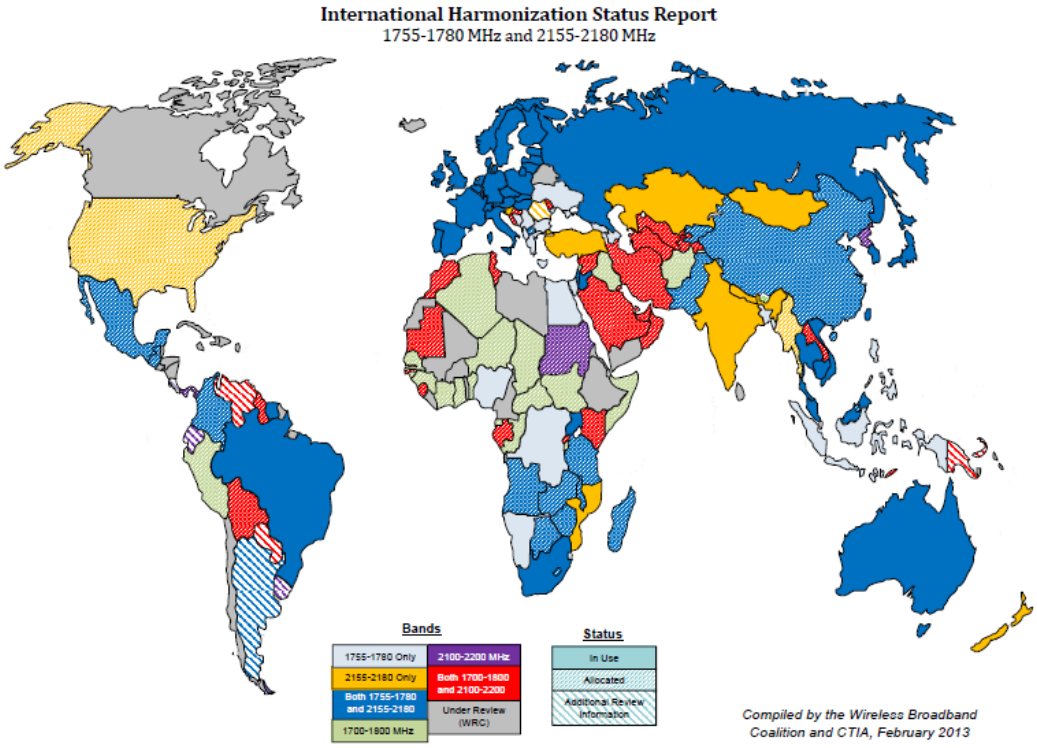


Figure 4.2. International harmonization status in the 1755-1780 and 2155-2180 MHz.

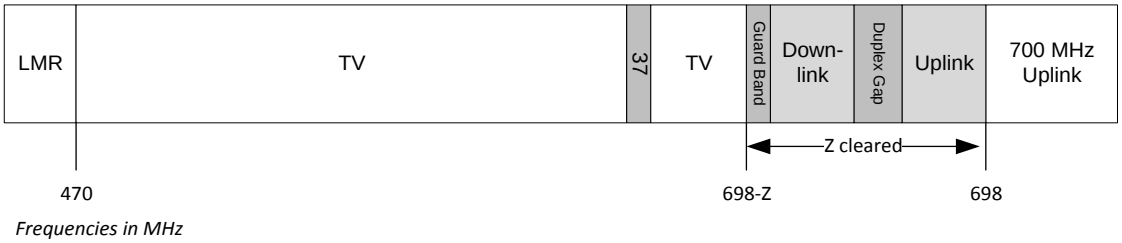
Nationally, the 1755-1780 MHz sub-band of the 1755-1850 MHz band is allocated on an exclusive basis to the Federal Government for fixed and mobile services. The 1755-1780 MHz band supports a variety of Federal functions: (1) conventional fixed microwave communications systems; (2) military tactical radio relay systems; (3) air combat training systems; (4) precision guided munitions; (5) high-resolution video data links, and other law enforcement video surveillance applications; (6) tracking, telemetry, and command for Federal Government space systems; (7) data links for short-range unmanned aerial vehicles; (8) land mobile robotic video functions (e.g., explosive ordnance and hazardous material investigations and disposals); and (9) control links for various power, land, water, and electric power management systems. The radio systems supporting these functions are deployed across the United States. The 1675-1710 MHz band is currently allocated on a co-primary basis for Federal and non-Federal use for the meteorological aids service and the meteorological-satellite service (space-to-Earth)

On March 20, 2013, the FCC issued a Public Notice to notify NTIA that it plans to commence the auction of licenses in the 1695-1710 MHz band and the 1755-1780 MHz bands as early as September 2014.

4.2.2 THE 600 MHZ BAND (TV INCENTIVE AUCTION)

In March 2010, the FCC released its National Broadband Plan, in which it is proposed that 120 MHz of TV broadcast spectrum be vacated and auctioned off for broadband wireless use. The spectrum has been dubbed "the 600 MHz band", ranging from 572-698 MHz, and located immediately below the 700 MHz band.

Congress, in passing the Middle Class Tax Relief and Job Creation Act of 2012, authorized the FCC to conduct voluntary incentive auctions, with the first auction to be of broadcast television spectrum. On October 2, 2012, the FCC had issued a Notice of Proposed Rulemaking (NPRM)[58], starting off the rule-making process for the 600 MHz band. The comment cycle was completed on January 25, 2012. The reply comment was also completed on March 12, 2013. The FCC intends to conduct the 600 MHz incentive auction in 2014.



One of the FCC's Potential 600 MHz band plan (Down from 51)

Figure 4.3. One FCC's proposed 600 MHz band plan.

This 600 MHz incentive auction will be the first such auction ever conducted, and will, thus, require a novel design. The 600 MHz incentive auction itself will actually be comprised of two separate but interdependent auctions – a reverse auction, which will determine the price at which broadcasters will voluntarily relinquish their spectrum usage rights, and a forward auction, which will determine the price the bidders are willing to pay for the use of spectrum licenses. In addition to the reverse auction and forward auction, there is also a "repacking

[58] [Ref 4.5] FCC NPRM on Broadcast Television Spectrum Incentive Auction September 2012 http://www.fcc.gov/document/broadcast-television-spectrum-incentive-auction-nprm

process" that needs to happen. In order to free up additional spectrum for mobile broadband use, the Spectrum Act directs the FCC to repack the broadcast television channels that do not exit the 600 MHz band while "making reasonable efforts to preserve the coverage area and population served of each broadcast television licensee."

Well-designed schemes for the forward auction, the reverse auction, and the repacking process are critical to a successful auction, which in turn will bring substantial benefits to the nation. While maximizing the amount of spectrum that will be freed up for mobile broadband use through this auction is FCC's goal, which is highly praised by the mobile broadband industry, how much spectrum can be actually freed up and made available for mobile broadband use remains to be seen.

4.2.3 THE H-BLOCK

The H-block refers to the 5x5 MHz paired FDD spectrum, uplink in 1915-1920 and downlink 1995-2000 MHz. It is right next to the so-called G-block, another 5x5 MHz paired FDD spectrum, uplink in 1910-1915 and downlink 1990-1995 MHz. The H-block and G-block together are immediately adjacent to the PCS band, and can be regarded as an extension of the PCS band. (Figure 1) These bands are most suitable for mobile broadband application. As a matter of fact, the PCS band is one of the most used spectrum bands for Mobile broadband in Northern America. The H-block, as well as the G-block, will benefit from the existing PCS band ecosystem, therefore enjoy shorter time to deployment and lower cost for devices and networks.

On December 17, 2012, the FCC released a NPRM proposing rules for Advanced Wireless Services in the H Block – 1915-1920 MHz ("Lower H Block") and 1995-2000 MHz ("Upper H Block")[59]. Note that this is not the first time the FCC proposed service rules for the H Block.

Comments were solicited back in 2004, and again in a follow-up in 2008. Only this time, the FCC has set a relatively fast turn-around schedule on the H Block. The comment cycle was completed on February 6, 2013. The reply comment was also completed on March 6, 2013. It is expected that the FCC could auction the H-block as soon as end of 2013 or early 2014.

[59][Ref 4.6] FCC NPRM AWS in 1915-1920/1995-2000 MHz (H Block) – December 2012
http://www.fcc.gov/document/aws-1915-19201995-2000-mhz-h-block-nprm-adopted

While the H-block will further extend the PCS band, and thereby bring about additional capacity to the avail of mobile broadband services, it will also reduce the PCS band duplex-gap down to 10 MHz. One concern is that a 10 MHz duplex-gap may not be sufficient to prevent PCS band from "self-interfering", caused by H block mobile device transmission in 1915-1920 MHz interfering with mobile device reception near the lower edge of the PCS downlink band. At the upper end, the H-block downlink band is adjacent to the AWS-4 uplink band in 2000-2020 MHz without any guard band.

As there is no guard band between the H-block downlink and the AWS-4 uplink, interference from AWS-4 mobile to H-block mobile is a big concern. Without additional protection, the H-block usability will be greatly compromised. On December 17, 2012 the FCC released an AWS-4 REPORT AND ORDER [ref. 8]. In this REPORT AND ORDER, the service rules impose more stringent mobile out-of-band emission (OOBE) limits and power limits on a portion of the AWS-4 band to protect future operations in 1995-2000 MHz. More specifically, the AWS-4 service rules are imposing (1) increased OOBE limits of 70 + 10 log10(P) at and below 2000 MHz, and (2) reduced power limits of 5 milliwatts EIRP for mobile terrestrial operations in 2000-2005 MHz. However, the licensee of the AWS-4 band has filed a petition with the FCC seeking the flexibility to voluntarily designate which portions of the band will be uplink and downlink within 30 months of a FCC order granting the petition. Thus, the afore-mentioned co-existence issue could become moot.

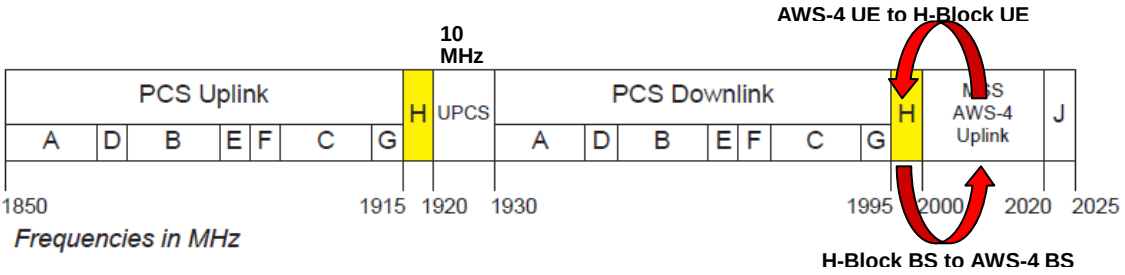


Figure 4.4. H-Block.

In order to put the H-block in use, some standardization work needs to be done. Assuming LTE is the technology, a new 3GPP LTE FDD band class needs to be created. When the G-block first came to be available, LTE Band 25 was created in such a manner that it covers a swath of spectrum that includes both the PCS and G-block. Conceivably, the to-be-created H-block LTE band class can be expected to cover an even wider swath of spectrum that includes the PCS, G-block, and H-block. In this manner, the H-block and G-block can be regarded as an extension of the PCS band and can benefit from the existing PCS band ecosystem.

4.2.4 THE 3.5 GHZ BAND (SMALL CELL)

The 3550-3650 MHz band is currently allocated to the Radiolocation Service and the Aeronautical Radio Navigation Service (ground-based) for federal use, primarily a variety of high-powered Department of Defense (DoD) radars, as well as on a secondary basis for non-federal Fixed Satellite Service (FSS) earth stations for receive-only, space-to-earth operations and feeder links, and a handful of other non-federal secondary uses.

In October 2010 the NTIA released the so-called "Fast Track Evaluation" of four government spectrum bands, including 3500-3650 MHz, that held promise to be released for commercial use. The NTIA concluded that it was not practical to clear the incumbent federal users from the entire 3500-3650 MHz band, but that geographic sharing of the 3550-3650 MHz band was possible. However, the NTIA concluded that large exclusion zones surrounding incumbent facilities would be required if the band were used for mobile broadband, precluding commercial service along most of both coasts and in other areas covering approximately 60 percent of the population of the United States. Note that this exclusion zone analysis was based on WiMAX operating characteristics and macro cell type deployment.

On July 20, 2012 a report[60] released by the President's Council of Advisors on Science and Technology (PCAST) took a fresh look at 3550-3650 MHz band, and concluded that the band could be made more widely available than anticipated by the NTIA Fast Track Evaluation if usage is limited to small cells. Because small cells are low-powered wireless base stations that cover smaller geographic areas than traditional wireless base stations, PCAST concluded that they pose less of an interference threat to incumbent users, particularly if emerging opportunistic sharing technologies are used to facilitate interference protection.

[60] [Ref 4.7] Report To The President Realizing The Full Potential Of Government-Held Spectrum To Spur Economic Growth – July 2012
http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf

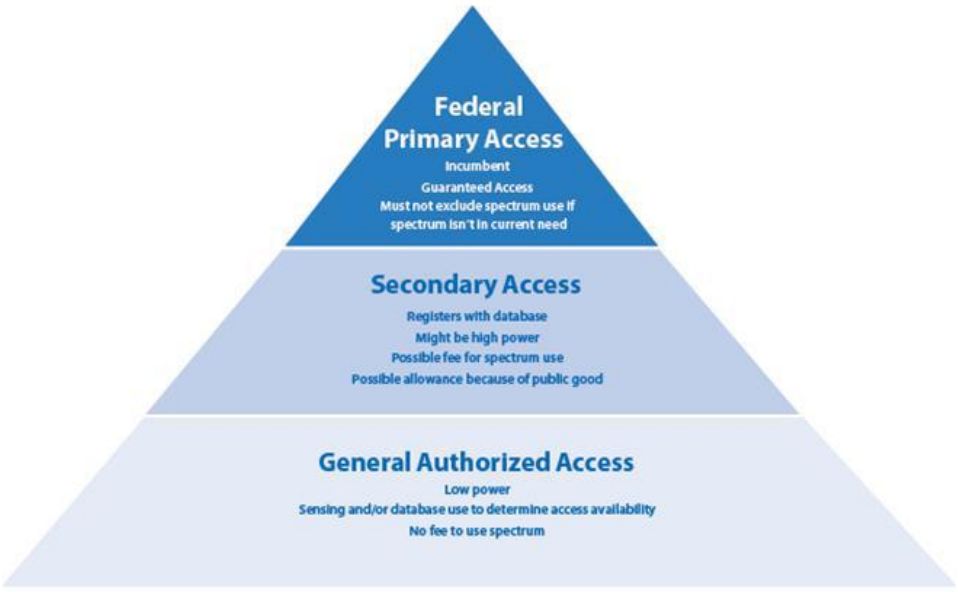


Figure 4.5. The PCAST proposed three-tiered shared access hierarchy.

Due to limited signal propagation, the 3.5 GHz band is not particularly well-suited for macro-cell wide-area cellular deployment. However, this very same propagation characteristic makes the 3.5 GHz band a good fit for dense deployment of small cells. Also, deploying small cells in 3.5 GHz will limit the interference potential to incumbent users. Making the 3.5 GHz band available for small cells for commercial use offers a promising opportunity for mobile broadband operators to deploy the so-called Heterogeneous Access Network, or HetNet, in which macro-cells can be deployed in a lower frequency band to provide coverage and to ease mobility while small cells in a higher frequency band provide capacity in areas where mobile broadband usage is high.

On December 12, 2012, the FCC adopted a Notice of Proposed Rulemaking and Order, proposing to create a new Citizens Broadband Service (CBS) in the 3550-3650 MHz band[61], advancing rules to govern the sharing of that band with incumbent users, and asking whether to include the neighboring 3650-3700 MHz band under the new regulatory regime. Comments in response to the NPRM were completed on February 20, 2013 and reply comments were also completed on March 22, 2013.

[61] [Ref 4.8] FCC NPRM & Order on Small Cells in 3.5 GHz Band http://www.fcc.gov/document/enabling-innovative-small-cell-use-35-ghz-band-nprm-order

Figure 4.6. The proposed Citizens Broadband Service (CBS) band.

The NPRM proposes that the CBS band be structured according to a three-tiered shared access system enforced by a Spectrum Access System (SAS) and the use of geo-location based opportunistic access technology. The first tier, Incumbent Access, would include authorized federal users and grandfathered fixed satellite service licensees. These incumbents would be afforded protection from all other users in the 3.5 GHz Band. The second tier, Priority Access, would include critical use facilities, such as hospitals, utilities, government facilities, and public safety entities that would be afforded quality- assured access to a portion of the 3.5 GHz Band in certain designated locations. The third tier, General Authorized Access, would include all other users – including the general public – that would have the ability to operate in the 3.5 GHz Band subject to protections for Incumbent Access and Protected Access users and can use the spectrum when Incumbent and Priority Access users are not using it.

As explained below, the FCC also made an alternative proposal, which was to use the Authorized Shared Access/Licensed Shared Access model—a two-tiered approach. Under this model, operators would get the right to use the spectrum on an exclusive basis when and where the government was not using the spectrum.

4.2.5 UNLICENSED SPECTRUM

In addition to licensed spectrum, use of unlicensed spectrum, for offload to Wi-Fi, as well as for Bluetooth, NFC, and other unlicensed technologies, has become an important technique to deliver new applications and services and to help address the exponential growth of data traffic on cellular networks over the last several years. In the US, users can operate in unlicensed spectrum without the need for a license from the FCC, as long as the transmitting radio equipment is certified and complies with defined rules for limiting and/or avoiding interference

(e.g. Tx power limits) as defined in the FCC's Part 15 rules[62] [1]. Historically, the most commonly used unlicensed bands are the Industrial, Scientific and Medical (ISM) bands. They are defined by the ITU-R. As for licensed spectrum, they enjoy a global level of harmonization. In an unlicensed scheme, RLAN devices collectively share spectrum with incumbent users (e.g., radars) in 5.15-5.825 GHz or ISM equipment in 902-928 MHz and 2400-2500 MHz.

Wi-Fi technology, like cellular technology, is advancing, and in its latest form, 802.11ac, it uses very wide contiguous channels (up to 160 MHz) to achieve faster data rates and to expand capacity. Thus, the additional spectrum best suited to advance Wi-Fi is spectrum that is contiguous to existing unlicensed bands, thereby creating wider contiguous channels on which 802.11ac can be deployed. Fortunately, Congress recognized this in enacting the Spectrum Act. In that legislation, Congress identified an additional 195 MHz of spectrum in portions of the 5 GHz band that are adjacent to the existing spectrum used for Wi-Fi. Congress directed the NTIA and the FCC to study whether this 195 MHz could be made available for Wi-Fi on a shared basis. Accordingly, on February 20, 2013, the FCC issued a Notice of Proposed Rule Making to consider whether the 195 MHz could be made available for Wi-Fi on a shared basis. NTIA is also studying this. As further explained in Section 4.3.1 below, for several years now, there has been research work, studies, and mini-deployments using TV White Spaces. This spectrum consists of one or more 6 MHz TV channels on which no TV station operates. The difficulty is that even if there are three or four contiguous White Space channels in a given location, that is a very small amount of contiguous spectrum (18 to 24 MHz), as compared to the 40/80/160 MHz of contiguous spectrum that Wi-Fi requires today. As a result, there has been very little commercial traction in actual deployments and devices using the TV White Spaces.

4.2.6 SPECTRUM LANDSCAPE INITIATIVES IN CANADA

Commercial Mobile Services

The rapid growth of commercial mobile services is increasing the amount of spectrum required to deliver these services in Canada. Industry Canada has developed an overall approach and planned activities to ensure appropriate spectrum resources are available to meet the demand for commercial mobile services over the next five years.

[62] [Ref 4.9] FCC's Part 15 rules http://www.gpo.gov/fdsys/pkg/CFR-2010-title47-vol1/pdf/CFR-2010-title47-vol1.pdf

Various projections estimate that Canada will require at least 473 MHz and as much as 820 MHz of spectrum to be allocated to commercial mobile services by 2017. Based on these projections, Industry Canada has set an objective of allocating a total of 750 MHz of spectrum to commercial mobile services by the end of 2017.

Taking into account the already-announced auctions of spectrum in the 700 MHz (68 MHz)[63] and 2500 MHz (between 60 to 120 MHz, depending on geographic areas) bands[64], Canada currently has plans in place to have a total of 528 MHz of spectrum available for commercial mobile services by 2015. This means that at least 222 MHz of spectrum will have to be allocated to commercial mobile services over the next four years in order to meet the 750 MHz objective.

Industry Canada has analysed candidate bands to meet this objective based primarily on a combination of the following considerations: (1) the current use of the band in Canada; (2) the suitability of the band to support new services as well as the potential availability of equipment; and (3) international harmonization. Based on this analysis, Industry Canada has identified 300 to 415 MHz of additional spectrum in the following bands that could be the source for the additional 222 MHz needed for commercial mobile services by 2017:

- AWS 2 15 MHz
- AWS 3 50 MHz
- AWS 4 40 MHz
- WCS 20 MHz
- 600 MHz 80-120 MHz
- 3500 MHz 100-175 MHz

Industry Canada is planning to have separate and comprehensive consultations with industry stakeholders before making any specific decisions with respect to these bands. It is also recognized that not all of these spectrum bands will be available by 2017, and that the timing of specific decisions will be subject to international developments.

[63] [Ref 4.10] Consultation on a Licensing Framework for Mobile Broadband Services (MBS) — 700 MHz Band http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10363.html

[64] [Ref 4.11] Consultation on a Licensing Framework for Broadband Radio Service (BRS) - 2500 MHz Band http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10471.html.

A possible timeline for the spectrum allocation is shown in Figure 4.4[65].

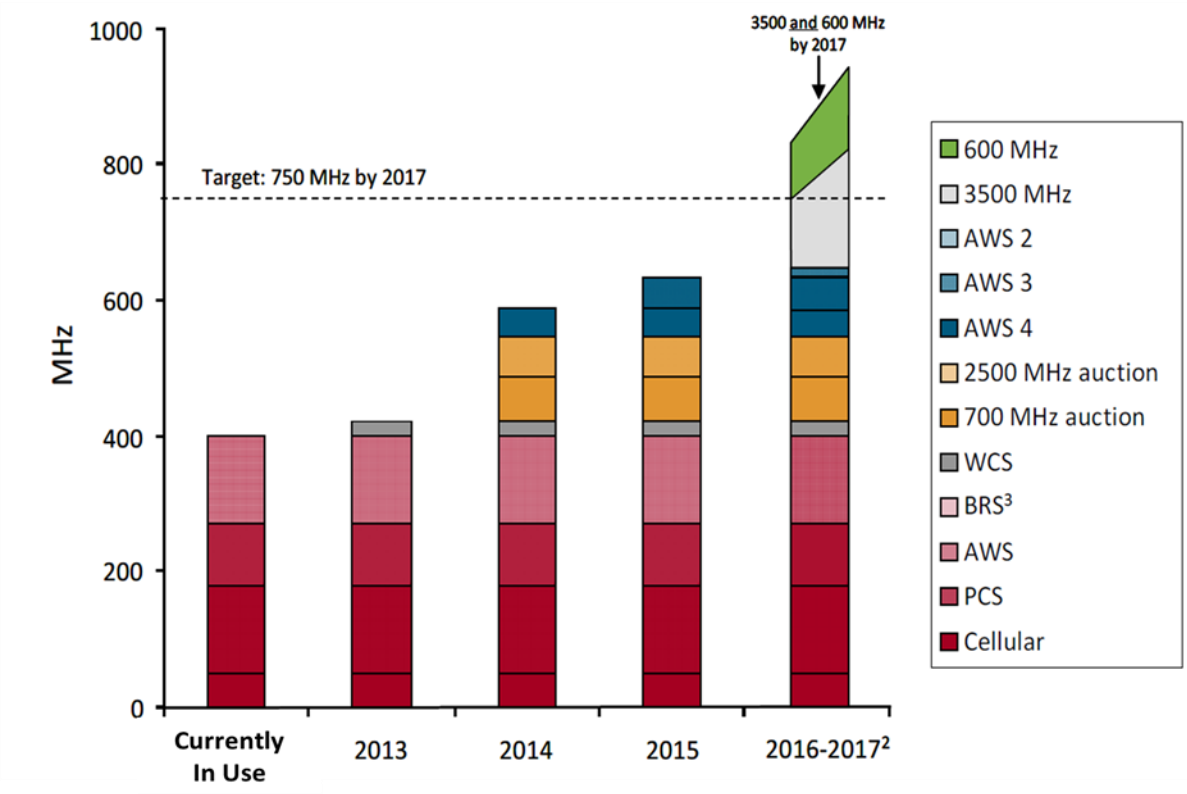


Figure 4.7. Possible Timeline for the Release and Availability of Spectrum to Support Commercial Mobile Services.

Notes:

1. This possible timeline is based on available information and is therefore subject to change. Specific decisions with respect to individual bands will be subject to separate and comprehensive consultations with stakeholders.
2. These years of the possible timeline reflect uncertainty over the amount of spectrum that will be available in the 600 MHz and 3500 MHz bands, as well as the timing of decisions in other countries.

[65] [Ref 4.12] Commercial Mobile Spectrum Outlook http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09444.html

3. Depending on the region of the country, between 60 and 120 MHz of spectrum in the 2500 MHz (BRS) band is currently available for commercial mobile services. The remaining spectrum will be auctioned in 2014, bringing the total amount of spectrum available in the BRS Band to 190 MHz in all regions.

Wireless backhaul

The rapid growth in commercial mobile services is also increasing demand for spectrum to support wireless backhaul services. Overall, Industry Canada believes that the 21 GHz of backhaul spectrum available is sufficient to support the growing wireless sector until 2017. However, while the overall amount of spectrum may be adequate, finding sufficient spectrum in mid-range frequency bands (11-23 GHz) capable of handling increasingly large data rates and throughput to cover longer distances remains a challenge. As a result, Industry Canada is consulting stakeholders to obtain their feedback on additional spectrum requirements across frequency ranges, as well as on updated policies and technical requirements developed to increase efficiency, flexibility and the utilization of all backhaul spectrum.

Unlicensed Spectrum

Wi-Fi is playing an increasingly important role in the deployment of wireless networks by offloading data traffic from cellular networks onto wired networks. It is estimated that by 2015, Wi-Fi networks will carry half of all Internet traffic. As a result, spectrum bands reserved for licence-exempt equipment can be expected to become increasingly congested over the next five years. Industry Canada is taking steps to provide additional spectrum for licence-exempt equipment. The Department recently announced its decision to allow the use of TV white spaces, and Canada is joining other countries in examining the potential of making additional spectrum available in the 5 GHz range for use by licence-exempt equipment.

Beyond 2015

Mobile data traffic will undoubtedly continue to grow, likely resulting in additional spectrum requirements for commercial mobile services, backhaul and licence-exempt equipment. However, given the rapid pace of technological change — particularly technologies which could have dramatic consequences for spectrum use efficiency, network architecture and consumer behaviour — it is difficult to make credible forecasts. It is conceivable, though, that at least 1000 MHz of mobile broadband spectrum will be required by the start of the next decade.

Based on existing inventory with addition of 20 MHz of WCS band and upcoming auction of 700 MHz and 2500 MHz spectrum in 2014, Canadian government has identified that there is

sufficient spectrum available and planned for release to meet the demand up to 2015. The government acknowledges that there will be a spectrum gap in Canada beyond 2015. To close the gap they are socializing their internal spectrum targets to industry:

- Make available an additional 200 to 300 MHz by 2017 (in 600 MHz and 3500 MHz bands);
- Make available up to another 300 MHz by 2022.

This would make up to 843 MHz available by 2017 and up to 1143 MHz available by 2022.
Figure 4.5 provides a view of possible sources of additional commercial mobile services spectrum to satisfy the demand growth between 2015 and 2022.

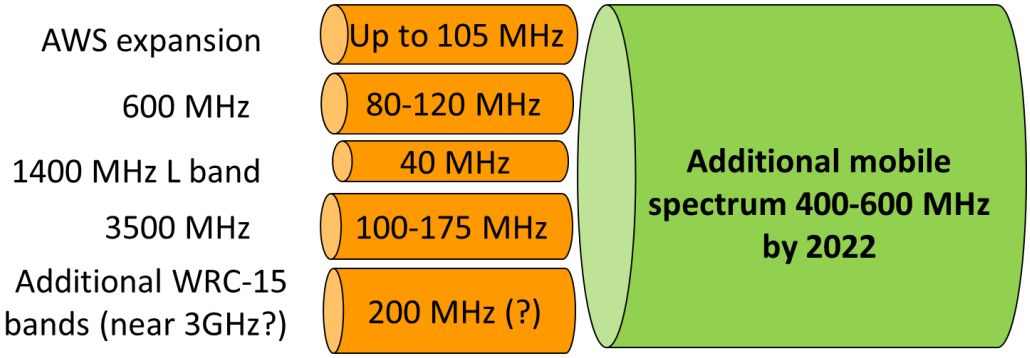


Figure 4.8. Possible Spectrum for Release by 2022.[66]

Industry Canada believes that:

- up to 105 MHz could be made available by aligning with the United States initiatives to expand the existing AWS bands:
  - AWS-3 – Pairing with 1755-1780 MHz is a natural expansion of AWS-1 (50 MHz);
  - AWS-2 – Natural expansion of PCS bands, but limited capacity (15 MHz);
  - AWS-4 – Canada is monitoring closely development in the U.S. (40 MHz).

[66] [Ref 4.13] Mobile Broadband Spectrum – Opportunities and Challenges http://www.isacc.ca/isacc/_doc/ArchivedPlenary/ISACC-12-47303.pdf.

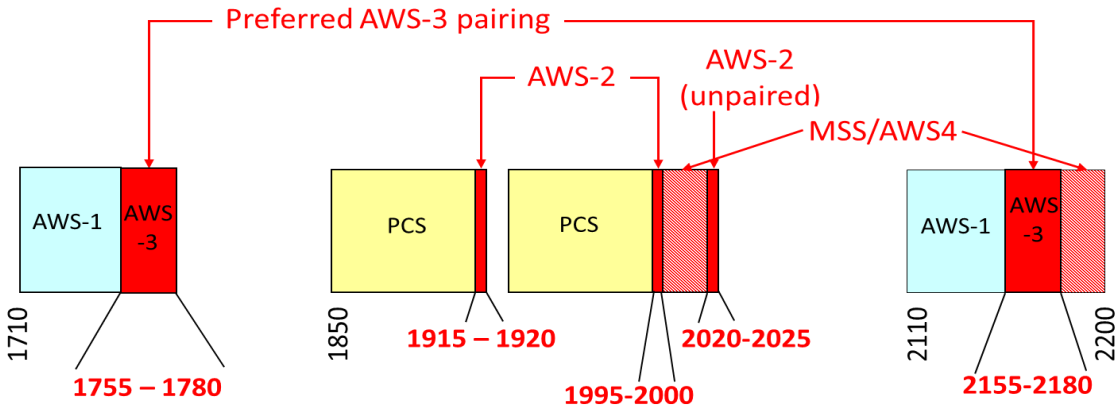


Figure 4.9. AWS Band Expansion.

- spectrum could be made available in the 600 MHz band. They will be monitoring the U.S. process (reverse incentive auction, re-packing, and forward auction) to determine if such an approach might work in Canada. Industry Canada estimates that 80 to 120 MHz of spectrum could become available in this band.
- spectrum could be made available in the L-Band (1435-1528 MHz). The plan would have to accommodate existing aeronautical mobile telemetry user requirements. Industry Canada is reviewing the use of the entire band and indicates a potential of around 40 MHz could be available for mobile use there.
- spectrum could be made available in the 3500 band (3400-3800 MHz), based on the developments in small cell technology and international interest for mobile services. A challenge here is the current radar (below 3500 MHz) and FSS (above 3700 MHz) global allocations, but it's estimated that between 100-175 MHz could be available for mobile broadband in 3475-3650 MHz and 3650-3700 MHz sub-bands.
- an additional 200 MHz of spectrum around 3 GHz may be identified at the WRC-15 meetings.

4.2.7 SPECTRUM LANDSCAPE INITIATIVES IN LATIN AMERICA

After Asia and Africa, Latin America is the world's third largest mobile market with over 684 million connections in 2012 and a growth rate of 13 percent CAGR during the period from 2007 – 2011[67]. It is thus surprising that the average amount of spectrum assigned to mobile operators in Latin America is lower than that of many developed countries.

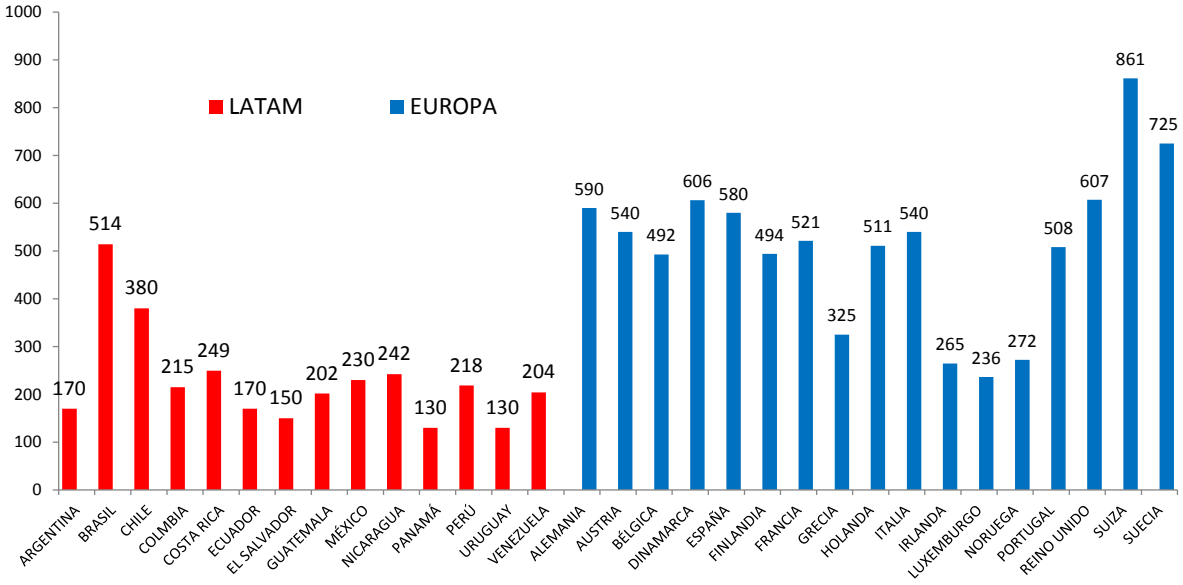


Figure 4.10. Amount of spectrum allocated to mobile operators in Latin America and Europe.[68]

Today most operators in Latin America are using two major bands: 850 MHz and 1900 MHz. In addition, the major economies have also auctioned additional spectrum such as AWS/1.7 GHz and 2.5 GHz. An AWS band has been auctioned in Chile (September 2009), Mexico (August 2010), Colombia (June 2013) and Peru (July 2013). In some cases, the allocation has been partial while some portions of spectrum are still available. The 2.5 GHz Band has been auctioned in Brazil (June 2012), Chile (July 2012) and Colombia (June 2013). The 700 MHz band has been assigned in Bolivia, Ecuador, Nicaragua and Puerto Rico. Full use of this band is contingent upon the discontinuation of analog TV operation and may take many years to be completed in several countries.

[67] [Ref 4.14] Latin American Mobile Observatory 2011- Driving Economic and Social Development through Mobile Broadband, GSMA.

[68] Mobile operators for LATAM, Cullen for Europe, December 2012

However, in view of the mobile data increase and the smartphone rapid migration, the need for more spectrum has been acknowledged by both regulators and the industry throughout the region. Some auction processes have occurred over the past two years and more will take place throughout 2013 – 2014.

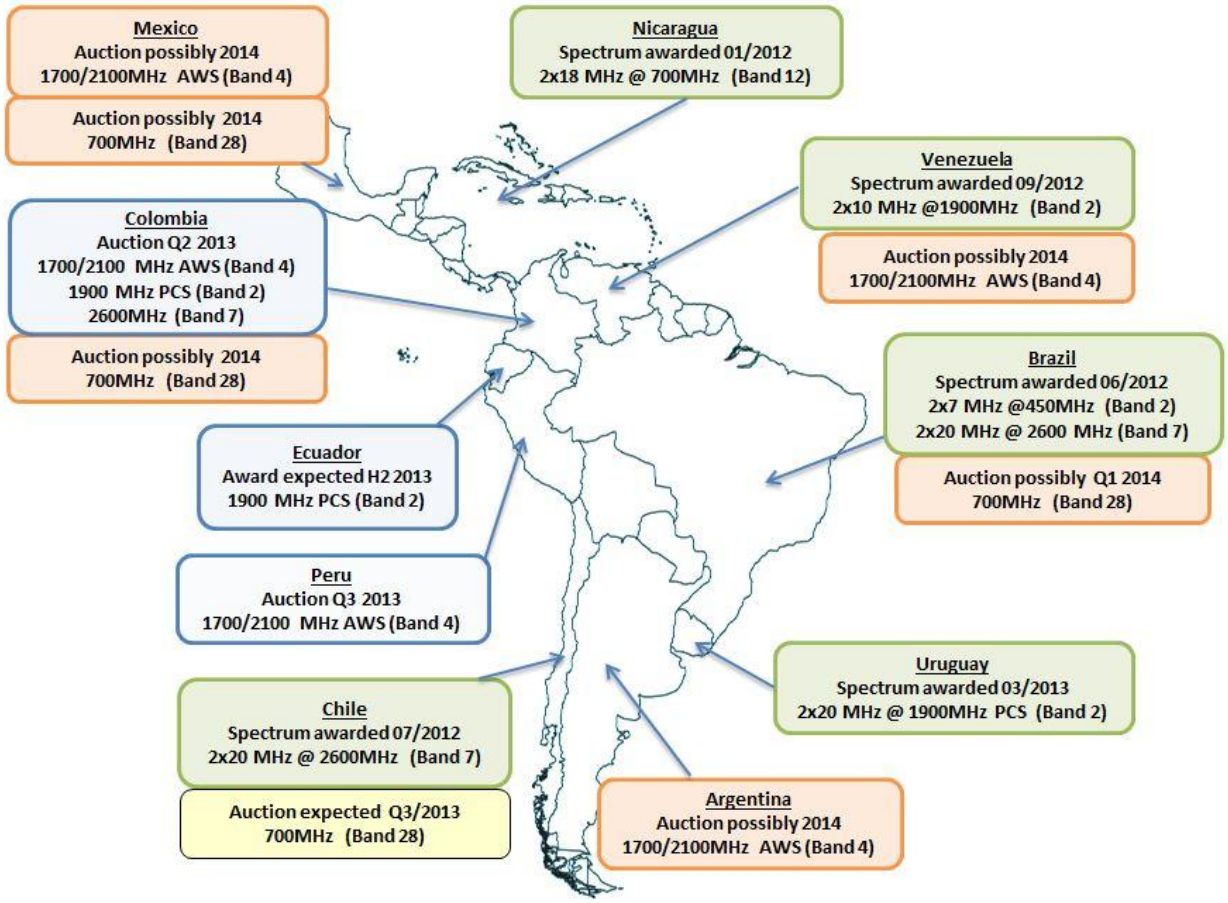


Figure 4.11. Spectrum plans in LATAM.

The design of these auction processes is essential to guaranty that a resource as scarce as spectrum is used in the most efficient manner and ensure reasonable prices and consumer adoption.

The main concerns regarding current and future spectrum allocation processes are:

- Allocation of frequencies directly to public operators

- Incremental costs due to license obligations to cover rural areas with low population density
- National roaming obligations at regulated prices
- Procurement obligations and/or incentives associated with national production of goods

Policy makers should provide regulatory incentives (including related to spectrum acquisition cost) to industry stakeholders to be able to compete and invest in networks and services while providing consumers with a quality and affordable experience. Therefore it is important to consider the following in terms of spectrum management:

- Provide economically sustainable alternatives to certain license obligations
- Allow for increased flexibility in the concession terms including longer renewals to increase stakeholders' investment certainty
- Complete the assignment of the 700 MHz band to mobile services according to the APT band plan for Latin America
- Continue to identify further spectrum availability including policy innovations discussed in this paper (see next section 4.3 on new policy initiatives)

4G Americas has finalized a Report on spectrum in Latin America [69] [Ref 4.15]

[69] [Ref 4.15] 4G Americas White Paper, August 2013, "Analysis of ITU Spectrum Recommendations in the Latin America Region, Understanding Spectrum Allocations and Utilization"

http://www.4gamericas.org/documents/Analysis%20of%20ITU%20Spectrum%20Recommendations%20in%20Latin%20America-August%202013.pdf

4.3 EXPLORATION OF NEW POLICY INITIATIVES

4.3.1 POLICY INNOVATION AND AUTHORIZED/LICENSED SHARED ACCESS (ASA/LSA)

4.3.1.1 BACKGROUND AND DEFINITIONS

Background:

As mentioned in the sections above, technology innovation and massive investment are essential elements to successfully address the 1000x data challenge, but those factors, by themselves, will not be sufficient. More harmonized spectrum for mobile broadband use will also be an essential pillar with exclusive use licensing of spectrum the preferred model for the industry.

To date, the traditional policy approaches to commercial spectrum allocation and management, "licensed" and "unlicensed", have been the mainstream and will continue to be, especially since the mobile broadband industry continues to need cleared, exclusive, licensed spectrum as its highest priority. However, there is recently a strong realization that some bands simply cannot be cleared in a reasonable time frame or could be too costly to clear. Along with the growing demand to free up much more spectrum for mobile broadband, there is also a need to enhance spectrum harmonization, and to advance economies of scale, affordability, and roaming capabilities. Operators cannot just wait for new bands to become available in a decade or more. This situation has led to discussions around new innovative spectrum policy approaches to identify spectrum for mobility applications and in particular considerations of various sharing models.

On June 14, 2013, President Obama issued a Memorandum that directs Federal agencies and offices to take a number of actions for agencies to facilitate the relinquishment or sharing of spectrum allocated to US government agencies to make this spectrum available for commercial wireless broadband technologies and create new avenues for wireless innovation.[70] Among its directives, the memorandum calls for the establishment of a White House-level Spectrum Policy Team that shall monitor and support advances in spectrum sharing policies and technologies

[70] [Ref 4.16] Presidential Memorandum – Expanding Americas Leadership in Wireless Innovation – June 2013 http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovation

while protecting the incumbent agencies, collaboration on spectrum sharing and recommendations to give agencies greater incentives to share or relinquish spectrum. This Presidential Memorandum confirms the need for a paradigm shift in spectrum policy in which sharing will play a key role. ASA/LSA as described in this paper would fit perfectly in this new approach.

This section aims to clarify the different approaches under consideration, provide definitions to characterize them, and describe a few concrete examples that will shed light on the opportunities that will flow from new regulatory approaches, especially ASA/LSA. That framework, in essence, consists of a an exclusive, binary, vertical sharing in time, location, and/or frequency between a spectrum incumbent, which has not been granted rights of use under a competitive assessment, and an authorized economic stakeholder which operates a Quality of Service (QoS)-based network and will gain access to the spectrum when and where the incumbent does not use it under a well-defined interference protection/sharing arrangement. ASA/LSA is a technology neutral approach and can be applied to both FDD and TDD technologies as discussed in the two case studies presented in this paper: FDD at 1.7/2.1 GHz and TDD at 3.5 GHz.

In addition to addressing timely availability of harmonized spectrum under ASA/LSA, the industry has recognized the vast asymmetry of data traffic, with greater downloads than uploads primarily due to the increasing amount of media consumption from video streaming and the related large file downloads. To address this issue, there are positive developments on spectrum policy that are applicable to the Americas. The approach combines spectrum policy and technology innovation such as carrier aggregation or Supplemental Downlink to enable operators to deliver far more download capacity and a far better user experience especially for downloads.

Definitions (including different sharing mechanisms)

Authorized/Licensed Shared Access (ASA/LSA)[71]

ASA/LSA is a third and complementary way of authorizing spectrum, in addition to licensed (exclusive) and license-exempt (unlicensed). The reality is that some spectrum bands below 6 GHz are not used on a nationwide, 24/7 basis and could be made available for commercial mobile broadband usage in the time, location/geography, and/or frequency domains. In many

[71] In this document the term ASA and LSA will be used interchangeably

cases, this spectrum is not used across an entire nation or licensed area at all times – the spectrum is unused in various locations and/or at times. ASA will allow this spectrum, in its entirety, to be used efficiently at all times on a nationwide basis or license-wide basis subject to sharing rules to be defined ex ante.

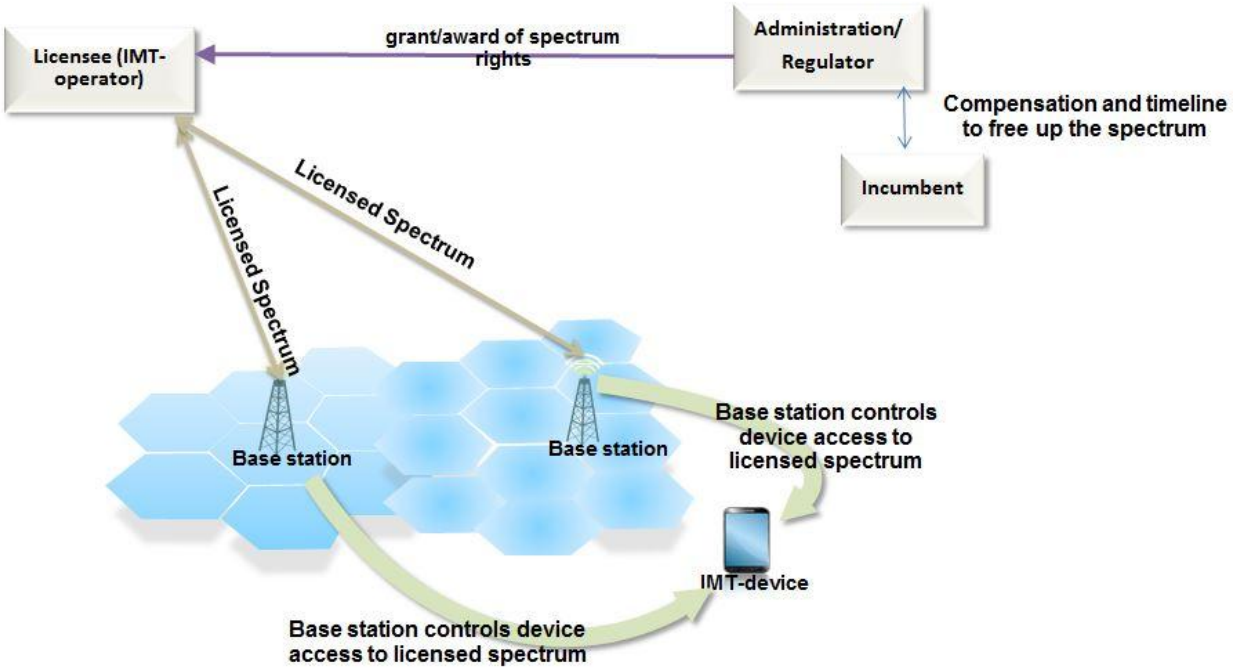


Figure 4.11. "Traditional" Exclusive Licensing.

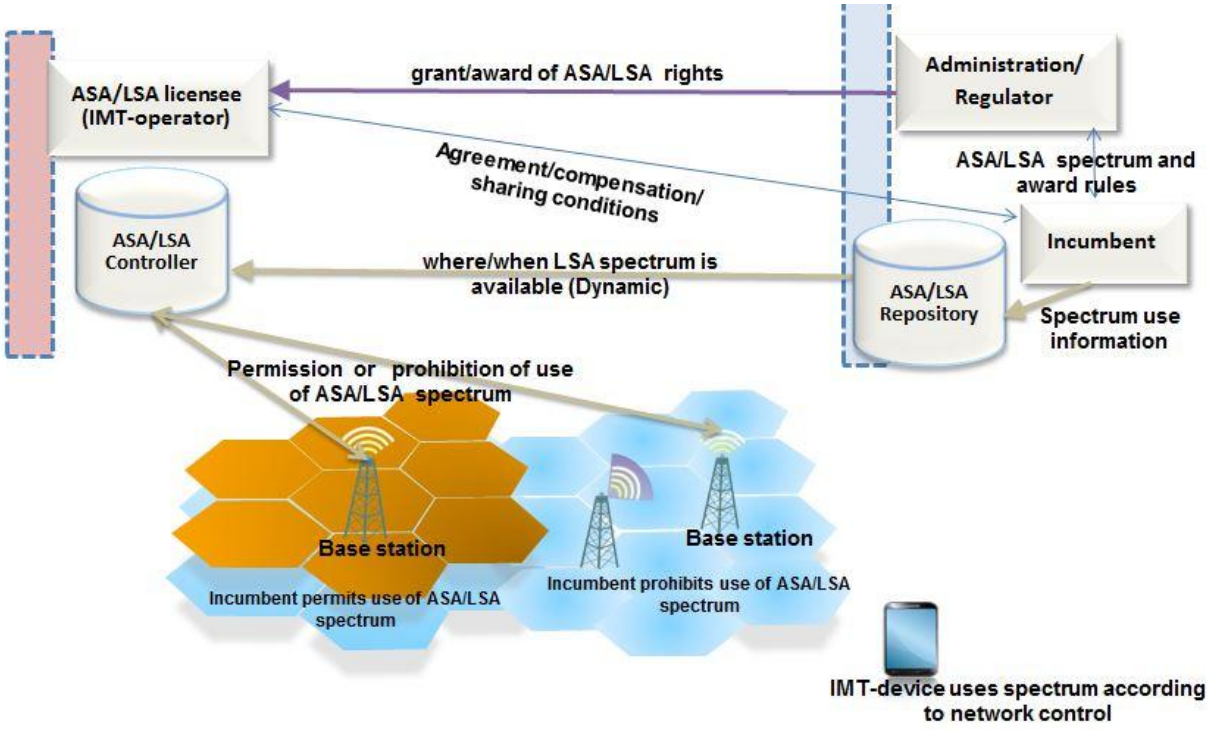


Figure 4.12. Example of ASA/LSA architecture.

ASA spectrum rights of use are granted on an individual and exclusive basis to ASA licensees subject to the terms defined by the relevant authority (government, regulator) and to the existing usage of the incumbent. ASA licensees use the spectrum for mobile broadband on a shared but non-interference basis with the incumbents. Sharing under the ASA framework is binary by nature, as it admits spectrum use by either the incumbent or the ASA licensee at a given location, at a given time, and on a given frequency. Sharing under this regulatory approach can be said to be strictly "vertical" or "additive" in the sense that the approach is limited to bands in which the incumbent user's rights were not granted under a competitive assessment and that the incumbent will continue to provide the same services as under its original spectrum usage while the ASA licensee will be authorized to provide mobile broadband services when and where the incumbent does not use the spectrum. The ASA licensee enjoys exclusive spectrum rights of use where and when the spectrum is not used by the incumbent. When the incumbent needs the spectrum back, the ASA licensee will need to vacate the spectrum and likely will shift to another spectrum band to ensure a seamless QoS experience to his customer base.

There may be one or several such ASA licensees in any given band since ASA rights of use for a frequency band may be awarded in more than one geographic region, depending on the usage

of the incumbent. ASA rights can be granted on a short or long term basis. A key feature of ASA is that it allows offering a predictable quality of service for the ASA licensee/s while protecting entirely the incumbent operations based on the sharing criteria established.

ASA targets frequency bands that are already, or have the potential to become, globally harmonized mobile bands**.** This regulatory approach takes advantage of economies of scale, ultimately enhances harmonization at the global and regional level and equips administrations with a valuable tool to unlock spectrum while overcoming lengthy, costly and politically sensitive re-farming processes.

The ASA/LSA concept has been developed in detail in academic papers supporting the above definition.[72]

PCAST 3-Tier approach[73]

One licensing proposal in the FCC Notice Proposal of Rule Making (NPRM)[74] on 3.5 GHz reflects recommendations made in a 2012 report by the President's Council of Advisors on Science and Technology (PCAST). The PCAST Report advocates a new spectrum usage model that allows commercial users to share spectrum with government users and with each other. Although the PCAST report did mention ASA/LSA, the PCAST Report recommends that shared access to Federal spectrum should be governed according to a three-tier hierarchy:

- Federal primary systems would receive the highest priority and protection from harmful interference;
- Secondary licensees must register deployments and use in a database and may receive some quality of service protections, possibly in exchange for fees;
- General Authorized Access users would be allowed opportunistic access to unoccupied spectrum to the extent that no Federal Primary or Secondary Access users are actually using the spectrum in a specific geographical area or time period.

[72] [Ref 4.17] Studio Economico Parcu & Associati – Authorised Shared Access (ASA), An Innovative Model of Pro-competitive Spectrum Management - May 2001 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2174518

[73] [Ref 4.18] PCAST, Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth (rel. July 20, 2012) (PCAST Report), *available at* http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

[74] [Ref 4.19] FCC NOTICE OF PROPOSED RULEMAKING AND ORDER "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550- 3650 MHz Band, December 12, 2012".

It should be noted that the PCAST report does not exclude non-critical users such as commercial operators that still require some guarantee of QoS from the Secondary Access tier. This is one major difference with the following FCC's proposal that is based on the PCAST report[75]:

- Incumbent Access that would include authorized federal users and grandfathered fixed satellite service (FSS) licensees. These incumbents would be afforded protection from all other users in the 3.5 GHz band.
- Priority Access that would include critical use facilities, such as hospitals, utilities, government facilities, and public safety entities that would be afforded quality- assured access to a portion of the 3.5 GHz band in certain designated locations.
- General Authorized Access (GAA) that would include all other users – including the general public – that would have the ability to operate in the 3.5 GHz band subject to protections for Incumbent Access and Protected Access users and can use the spectrum when Incumbent and Priority Access users are not using it.

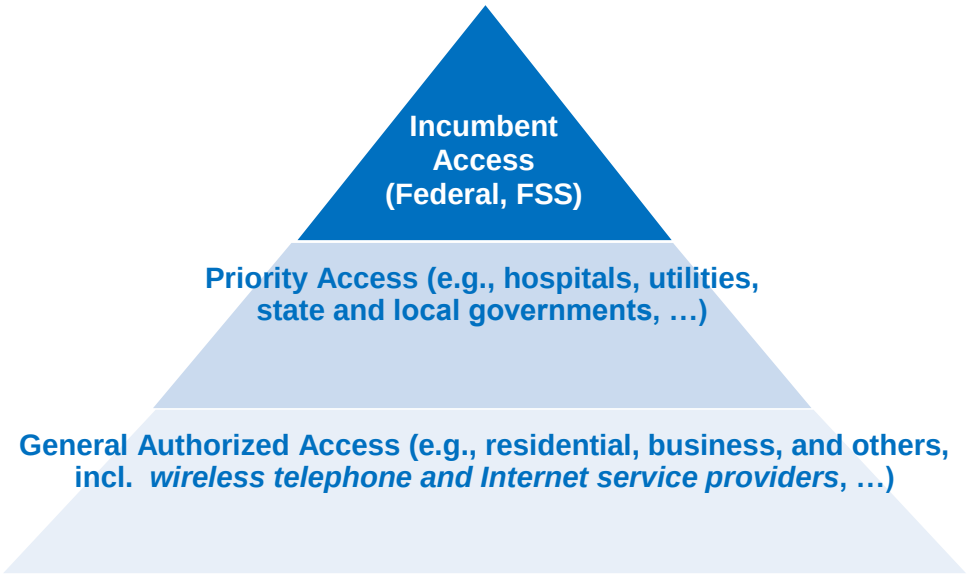


Figure 4.13. FCC's 3-Tier Proposal (based on PCAST 2012).

[75] [Ref 4.20] COMMENTS OF NOKIA SIEMENS NETWORKS, February 20, 2013, to FCC NPRM, "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550- 3650 MHz Band"

The FCC also asked for comment on the promising Authorized Shared Access (ASA) concept being explored currently in Europe and described above. The ASA model as outlined above is a good alternative solution for enabling deployment in the 3550-3650 MHz band. ASA offers a predictable environment for deployment of mobile broadband compared to the Commission's three-tier approach which adds complexity and uncertainty that could substantially impede the rollout of services using the spectrum. The ASA model can be implemented more easily and rapidly. The ASA model would result in a two-tier approach as shown in below.

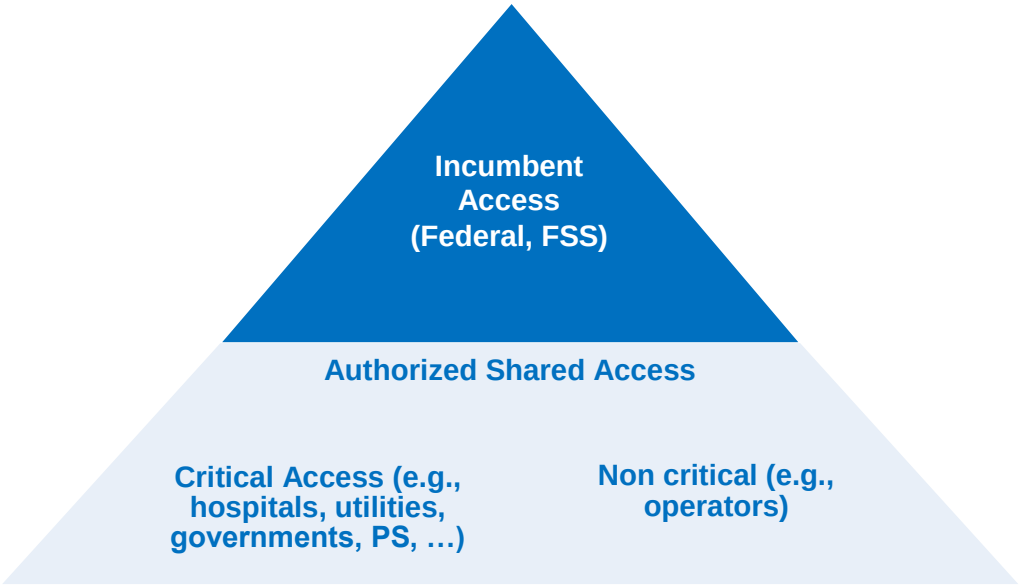


Figure 4.14. ASA 2-Tier Approach.

TV White Spaces

TV White Spaces are a form of unlicensed spectrum. The user has no exclusivity in its use of the spectrum. Any user of the TVWS may have to share the spectrum concurrently with an unlimited number of users. In other words, TVWS access points can and will overlap in coverage and collide with one another. And, users of the TVWS have no protection from interference.

In addition, the TVWS is a specific spectrum range, namely vacant TV channels within the UHF spectrum. A TV channel in the US is 6 MHz; elsewhere it is 8 MHz. Even aggregating a few contiguous vacant channels provides a relatively narrow swath of spectrum, providing much less bandwidth than is used in next-generation Wi Fi (802.11ac), which uses contiguous channels of up to 160 MHz. Moreover, there are substantial co-existence issues between TVWS and TV stations, particularly where broadcasters use multiple frequency networks (MFNs) for digital television.

Thus, the TVWS, like other unlicensed bands, can only support best effort services. This is because each sharing user under an unlicensed regime has equal rights to access the spectrum on a concurrent basis, providing that the user's device is in compliance with the relevant operating conditions. Since there is no regulatory management of the different unlicensed users in terms of user density or technology, there can be no guaranty of capacity, coverage or operating conditions.

On the other hand ASA as described above is also a form of licensed spectrum by which the rights holder will have exclusive use of the spectrum, subject to the usage of the incumbents. Thus ASA can provide spectrum resources better suited to mobile broadband services by delivering a predictable quality of service. In other words, with ASA, those services which require the ability to manage access among users in order to guarantee the level of capacity and operating conditions are enabled.

Collective use/License-Exempt Sharing

Both license-exempt use and licensed use are useful and needed for solving the challenge of an increasing demand for spectrum. In a license-exempt scheme, RLAN devices can collectively share spectrum with incumbent users, (e.g., radars in the 5 GHz band) or within an ISM band, (e.g. 2.4 GHz). In addition, those bands have been harmonized on a global basis.

Some work by regulators has looked at the concept of collective use. Collective use can be understood as a broader subset of spectrum sharing and particularly a model of spectrum access allowing multiple users to share spectrum at the same time and in a particular geographic area without individual exclusive licenses. It has shown success mostly in the context of opportunistic sharing between incumbent and new concurrent users and it has benefited from global harmonization and economies of scale espescially in the case of 2.4 GHz, 5 GHz or 60 GHz. In this context, Administrations and industry are globally pursuing the extension of the 5 GHz band to further enhance RLAN/Wi-Fi capabilities.

Unlicensed, unlike ASA, can only allow best effort services. This is because each sharing user under an unlicensed regime has equal rights to access the spectrum, providing that the user is in compliance with the operating conditions in the class license. Since there is no management of the different unlicensed users in terms of user density or technology or across the short range networks that sometimes have overlapping coverage that can collide with one another, there can be no guarantee of capacity, quality of service, wide area coverage or operating conditions.

On the other hand, ASA can provide spectrum resources better suited to mobile broadband services that require predictable quality of service; in other words, those services which require the ability to manage access among users in order to guarantee the level of capacity and operating conditions. ASA is about granting individual rights of use for exclusive access to spectrum where and when the incumbent is not using this spectrum under the terms of an agreement.

4.3.1.2 AMERICAS

- **US Allocation of AWS (1.7/2.1 GHz) Band**

The Federal Communications Commission (FCC) notified the National Telecommunications and Information Administration (NTIA) that it plans to commence the auction of licenses in the 1695-1710 MHz band and the 1755-1780 MHz band as early as September 2014.[76] These two bands are currently used by Federal Government and will need to be made available for commercial services.

The challenges to repurposing include the high cost and long timeline of the undertaking, estimated to be $18 billion over ten years.[77]

Congress directed the Commission to allocate and license the 2155-2180 MHz band and other bands by February 2015. The commercial wireless industry is advocating pairing this 2155-2180 MHz band as downlink with the 1755-1780 MHz Federal band as uplink and pairing of 2095-2110 MHz as downlink currently used by Broadcast Auxiliary Service ("BAS") with 1695-1710 MHz as uplink. These new spectrum bands would effectively extend the current US AWS band (1710-1755/2110-2155 MHz)[78], by 2x15 MHz on the lower edge and 2x25 MHz on the upper edge as shown in the figure below. The commercial industry views 1755-1780 MHz as being of higher priority than 1695-1710 MHz mainly because 25+25 MHz of the extended portion in

[76] [Ref 4.21] March 20th, 2013 Letter from FCC Chairman to NTIA Administrator
http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db0321/DOC-319708A1.pdf

[77] [Ref 4.22] "An Assessment of the Viability of Accommodating Wireless Broadband in the 1755-1850 MHz Band", U.S. Department of Commerce, March 2012
http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf

[78] 3GPP Band 4

1755-1780 (uplink) and 2155-2180 MHz (downlink) have already been identified. However, the downlink band to be paired with 1695-1710 MHz has yet to be confirmed by the FCC.

The new extended band in the US, when made available, would overlap with the 1710-1770/2110-2170 MHz band[79], which has been identified for IMT by the ITU and consequently to be made available in many countries in the Americas. There is on-going work in CITEL[80] to extend this band by 10+10 MHz (1770-1780/2170-2180 MHz) in the U.S., which would help develop a regional ecosystem for AWS spectrum.

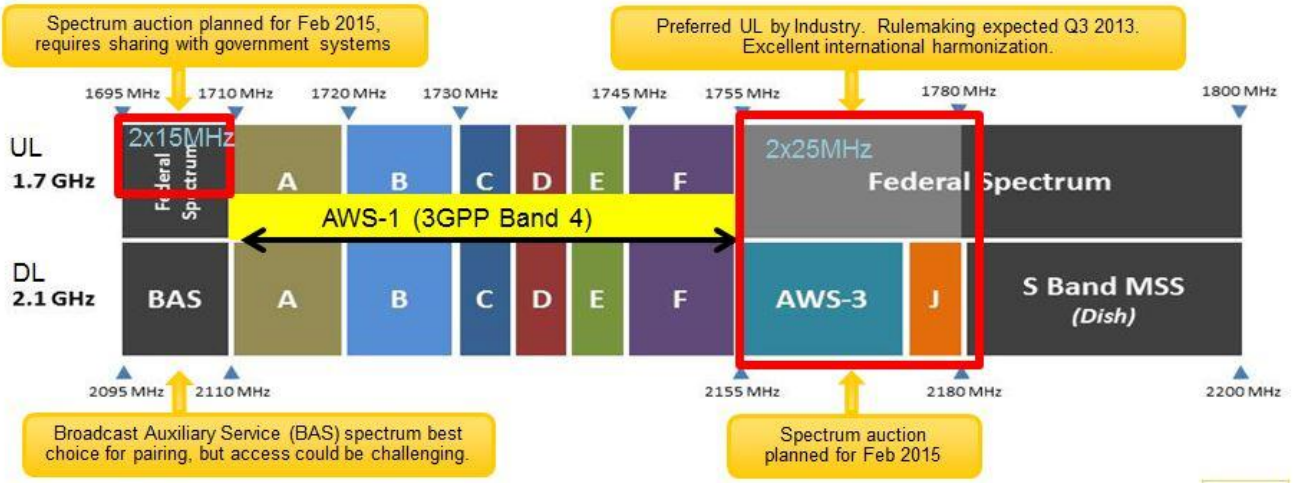


Figure 4.15. New AWS Spectrum Requiring Sharing with Federal Government Systems.

The US Commerce Spectrum Management Advisory Committee (CSMAC)[81], which advises the National Telecommunications and Information Administration (NTIA)[82] on a broad range of spectrum policy issues, established five Working Groups (WGs) "to facilitate the implementation of commercial wireless broadband in the 1695-1710 MHz and 1755-1850 MHz

[79] 3GPP Band 10

[80] [Ref 4.23] CCP.II-RADIO/doc. 3295/13 Draft Recommendation on "Use of 1710-1780 / 2110-2180 MHz BANDS IN THE AMERICAS FOR BROADBAND MOBILE SERVICES", 11 April 2013, http://www.oas.org/es/citel/P2!R.htm

[81] US Commerce Spectrum Management Advisory Committee (CSMAC) http://www.ntia.doc.gov/category/csmac

[82] National Telecommunications & Information Administration (NTIA) http://www.ntia.doc.gov/

band." The various CSMAC WGs have been working for one year releasing their analysis and recommendations as they complete their work. In particular, the WGs have been deriving protection distances or exclusion zones for two interference scenarios:

- Government system receiver as potential victim of interference from LTE UEs
- Government system transmitter as potential source of interference to LTE base stations

One common trend among many of the systems studied was the huge size of exclusion zones which could make the spectrum less attractive to operators since those exclusion zones could exclude major populated areas from LTE deployment in that band.

Based on the results of the analyses, the WGs were able to identify a number of issues for follow-up work items, promising sharing mechanisms as well as "lessons learned" that can be used in future assessments. One such promising sharing mechanism identified was ASA/LSA:[83]

"Time-Based Sharing – Commercial wireless industry presented information on proposed innovative spectrum sharing techniques (e.g., time-based sharing or real time monitoring via Licensed Shared Access)[84] that could exploit the advanced features in the LTE standards to enable use of spectrum assigned to government users without impact to operations. These mechanisms have the potential to facilitate sharing by enabling commercial wireless licensees to dynamically relinquish their use of the shared spectrum with minimal impact to users in areas during times that government users are using the band. The proposal did not include the implementation details and would need further study. Both government and industry interests writ large should work together to further study these approaches, sharing as much information as practicable about the systems that are envisioned to share using such mechanism, as well as the projected operational aspects and economically acceptable conditions, to determine feasibility of sharing without a negative impact to both government and commercial operations. This study should include the feasibility of the time-based sharing Licensed Shared Access regulatory construct. This study should also include the potential impact on government operations and proposed commercial operations in this band, and the implementation details on the real-time/near real-time information requirements for both government and commercial

[83] [Ref 4.24] CSMAC WG 5 Final Report DATE, "1755-1850 MHz Airborne Operations (Air Combat Training System, Small Unmanned Aircraft Systems, Precision-Guided Munitions, Aeronautical Mobile Telemetry)"

[84] [Ref 4.25] Nokia Siemens Networks' presentation to CSMAC WG4/5, 30 April 2013, "Spectrum Sharing Enablers"

wireless licensees, whether it is via a database or some other secure means. Further, the study should consider the economic acceptability of the proposal."

This was further echoed in a letter from the Commercial Wireless Industry to NTIA:[85]

"Through a combination of sharing, relocation and channel prioritization for the majority of operations in the 1755-1850 MHz band it appears feasible to provide industry early access to the 1755-1780 MHz portion of the band. In some cases, additional analysis may need to continue to further refine long-term arrangements for the entire 1755-1850 MHz band, including potential long-term sharing in the 1755-1850 MHz band and/or other frequency bands as appropriate. The additional analysis could not only further refine the static exclusion zone sizes as needed but also develop innovative spectrum sharing techniques that exploit the more dynamic nature of the use of the spectrum and the advanced features in the LTE standards that we have started to discuss in CSMAC WG-5 in particular."

- **US3.5 GHz Band for Mobile Broadband under ASA/LSA**

On December 12th, 2013, the FCC adopted a Notice of Proposed Rulemaking on the 3.5 GHz band to allocate 3550-3650 MHz to mobile broadband based on two important innovations in enabling more efficient use of spectrum. Specifically, the FCC is proposing to allocate the 3.5 GHz band utilizing small cells and spectrum sharing, on an authorized basis with government users (military radars) and non-government users (satellite earth station receivers) currently utilizing the band. The FCC extensively recognized the work of the mobile industry pertaining to the 1000x data challenge and the views that the 3.5 GHz is a complementary and important swath of spectrum with significant potential to meet the mobile data explosion and expand the reach to citizens of mobile broadband in the US.

[85] [Ref 4.26] Wireless Industry letter to NTIA on 1755-1780 MHz Band
http://files.ctia.org/pdf/filings/CTIA_files_letter_with_NTIA_on_1755-1780_MHz_Band.pdf

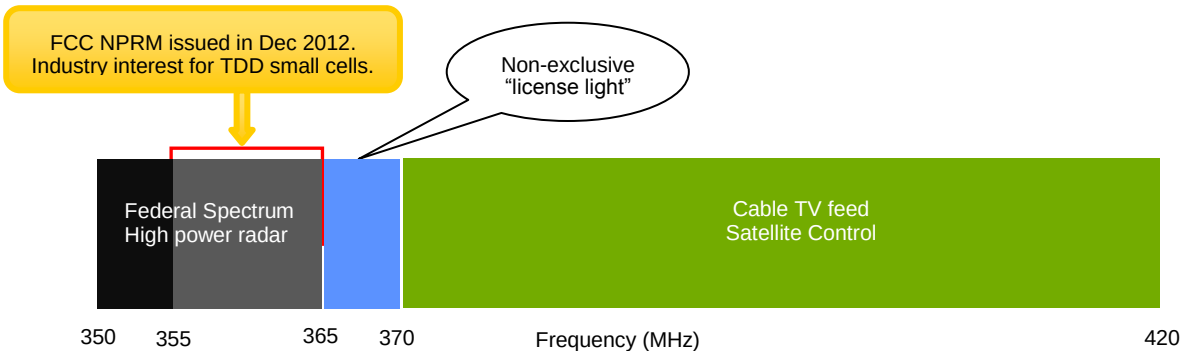


Figure 4.16: 3.5 GHz band in U.S.

During the comments phase, there was a significant interest from the mobile industry providing concrete steps forward and preferred approach for the use of the band and specific sharing model.

The following aspects were stressed in the comments:

1) ASA, binary and exclusive use preferred

Spectrum management in the U.S. and around the world is based principally on the separation of users by frequency band. As the *3.5 GHz Small Cells NPRM* notes, a large amount of spectrum is reserved for the U.S. government, but at least some of that spectrum is not fully utilized by these federal incumbents on a 24/7, nationwide basis[86].

At the same time, mobile broadband network operators are increasingly constrained by the difficulties involved in gaining access to the additional spectrum needed to support end users' skyrocketing data demands while providing a consistent quality of service. ASA offers an improved means of sharing spectrum with incumbent users via a two-tiered licensed sharing framework. It provides a straightforward means of improving spectrum utilization, as it opens partially-occupied spectrum for mobile broadband use while fully protecting incumbent operations that continue operating in the band. ASA also provides tools to allow ASA licensees and incumbent federal users to work cooperatively to meet demand spikes.

[86] [Ref 4.8] *See3.5 GHz Small Cells NPRM* at ¶ 6 (identifying 3.5 GHz as the "ideal band in which to propose small cell deployments and shared spectrum use"; noting that the incumbent uses in the band include high powered Department of Defense radars, non-federal Fixed Satellite Service ("FSS") earth stations for receive-only, space-to-earth operations and feeder links, and that the adjacent band below 3550 MHz contains high-powered ground and airborne military radars).

With regard to the 3.5 GHz band in particular, the ASA regulatory framework can incorporate the necessary "geographic restrictions to protect existing Department of Defense ("DoD") radar and FSS operations and to protect new commercial systems from co-channel interference from high-powered military in-band ship borne and adjacent band DoD ground-based radar systems.[87]"

While the FCC originally proposed a multi-tiered access approach, for the reasons mentioned above, many comments cautioned that such approach will compromise predictability and quality of service for both the incumbent and the new licensees. Instead, several industry players urged the FCC to adopt a more practical, less complex and predictable approach such as the 2-tier ASA approach to enable QoS mobile broadband services while providing full protection to incumbent users, in accordance with the FCC's goals. At its core, ASA is a binary system in which the spectrum is used at a given location either by the primary incumbent or by the ASA rights holder, which has an exclusive right to use the spectrum at the times, locations, and frequencies that are not being used by federal incumbents. In this way, ASA allows federal incumbent users to coexist with ASA licensees on a long-term basis as well as on a transitional basis while incumbent users transition to another band.

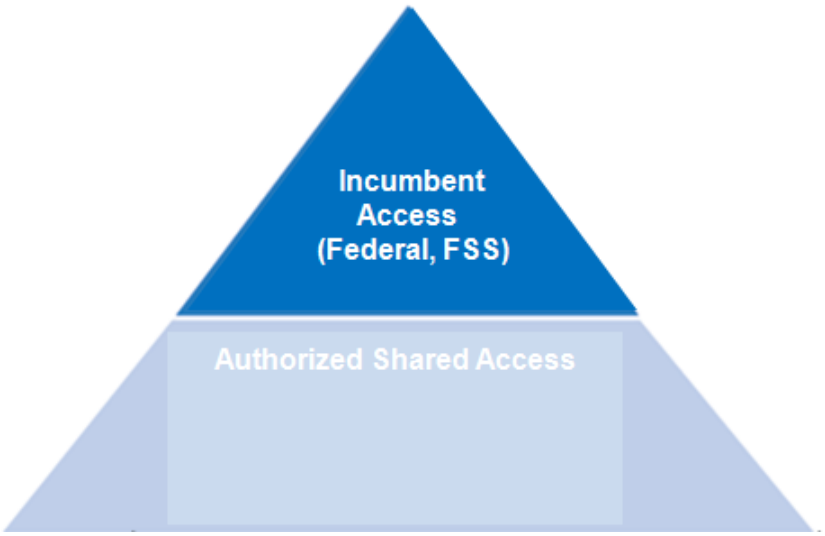


Figure 4.17. ASA/LSA binary approach.

[87] [Ref 4.8] *See 3.5 GHz Small Cells NPRM* at ¶ 18 (explaining that the 3.5 GHz radar systems overcome the inherent limitations due to increased propagation losses by using high transmitter power levels and high-gain antennas, and noting that these characteristics contributed to the size of the exclusion zones in NTIA's Fast Track evaluation).

2) The importance of 3.5 GHz and ASA in general in the context of spectrum harmonization and preferred band plan for 3.5 GHz

The important benefits of globally harmonized spectrum should not be overlooked. The amount of spectrum required to support mobile broadband services is expanding exponentially. Correspondingly increasing is the desirability for the existing and newly identified spectrum to be harmonized globally across frequency range, channel plans and emissions requirements. Spectrum harmonization helps to achieve economies of scale, enables global roaming, reduces equipment design complexity and improves spectrum efficiency[88]. All of this ultimately reduces costs for consumers. In particular, device costs are a significant issue as widely supported spectrum bands and channels can lower the crucial radio frequency (RF) component costs. Harmonization also aids in addressing cross border coordination.

A. Time Division Duplex (TDD) Mode in the 3.5 GHz Band

Harmonization in terms of a band plan includes the duplex mode of operation that may be deployed. Harmonizing the duplex mode with global preferences brings the economies of scale benefits highlighted above. Moreover, spectral efficiencies and other considerations factor into a decision on which band plan to apply.

Many of the technical aspects about this spectrum are yet to be decided and the FCC will need to finalize them during the rule-making phase. One of the most important aspects is duplex mode; different duplex modes will lead to drastically different band plan designs. During the comment and reply comment cycles, many companies have argued in favor of Time Division Duplex (TDD) over Frequency Division Duplex (FDD), although both options are still pretty much open.

In order to allow LTE to be used in this spectrum, some 3GPP defined LTE band class or band classes will be required. There are currently three already defined 3GPP band classes that are either within the range of the 3.5 GHz band spectrum or partially overlapped with this spectrum. These are:

- TDD Band 42: 3400-3600 MHz
- TDD Band 43: 3600-3800 MHz

[88] [Ref 4.27] *See* Document 5D/246-E, Canada's input to ITU-R WP 5D, "Technical perspective on benefits of spectrum harmonization for mobile services and IMT," 23 January 2013.

- FDD Band 22: 3410-3490 MHz uplink/3510-3590 MHz downlink

There should not be any controversy over defining a new band in 3GPP after the FCC establishes a band plan. In general, it is preferable if new spectrum is covered by an existing band to avoid having to create a new band. Band class harmonization also helps to achieve economies of scale, enables global roaming, reduces equipment design complexity and improves spectrum efficiency. In this case, there is no existing 3GPP band that is identical to the spectrum under consideration by the FCC.

If the FCC were to adopt TDD, the existing 3GPP Band 42 and 43 would cover the CBS band entirely. As illustrated in Figure 4.18, the first 50 MHz of the FCC's Citizens Broadband Service (CBS) band, 3550-3600, is covered by Band 42 and the second 50 MHz, 3600-3650, is covered by Band 43. Conceivably, the FCC, if it would, could devise a band plan that are compatible to and can readily use Band 42 and Band 43, for example by segmenting 3550-3650 MHz into 2x50 MHz TDD blocks. Note that if the FCC decided to extend the CBS band up to 3700 MHz, Band 43 will still cover the extended portion nicely. It would seem that a TDD band plan is more flexible and accommodating than a FDD band plan if the FCC were to expand the CBS band beyond 3550-3650 MHz in the future.

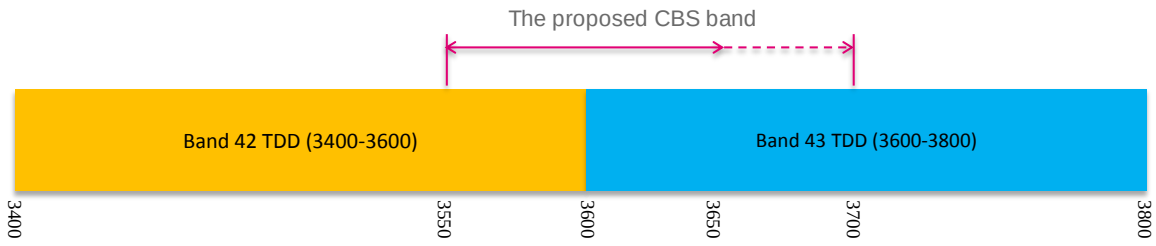


Figure 4.18. 3GPP Band 42 and 43 in relation to the CBS band.

If the FCC were to adopt FDD, the existing 3GPP Band 22 would not be able to cover the CBS band entirely. As illustrated in Figure 4.19, Band 22 uplink is totally outside of the CBS band, and Band 22 downlink overlaps only partially with the CBS band. Therefore the CBS band, as it is proposed today, will not be able to readily use 3GPP Band class 22. A new LTE FDD band class will need to be created, according to actual CBS band spectrum allocation. Moreover, if the FCC decided to expand the CBS band beyond 3550-3650 MHz, chances are another new band class will need to be created to accommodate such spectrum allocation change.

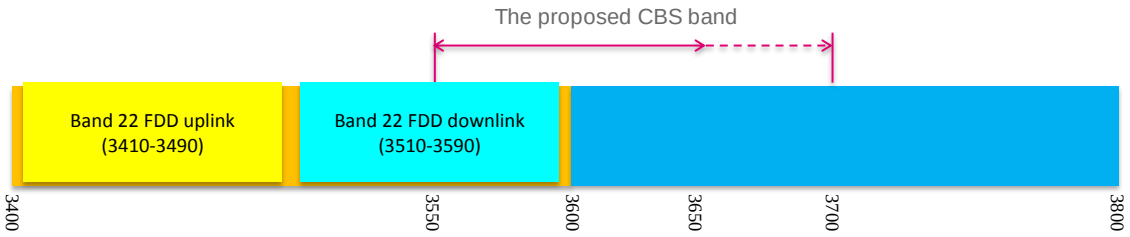


Figure 4.19. 3GPP Band 22 in relation to the CBS band.

The benefit of small cells / 3GPP technologies is to mitigate interference and provide quality of service at a lower cost.

The FCC NPRM "rightly" stated that the 3.5 GHz holds "great promise for small cell applications" and that the radio propagation characteristics can facilitate "dense deployment of small cells with a reduced risk of harmful interference to geographically or spectrally adjacent users" and thus tremendously increasing network capacity through intensive frequency reuse[89]. Indeed, leveraging small cell use, subject to the terms defined by the relevant authority (government and regulator) and to the existing usage of the incumbent users, will minimize interference issues that may exist when macro cells and small cells are deployed within the same band.

The FCC also rightly notes that these same characteristics make the band well-suited for "spectrum sharing, particularly geographic sharing" for it can "allow disparate radio systems to operate in closer proximity than lower frequency bands," and thus not only support enhanced sharing with incumbent users, but also enable greater sharing with potentially disparate commercial systems in the band[90].

In October 2010, the NTIA[91] released a report evaluating 3550-3650 MHz as a band that could potentially be shared with commercial broadband systems. Similar to the CSMAC studies on 1.7 GHz, the exclusion zones were huge based on a macro deployment of mobile broadband

[89] [Ref 4.8] *See 3.5 GHz Small Cells NPRM* at ¶ 20.

[90] [Ref 4.8] *See id.* at ¶ 21.

[91] [Ref 4.28] U.S. Department of Commerce, October 2010, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands"

systems as shown in the figure below, which could be 450km along the coastline impacting 60 percent of the population.

Figure 4.20. Exclusion Zones based on macro deployment.

A combination of technical and service characteristics for small cell deployments in the 3.5 GHz band has the potential to reduce geographic exclusion zones reduce geographic exclusion zones substantially based on interference from LTE- small cells transmissions to radar systems (reducing them from several hundred kilometers to just 10 to 15 kilometers)[92], while still providing necessary protections for incumbents. In that respect, the much lower transmit power typically used in small cells as compared to macro cells will greatly help mitigate interference from the broadband systems into the incumbent systems. However, on-channel interference from radar systems to LTE-based small cells may still occur. Therefore, ASA could be employed to enable small cell operation.

[92] [Ref 4.29] Comments of Qualcomm Incorporated, February 20, 2013, to FCC NPRM, "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550- 3650 MHz Band"

The 150 km exclusion zone in 3650-3700 MHz around Fixed Satellite Services (FSS) was created based on the assumption that Commercial Mobile Radio Services licensees would operate high-powered devices which could still be the case with small cells. The Commission allowed licensees in the 3650-3700 MHz band to negotiate with individual FSS earth station licensees for smaller exclusion zones. Allowing similar negotiations in 3550-3650 MHz is also recommended.

The calculation of an exclusion zone where no other service can transmit based on these parameters can be quite complex and not always a good reflection of reality. Implementation of such exclusion zones, especially when they are large, can also be over-restrictive if the incumbent is not using the spectrum at all times at a given location and therefore an ASA licensee can use that spectrum. The benefit of ASA is that it allows an ASA licensee to utilize the spectrum for mobile broadband on a shared and non-interference basis with the incumbents since the ASA licensee enjoys exclusive spectrum rights of use where and when the spectrum is not used by the incumbent. When the incumbent needs the spectrum back, the ASA licensees can evacuate the spectrum and can migrate to another spectrum block.

- **Applicability to the Americas**
    - Unlocking extended AWS spectrum under ASA in the US will secure device/chipset roadmap, bring economies of scale for South/Latin America and encourage governments to release the full AWS spectrum potential

Several countries in the Americas region have auctioned the AWS-1 band (1710-1755/2110-2155 MHz), among these, the US (2008), Canada (2008), Mexico (2010), Chile and Columbia (2013). Argentina, Paraguay and Peru have announced plans to award this spectrum. In addition, the 15+15 MHz in the 1755-1770/2155-2170 MHz band are available in many countries in Latin America. Many would like to award this portion of the band, but due to lack of economies of scale on devices supporting this band, no one has awarded it so far. Also, CITEL is considering an additional 10+10 MHz in the 1710-1780/2110-2580 MHz in the Americas for broadband mobile services.[93]

[93] [Ref 4.30] CITEL – CCP.II-RADIO/doc. 3295/13 Draft Recommendation on "Use of 1710-1780 / 2110-2180 MHz BANDS IN THE AMERICAS FOR BROADBAND MOBILE SERVICES", 11 April 2013, http://www.oas.org/es/citel/P2!R.htm

While a key focus in the region is to attract new entrants, it is also important to look into spectrum availability in terms of enhancing competition and increasing investment incentives. As explained in the previous section, unlocking the full/extended AWS in the US up to 1780 MHz in the uplink and 2180 MHz in the downlink via a sharing mechanism like ASA would therefore bring opportunities of economies of scale driven by the major US operators and incentives for governments to release the full band in the Americas.

- Exploring 3.5 GHz sharing

The important benefits of globally harmonized spectrum should not be overlooked. ASA is a possible policy innovation tool to can unlock some IMT bands currently occupied by incumbents and either bring economies of scale to the Americas (when band already available) from other regions (e.g. Europe) or unlock the band within the region itself.

Also as mentioned above, with regards to 3.5 GHz, 3GPP has defined two spectrum bands based on Time Division Duplex (TDD) mode and one band based on Frequency Division Duplex (FDD) mode[94].

- TDD Band 42: 3400-3600 MHz
- TDD Band 43: 3600-3800 MHz
- FDD Band 22: 3410-3490 MHz/3510-3590 MHz

3GPP defined these three bands based on a survey of how spectrum is allocated in various countries worldwide. The ITU-R also has identified 3400-3600 MHz as a candidate IMT band.

While spectrum below 3600 MHz and above 3600 MHz has been allocated independently of each other in many countries worldwide, a few countries in Latin America have assigned the lower band (also called extended C-Band) up to 3700 MHz. Regardless, the 3.5 GHz has been assigned in many countries for fixed data services following which, some limited WiMax deployments have occurred and discussion about migration from WiMax TDD to TD-LTE has been mentioned. Also, for example, Mexico has recently begun using 3400-3700 MHz for government's new satellite network (Mexsat). Brazil has the 3400-3600 MHz band identified for fixed and mobile services while protecting the existing 3600-4200 MHz band for satellite services. Other countries like Argentina, Bolivia, Chile, Colombia, Peru and Venezuela have

[94] [Ref 4.31] 3GPP TR 3GPP TR 37.801 V10.0.0 (2011-10), "Technical Specification Group Radio Access Networks; UMTS-LTE 3500 MHz Work Item Technical Report (Release 10)." http://www.3gpp.org/ftp/Specs/html-info/37801.htm

licensed or reserved the 3400-3600 MHz for broadband fixed/mobile services. So, in spite of strong interest in the lower frequency bands, the higher bands such as 3400-3600 MHz, available or identified in a number of Latin American countries, will also be quite popular for the development mobile broadband services.

4.3.1.3 ASA IN 2.3 GHZ IN EUROPE

In Europe, spectrum sharing has been introduced by the Radio Spectrum Policy Programme (RSPP) approved by the European Parliament and the Member States in March 2012. In September 2012[95], the European Commission published a Communication on "Promoting the shared use of radio spectrum resources in the EU" proposing to the Member States the use of shared access as one of the major tools to respond to the spectrum demands of both public and private users and therefore help achieve the goals of the Digital Agenda. In December 2012, the Radio Spectrum Policy Group (RSPG[96]) published a Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches. The Report identified Authorized Shared Access (ASA) as the appropriate approach to promote sharing of spectrum not currently used for mobile broadband. ASA is a regulatory framework that allows for licensed sharing of underutilized spectrum, by a limited number of rights holders, in incumbents' bands, through an individual authorization scheme following the terms set forth by Directive 2002/20/EC (Authorization Directive). Since December 2012, the RSPG has been developing a response to the European Commission's request for an Opinion on spectrum regulatory and economic aspects of Licensed Shared Access[97] and launch in June 2013 a new public consultation on this Draft Opinion[98] which will run until August 2013. In this revised Opinion, the RSPG has agreed on the revised definition for LSA:

[95] [Ref 4.32] European Commission Communication on "Promoting the shared use of spectrum resources in the EU" https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/com-ssa.pdf

[96] [Ref 4.33] Radio Spectrum Policy Group (RSPG) Constituted by the Member States http://rspg.groups.eu.int/

[97] [Ref 4.34] RSPG Request for Opinion on Licensed Shared Access (LSA) – Document RSPG12-424 Rev2, 8 November 2012 http://rspg.groups.eu.int/_documents/documents/meeting/rspg29/rspg12-424_final-rfo_lsa.pdf

[98] [Ref 4.35] Draft RSPG Opinion on Licensed Shared Access – Document RSPG13-529 rev1, 30 May 2013 https://circabc.europa.eu/sd/d/dc44e39f-7fab-4cc2-8513-f6fce5c25c34/RSPG13-529rev1-Draft%20RSPG%20Opinion%20on%20LSA.pdf

"A regulatory approach aiming to facilitate the introduction of Radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the LSA framework, the additional users are allowed to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain QoS".

The RSPG is also strongly relying on the technical expertise of The European Conference of Postal and Telecommunications Administrations (CEPT)[99] to assess ASA/LSA technical sharing requirements on specific bands. CEPT's Electronic Communications Committee (ECC) has been studied ASA/LSA since 2011. In October 2012, CEPT Work Group Frequency Management (CEPT WGFM) decided to further develop the necessary regulatory framework to enable ASA/LSA. It establishes two Project Teams FM52[100] and FM53[101] to study respectively the 2.3-2.4 GHz band toward a draft ECC Decision and Reconfigurable Radio Systems (RRS) and Licensed Shared Access (LSA) toward an ECC Report on general conditions and band-specific conditions for the implementation of the LSA, establishing relevant interactions with ETSI further explained in the section below.

Finally, the European Commission issued standardization mandate M/512 to CEN, CENELEC and ETSI, requesting Standard Development Organizations (SDOs) to enable the deployment and operation of ASA devices.

On the industry side, trade associations such GSMA[102] and Digital Europe[103] (DE/the European consumer electronics association) have also taken position with regard to ASA/LSA definition.

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[99] European Conference of Postal and Telecommunications Administrations – 48 European countries cooperating to regulate radio spectrum and communications networks. www.cept.org.

[100] [Ref 4.36] CEPT PT FM52 on 2300-2400 MHz band Terms of Reference http://www.cept.org/ecc/groups/ecc/wg-fm/fm-52/page/terms-of-reference

[101] [Ref 4.37] CEPT FM Project Team 53 on Reconfigurable Radio Systems (RRS) and Licensed Shared Access (LSA) Terms of Reference http://www.cept.org/ecc/groups/ecc/wg-fm/fm-53/page/terms-of-reference

[102] [Ref 4.38] GSMA Public Policy Position on Licensed Shared Access (LSA) and Authorized Shared Access (ASA) http://www.gsma.com/spectrum/licensed-shared-access-lsa-and-authorised-shared-access-asa

[103] [Ref 4.39] DIGITALEUROPE response to draft RSPG Opinion on Licensed Shared Access (LSA) http://www.digitaleurope.org/DocumentDownload.aspx?Command=Core_Download&EntryId=593

In particular, DE recently responded to the RSPG public consultation regarding its draft opinion on LSA. It encourages the RSPG to further advance its work, calling for a clear and stable definition of LSA based on a set of regulatory principles that will lead to investments and innovation.

In Europe, the 2300-2400 MHz band is a band that has been identified for IMT during the World Radio Conference 2007 and is widely used for mobile broadband outside of Europe. However, it remains unavailable for mobile broadband in Europe due to incumbents' persistent need to access the spectrum. As such, the 2.3 GHz band is the prototypical example of a band where ASA can enable access to the band in Europe or, at the very least, significantly speed up its adoption.

4.3.1.4 STANDARDIZATION UPDATE

As mentioned above, ASA and spectrum harmonization go hand in hand. Spectrum harmonization is required to enable the development of global standards, markets and services that benefit from scale.

Since October 2012, CEPT decided to further develop the regulatory framework in order to enable the usage of ASA at 2.3-2.4 GHz (additional bands are expected to follow) and established a formal direct liaison with ETSI. The CEPT then created two new working groups related to this opportunity: FM52 is responsible for drafting a new ECC Decision for mobile broadband in 2.3 GHz, while FM53 is responsible for general ASA studies including the analysis of ASA 'Levels of Guarantee' and of the regulatory framework for delivering ASA licenses, as well as the development of general conditions and band-specific technical/operational conditions for the implementation of the ASA concept.

The European Telecommunications Standards Institute (ETSI)[104] also launched the standardization process of ASA systems. In this context, it is therefore important to understand that in Europe, the regulatory (CEPT/EC) and standards (ETSI) activities are happening in parallel. Since 2011, CEPT and the Member States have been studying ASA and since May 2012, the ETSI Technical Committee Reconfigurable Radio Systems ("TC RRS") has been working towards standardizing the use of ASA/LSA to enable mobile broadband services at 2.3-2.4 GHz.

[104] [Ref 4.40] ETSI Technical Committee Reconfigurable Radio Systems http://portal.etsi.org/portal/server.pt/community/RRS/329

The ETSI standardization work is being carried out in several steps. A Technical Report called a "System Reference Document (SRDoc)" is now complete.[105] It defines the criteria and operational features, especially spectrum compatibility issues, of ASA/LSA at 2.3 GHz thus supporting the cooperation with CEPT. While focus on the 2.3 GHz band and pan-European applications, there is no reason why the underlying concept could not also applied to other spectrum bands and regions including 1.7 GHz and 3.5 GHz in the US. ETSI RRS has begun developing the relevant Technical Specifications for mobile broadband at 2.3 GHz using ASA/LSA, taking into account the regulations developed by CEPT for this band.

4.3.2 MOBILE SUPPLEMENTAL DOWNLINK

Definition Mobile Supplemental Downlink (SDL)[106]

Mobile broadband traffic will continue to grow exponentially over the coming years. A significant portion of this traffic is multimedia. This type of multimedia based traffic is to a large extent highly asymmetrical with users downloading and down streaming much more data than they are uploading – for example the downloading of movies, videos, photos, music, maps, applications etc. which would represent significant additional traffic in the future when consumers are fully embracing and adopting to the new mobile broadband services and applications. Because wireless broadband traffic tends to be asymmetrical (i.e., downlink Internet traffic is greater than uplink traffic because users download more data than they upload), it is anticipated that wireless providers could use supplemental downlink spectrum to supplement their spectrum holdings in other bands.

Supplemental downlink technology uses unpaired spectrum to enhance the downlink capability of mobile broadband networks by enabling significantly faster downloads and supporting a much greater number of users with mobile or portable wireless devices. Supplemental downlink and carrier aggregation are now enabled in the HSPA+ and LTE-Advanced

[105] [Ref 4.41] System Reference Document (SRDoc) "Mobile Broadband Services in the 2300 – 2400 MHz band under Licensed Shared Access regime" (TR 103 113) http://www.etsi.org/deliver/etsi_tr/103100_103199/103113/01.01.01_60/tr_103113v010101p.pdf

[106] [Ref 4.42] "Benefits from use of 1452-1492 MHz for Mobile Multimedia Downlink", FM PT50, 2nd meeting, Ericsson, Qualcomm http://www.cept.org/Documents/fm-50/1215/FM50(11)019_Ericsson-Qualcomm-MMDL-Study-FINAL.

standards[107].The technology allows the bonding of the usual downlink with a supplemental downlink channel(s) in the same or in a different band, into a single wider downlink channel as shown below. This provides an efficient way of using spectrum because consumption of rich content and other data heavy applications is asymmetric.

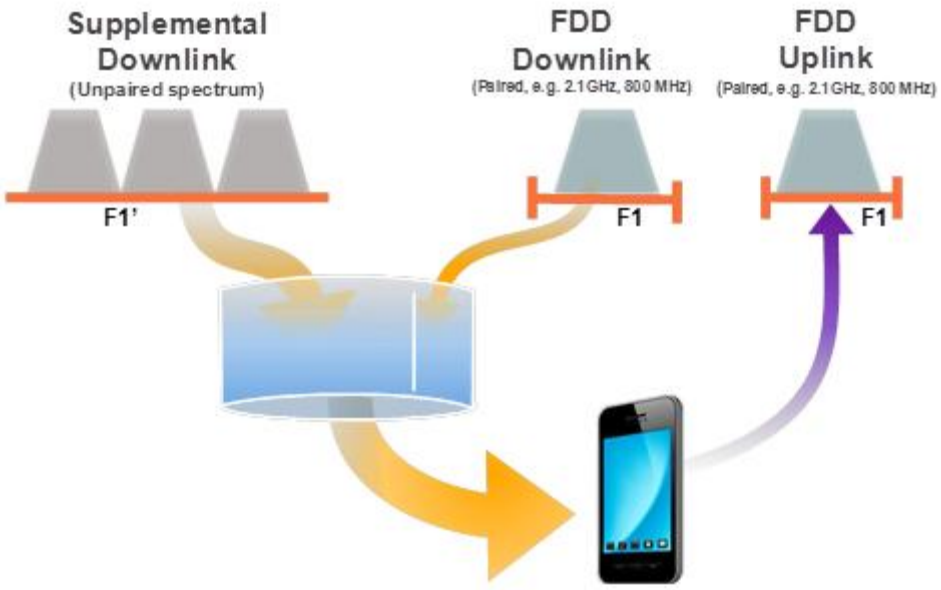

Figure 4.21. Mobile Supplemental Downlink.[108]

[107] [Ref 4.43] Carrier aggregation across bands is supported in HSPA+ R9 (and beyond) and LTE R10 (and beyond) standards, but each specific bands combination has to be defined in 3GPP. http://www.3gpp.org/ftp/Specs/html-info/FeatureOrStudyItemFile-600021.htm

[108] Source: Qualcomm

Band 600 MHz/Incentive auctions[109]

The FCC is developing a rulemaking record that will reclaim the 600 MHz broadcast spectrum through an incentive auction. The incentive auction of broadcast television spectrum will have three major pieces:

(1) a "reverse auction" in which broadcast television licensees submit bids to voluntarily relinquish spectrum usage rights in exchange for payments;

(2) a reorganization or "repacking" of the broadcast television bands in order to free up a portion of the ultra-high frequency (UHF) band for other uses; and

(3) a "forward auction" of initial licenses for flexible use of the newly available spectrum.

FCC has put forward several possible band plans.

In one approach, FCC would clear broadcast television channels starting at channel 51 and expand downward. As illustrated in the figure below, FCC could organize the cleared spectrum into an uplink portion, a downlink portion, and any necessary guard bands.

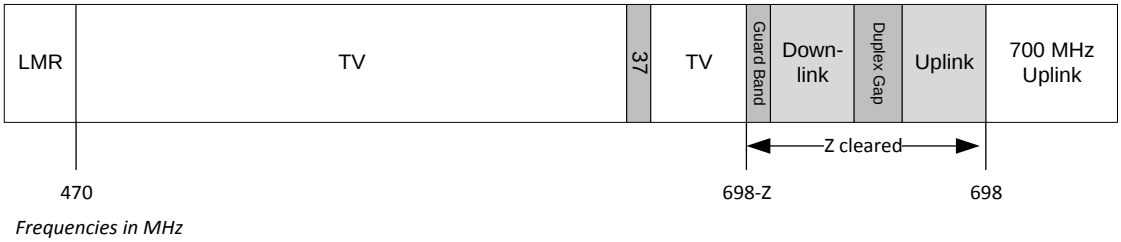

Figure 4.22. One FCC's 600 MHz band plan, down from 51.

FCC proposes to offer a uniform amount of downlink spectrum nationwide on spectrum formerly allocated for broadcast use with no in-band television stations. They also propose to offer varying amounts of uplink spectrum in each service area, depending on the amount of spectrum available, due to the greater flexibility to accommodate different filters in base

[109] [Ref 4.44] FCC NOTICE OF PROPOSED RULEMAKING, Released: October 2, 2012, "Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions" http://www.fcc.gov/incentiveauctions

stations than in mobile terminals. Although FCC planned to provide paired spectrum blocks wherever possible, the relinquished broadcast television spectrum usage rights will not always fit neatly into pairs in each license area. In order to maximize the amount of spectrum available, the FCC proposes to offer any excess spectrum as supplemental downlink expansion for FDD operations. These downlink expansion blocks would be located immediately adjacent to the downlink portion of paired blocks to minimize interference issues.

AT&T Lower 700 MHz Band Class 29[110]

The use of SDL is no longer only a concept. AT&T plans to use SDL in its LTE network to provide incremental capacity to address growing traffic demand where needed, aggregating Lower 700 MHz unpaired spectrum (Lower 700 MHz D and E blocks in figure below) with other paired spectrum on which it could deploy LTE, including the PCS, 850 MHz, or AWS spectrum.[111] 3GPP has defined an LTE FDD downlink only band to cover AT&T's spectrum from 717-728 MHz. This is 3GPP Band Class 29. AT&T expects to be able to deploy handsets and equipment using a supplemental downlink as early as 2014.[112]

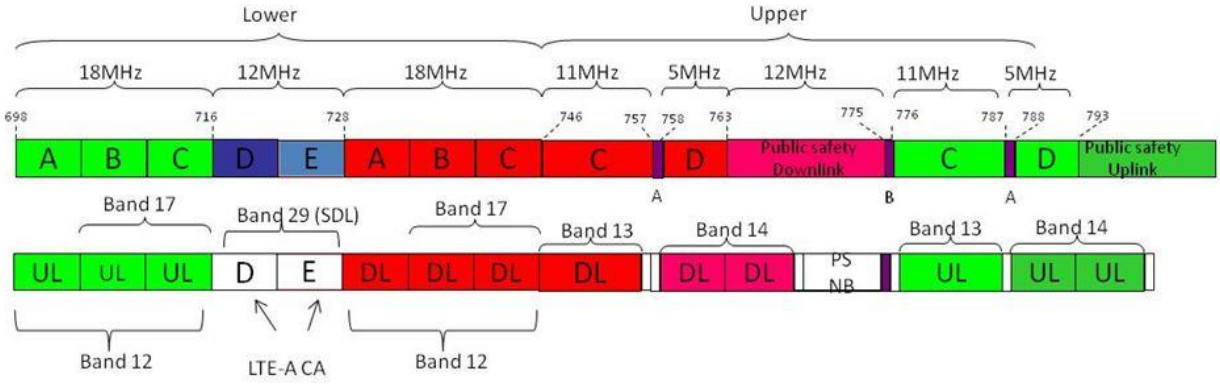

Figure 4.23. US 700 MHz band.

[110] [Ref 4.45] 4G Americas White Paper, "The Benefits of Digital Dividend", September 2012

[111] [Ref 4.46] AT&T spectrum acquisition press release http://www.att.com/gen/press-room?pid=18854&cdvn=news&newsarticleid=31447&mapcode=financial|wireless

[112] [Ref 4.47] Declaration of Kristin Rinne, AT&T to the FCC 12 January 2011 (http://assets.fiercemarkets.com/public/mdano/rinneonmediaflo.pdf).

1452-1492 MHz[113]

The CEPT reviewed the 1452-1492 MHz band, sometimes referred to as the "L-Band". This frequency range has good propagation characteristics for many applications but currently its usage has been very limited. CEPT reached an important conclusion that the most appropriate regulatory framework for the future use of the 1452-1492 MHz band in CEPT is the harmonization of this band for 'mobile supplemental downlink', while allowing individual countries to adapt to specific national circumstances in parts of the band for terrestrial broadcasting and other terrestrial applications. CEPT believes that this regulatory framework will bring the highest overall benefits in the CEPT countries.

In May 2013, CEPT published for consultation the ECC Decision on L-Band SDL harmonization[114]. In addition, the ECC Decision on the suppression of satellite in L-band is now approved. The two draft ECC Decisions were endorsed by the 30 European Administrations present at CEPT Working Group FM.

There is considerable scope for the harmonization of 1.4 GHz as SDL in Europe, Middle East and Africa, Australia, Canada and Mexico as shown below.

[113] [Ref 4.48] CEPT "Major steps forward the harmonized used of the band 1452-1492 MHz: Mobile Supplemental Downlink is the way ahead" http://apps.ero.dk/eccnews/dec-2012/major-step.html

[114] [Ref 4.49] CEPT Draft Decision The harmonized use of the frequency band 1452-1492 MHz for Mobile/Fixed Communications Networks Supplemental Downlink (MFCN SDL) http://www.cept.org/files/1051/Tools%20and%20Services/Public%20Consultations/2013/Draft%20new%20ECCDEC(13)CC.docx

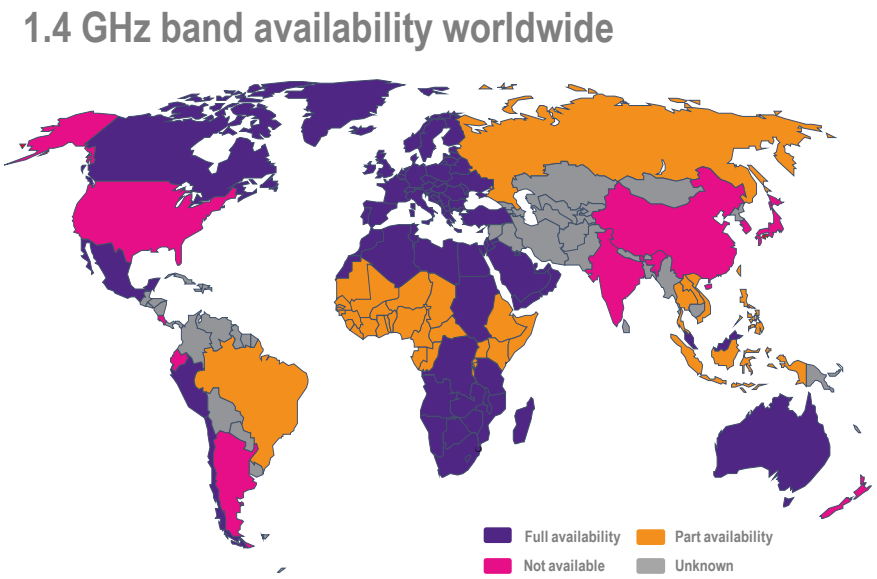

Figure 4.24. 1.4 GHz band availability worldwide.[115]

As discussed in this paper, more spectrum, particularly more licensed spectrum, is essential to achieve the 1000x capacity. In fact, more spectrum, more small cells, and greater efficiency across the system are all essential to reach this difficult, but critical, goal.

With regard to spectrum, this section has discussed in details key elements to achieve capacity, for which both licensed and unlicensed spectrum approaches are essential, but also quality of service/predictability, for which licensed spectrum remains the most preferred approach, as well as affordable cost and scale, which can only be achieved with harmonization both spectrum and global technology standards. Keeping all the above in mind, it is clear that regulators are facing increasing challenges today in finding more harmonized clear spectrum for mobile broadband. That is why spectrum policy innovation will become a crucial trend in the way policy makers and governments are thinking.

As discussed in section 4.4, at the root of the phenomenal success and ubiquity of the global mobile communications services are the basic elements of "globally harmonized spectrum", "harmonized technical regulations" and "harmonized international standards". These

[115] [Ref 4.50] "Economic Study of the benefits from use of 1452-1492 MHz for a supplemental mobile downlink for enhanced multimedia and broadband" (June 2011) – Source: Plum Consulting http://www.plumconsulting.co.uk/pdfs/Plum_June2011_Benefits_of_1.4GHz_spectrum_for_multimedia_services.pdf

elements have been, and will continue to be, the keys to reaping the economies of scale for global services, the manufacture of globally interoperable equipment and ensuring that all users can communicate with each other. Continuing growth of mobile communication services, at prices users can afford, will be predicated on the expanding availability of globally harmonized spectrum assignments and common technical standards and communication protocols across multiple bands. For example, although the ITU Spectrum Allocation tables designate about seven bands internationally for IMT services, differences in technical regulations between areas have led to there being over thirty different band plans defined for mobile radio standards. As the users of the mobile devices expect to roam among service providers with different bands and globally across different regions, the number of band plan combinations from the choice of 30 standard bands is rapidly becoming impractical to implement in the small personal portable devices that users have come to expect. New spectrum assignments, if they are to take advantage of global economies of scale, must adopt technical regulations that are harmonized. Meeting the 1000x traffic challenge, while continuing to reap the global economies of scale for newly designated mobile spectrum assignments, will only be possible if there is a concerted effort for harmonization at all levels of spectrum assignment, technical regulations and interoperability communications standards.

As mentioned above and explained in section 4.3, new innovative spectrum policy will be crucial to economically and efficiently sustain the exponential growth of mobile data traffic at a time when policy makers are facing challenges in finding more clear globally harmonized spectrum. Policy makers will need to balance the different approaches described above. The industry has understood the necessity to find alternative spectrum policy approaches in addition to cleared licensed spectrum for mobile broadband (often too long and costly) and to unlicensed Wi-Fi (difficult to monetize) but also to lower the cost of "good" spectrum (hopefully, harmonized). Indeed, with ASA/LSA, in view of the terms/conditions to share with an incumbent with primary usage rights, there may not be any auction process and/or coverage/universal service obligations, etc.

ASA/LSA is a novel authorization scheme targeted to meet the 1000x mobile data challenge. It complements the two traditional authorization models (exclusive/cleared licensed and unlicensed) while enhancing spectrum harmonization on a regional and global level. For example, unlocking a particular mobile band not fully available using the ASA/LSA framework in the US (or Europe for that matter), could benefit Latin America where the band may be available but not assigned yet due to lack of economies of scale.

It is a unique spectrum policy approach in the form of a binary framework granting individual exclusive spectrum rights of use for mobile broadband with so-called "vertical" or "additive" sharing enabled between an incumbent and an ASA/LSA licensee with interference protection requirements vis-a-vis the primary user. It is nothing to do with light licensing or secondary trading or TV WS or a 3-tiered priority approach model as proposed by the PCAST report. ASA allows sharing of underutilized spectrum on a non-interference basis with incumbents while permitting commercial offering of mobile broadband services with predictable quality of service.

Another example of policy innovation exists in the case of frequency bands, often underutilized, that originally could not be used for mobile broadband due to the size of the band, channelization, compatibility with other services, among other criteria. However these bands can be used in a greatly beneficial and efficient manner by mobile supplemental downlink/SDL (e.g. 600 MHz, lower 700 MHz, L-Band, etc.), by adapting the technical regulations while ensuring possible harmonization at regional level and its applicability globally.

Finally, the industry is committed to continue investing in the development of mobile broadband technologies to ensure that innovation will support consumer usage of mobile broadband in the most cost efficient way. In particular and as an example, leveraging ASA/LSA in high frequencies and using these spectrum bands with new technology innovation described in the first section of the document (especially small cells, SON/interference management, along with TDD technology and/or SDL) will meet the growing market demand for mobile broadband while ensuring sustainable long term investments.

4.4 SPECTRUM GLOBAL HARMONIZATION AND REAPING ECONOMIES OF SCALE

At the root of the phenomenal success and ubiquity of the global mobile communications services are the two basic elements of "globally harmonized spectrum" and "harmonized international standards". These elements are the keys to reaping the economies of scale for global services, the manufacture of globally interoperable equipment and ensuring that all users can communicate with each other. Continuing growth of mobile communication services, at prices users can afford, will be predicated on the expanding availability of globally harmonized spectrum assignments and common standards for communications across multiple bands.

To be successful, harmonization must reach through all levels of the communications stack from the basic radio frequency physical layer of channelization, modulation and coding right up through the data links, the network, security, transport, session, accounting and

presentation/application layers. It is necessary not only that common bands be designated in the international frequency allocation table, but also that there be common technical specifications for channeling and radio frequency emissions as well as network protocol interactions. Although for example the ITU Spectrum Allocation tables designate about 7 bands internationally for IMT services[116] (International Mobile Telecommunications - sometimes also called IMT-2000), differences in technical regulations between areas have led to there being over 30 different band plans defined for the mobile radio standards[117]. The most ubiquitous of these are the harmonized "quad" bands at 800/900 MHz and 2 GHz that provide mobile coverage globally.

As the users of the mobile devices expect to roam among service providers with different bands and globally across different regions, the number of band plan combinations from the choice of 30 standard bands is rapidly becoming impractical to implement in the small personal portable devices that users have come to expect. New spectrum assignments, if they are to take advantage of global economies of scale, must adopt technical regulations that are harmonized across multiple regions. Without spectrum and technical harmonization, such new bands risk becoming underutilised orphans.

Continuing to reap the global economies of scale for newly designated mobile spectrum assignments, will only be possible if there is a concerted effort for harmonization at all levels of spectrum and operational standards.

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[116] The following frequency bands are currently identified for IMT in all three ITU Regions:
450 – 470 MHz
790 – 960 MHz
1710 – 2025 MHz
2110 – 2200 MHz
2300 – 2400 MHz
2500 – 2690 MHz
Additional frequency bands identified for IMT on a Regional or National basis:
698-790 MHz (Region 2)
610 – 790 MHz (9 countries in Region 3: Bangladesh, China, Rep. of Korea, India, Japan, New Zealand, Papua New Guinea, Philippines and Singapore.)
3400 – 3600 MHz (Over 80 Administrations in Region 1 plus 9 in Region 3 including India, China, Japan and Rep. of Korea).

[117] See, for example, technical specification 3GPP TS136-101 "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception" table 5.5-1

Specifically, some of the underlying benefits from harmonization include:

i. economies of scale in the manufacturing of equipment;
ii. competitive market for equipment and component procurement;
iii. increased spectrum efficiency;
iv. stability and efficiency in band planning and deployment;
v. globally/regionally harmonized spectrum arrangements assures roaming; and
vi. Increased adoption of new services across multiple markets.

(i) The economy of scale for user devices reaches through all equipment levels, including whole devices, but also the common components (e.g., filters, antennas, processors and displays) that are incorporated into a multitude of different market offerings. Wide availability of components for the harmonized bands and standards assures continuing technical innovation and the global availability of low cost equipment suitable for all bands, markets and services. Such harmonized component and equipment supplies are made possible through the harmonized standards and spectrum assignments.

(ii) The non-proprietary nature of the international standards helps to ensure a competitive market for generic components, equipment and network services. Suppliers can develop components and equipment with the assurance that they will address a global market. The availability of harmonized spectrum bands and well defined global standards for services and equipment are the enablers for a mass market upon which competitive equipment and component suppliers can base their investment in production. The mass market of standardised platforms also forms the basis for development of innovative software services and applications both locally and globally. In contrast, un-harmonized bands require non-standard equipment using specialized components and testing that slow or delay the utilization of the bands.

(iii) Harmonized spectrum assignments with large spectrum bandwidths leads to increased spectrum efficiency. Larger assigned bandwidths more easily accommodate the varying throughput/bandwidths of user traffic. Both large and small user data transfers can be efficiently absorbed into a wide band channel. The wide spectrum bandwidths reduce the challenge for implementation of multiple spectrum bands, especially in the user equipment as contiguous spectrum assignments are preferred to reduce the complexity of RF front-end designs. Wide spectrum bandwidths permit network operators to deliver high speed services to users in a single band, and also simplify roaming for users among operators within the same band.

(iv) Global harmonization of spectrum assignments leads to stability and efficiency in band planning and deployment as common regulations and technical standards can be adopted across jurisdictions. This technical commonality ensures wide adoption of the network deployments, services and the economical availability of network equipment and mobile devices. The adoption of harmonized standards and regulations speeds the deployment and entry into service of newly assigned bands.

(v) Globally harmonized spectrum assignments and standards assures end users that their equipment and services will be available where-ever they travel and encourages roaming due to the ubiquitous and consistent availability of an individual's service. Improved roaming also encourages uptake of services as users expect to always be connected and to rely on anywhere/anytime access. Globally harmonized spectrum arrangement and standards also simplifies the design/manufacture/testing of devices for larger global/regional markets.

(vi) Harmonization also enables increased adoption of new services across multiple markets as the user applications and universal coverage enables wide adoption of applications for multiple services and a variety of markets. The availability of a universal communications platform may enable, for example, improved communications for electronic commerce, industrial applications, vehicular communications, machine-type communications and enhanced communications for public safety and disaster relief.

Band plans in use today in many countries are often divided, and in some cases fragmented into multiple smaller bands in support of a variety of applications. Such fragmentation has led to the inefficient use of spectrum, especially when guard bands are needed to avoid interference at boundaries between frequency blocks for different applications (e.g., between broadcasting and mobile services and between different countries.)

There are certain planning methods that are conducive to the efficient and effective use of spectrum for land mobile broadband applications. Ideally, there should be an overall harmonized band plan for such applications in a wide portion of the radio frequency spectrum. The band planning, rather than first carving the spectrum into pieces for different uses and then defining a sub-band plan for each use, should instead develop a large multi-use harmonized band plan and then users may be assigned blocks or sub-bands (commercial operators, public safety agencies, utility companies, etc.).

For example, the illustration in Figure shows a large flexible and harmonized band plan including paired assignments that have the same duplex separation, a center gap that can be used for multiple purposes, and, if necessary, guard bands at the ends. The transmission

direction (i.e., uplink or downlink) in adjacent sub-bands should be in the same direction and the sub-bands should be organised so that stations with similar transmit power levels are grouped. Ideally, all sub-bands in the same block should have the same maximum transmit power. In a paired arrangement, it is typical to have the base-station transmit (BS-Tx) in the upper block (i.e., the higher frequencies).

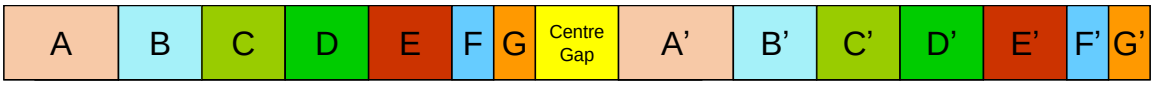

Figure 4.25. Flexible and harmonized band plan.

This approach to band planning is of benefit for contiguous amounts of spectrum intended for land mobile broadband applications in bands allocated to the mobile service. Even if the entire band need not be fully assigned initially, it is essential to plan ahead and develop a plan that can evolve over time.

5. CONCLUSIONS

Widespread adoption of wireless broadband and smartphones has resulted in tremendous growth in traffic volumes. Mobile devices have evolved from being used predominantly for talking into a versatile communication companion. People spend more and more time being connected to the internet over a mobile device. More and more people own a smartphone and that number is growing. The traffic growth will be further driven by larger-screen devices and video rich tablets, Machine-to-Machine applications, and soon, also the connected vehicle and home.

Mobile data traffic will grow exponentially and video traffic will drive the growth. According to Cisco Visual Networking Index (VNI), mobile video traffic is already over 50 percent of mobile data traffic, and Cisco predicts the global mobile data traffic to grow steadily at CAGR of 66 percent from 2012 to 2017. Ericsson Mobility Report predicts mobile data traffic to grow with a CAGR of around 50 percent between 2012 and 2018. Other companies such as, Qualcomm and Nokia Solutions and Networks have also talked about '1000x' increase in data traffic.

All traffic growth predictions are suggesting demand for mobile data could overwhelm the wireless network resources due to finite and limited spectrum availability even though technology evolution is improving the efficiency and capacity of the wireless networks. To be ready to accommodate the growth, the wireless industry needs additional spectrum and associated policy innovation.

Technology evolution and Third Generation Partnership Project (3GPP) standards have successfully increased the performance, efficiency and capabilities of wireless networks. The continuing enhancements of High Speed Packet Access (HSPA/HSPA+) and Long Term Evolution (LTE/LTE-Advanced) are needed to enable advanced services and support the growing mobile data traffic. In the coming years as the traffic continues to grow, rich services like video will reach peaks never imagined and new vertical industries such as machine-to-machine connectivity will enter the picture.

Technology evolution to provide increases and efficiencies span across macro cells, small cells, Heterogeneous Networks and spectrum utilization techniques, such as Carrier Aggregation and Supplemental Downlink.

Devices will also evolve to become more efficient. Advanced receivers, RF front-end optimization and intelligent connectivity are examples of advances made to improve efficiency of the devices.

Despite the long list of enhancements on the technology side, the increase in efficiency alone is not sufficient to meet the traffic growth predictions and the needs of the consumer. In addition to technology advances, the wireless industry needs additional spectrum and associated policy innovation.

More spectrum, particularly more licensed spectrum, is essential to achieve the 1000x traffic capacity requirements. In fact, more contiguous spectrum, including for small cells deployment in higher bands and greater efficiency across the system, are all essential to reach this difficult, but critical, goal. While licensed spectrum will remain a key priority to complement unlicensed spectrum usage (e.g., for offloading mobile networks), new innovative spectrum policy will be crucial to sustain the exponential growth of mobile data traffic economically and efficiently. Indeed, at a time when policy makers are facing challenges in finding more cleared spectrum for mobile broadband, there will be a need for innovative spectrum management tools to rapidly meet the 1000x data traffic challenge. The industry has understood the necessity to find alternative approaches in addition to cleared licensed spectrum (often taking too long and costly) and to unlicensed spectrum (difficult to monetize as based on "best effort"), but also to attain more of "good" internationally harmonized spectrum.

Authorized/Licensed Shared Access (ASA/LSA) is a novel authorization scheme designed to complement the two traditional authorization models – exclusive/cleared licensed and unlicensed. ASA can be used to unlock an underutilized spectrum band that would otherwise not be made available for a decade or more, if ever. ASA/LSA is an innovative spectrum sharing policy approach in the form of a binary framework granting individual exclusive spectrum rights of use for mobile broadband operations. The so-called "vertical" incumbent is defined as a current holder of spectrum rights of use which has not been granted through an award procedure for commercial use.

Another example of policy innovation is supplemental downlink (SDL). In the past, relatively small unpaired blocks of spectrum could not be used for mobile broadband due to the size of the band, channelization, and compatibility with other services, among other factors. However, these bands can be used in a highly efficient manner for mobile broadband through SDL. The 600 MHz, Lower 700 MHz, and L-band are all examples of bands that could be well suited for SDL.

Finally, the industry is committed to continue investing in the development of mobile broadband technologies to ensure that innovation will support consumer usage of mobile broadband in the most cost efficient way. As an example, leveraging ASA/LSA in higher frequencies and using these spectrum bands with new technology innovation (such as small

cells, SON/interference management, along with TDD technology and/or SDL) will meet the growing market demand for mobile broadband while ensuring sustainable long term investments.

New spectrum bands are being identified in the context of the ITU Radio communication process. In the U.S., allocations, such as some of the bands identified in NTIA's Fast Track report, are being worked on and brought to the market. In the rest of the Americas, spectrum allocation and harmonization also remain a key priority to ensure quality of service and economies of scale. The traffic growth is expected to continue in the coming years and all predictions are suggesting that demand for mobile data could overwhelm the wireless network resources due to finite and limited spectrum availability even though technology evolution is improving the efficiency and capacity of the wireless networks. This means that that despite the new spectrum being brought to the market, it is essential to consider in parallel new alternative spectrum management trends when traditional tools are not sufficient and/or timely enough to meet the market's need.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
CEPT	European Conference of Postal and Telecommunications Administrations – 48 European countries cooperating to regulate radio spectrum and communications networks.
RSPG	Radio Spectrum Policy Group (RSPG) Constituted by the European Member States

APPENDIX I

An illustration of the NSC network concept is shown in Figure AI-1.

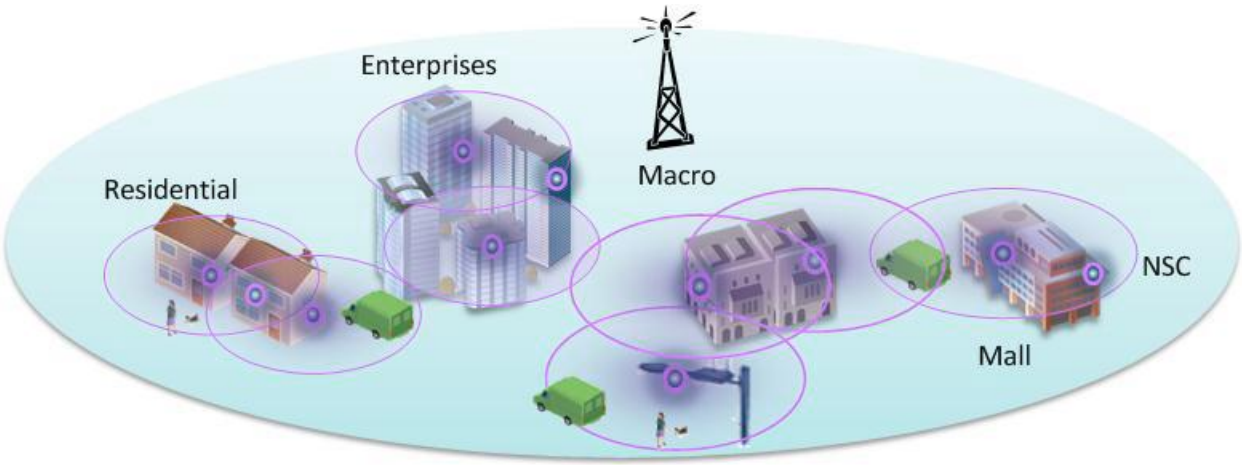

Figure AI-1: Illustration of Neighborhood Small Cells Deployment model (Source: Qualcomm)

As illustrated, NSCs handle indoor user traffic and also serve users passing-by on the street or moving in at moderate speed vehicles. A key feature of NSCs is that they provide continuous coverage and seamless mobility experience to users in the neighborhood by supporting handovers among NSCs as well as between NSCs and macro cells. Users not offloaded to NSCs (e.g., high mobility users) are served by the macro cells.

Neighborhood small cells can be deployed on the same carrier as existing macrocells or on a dedicated carrier. The deployment model is applicable to 3G and LTE networks. Studies indicate the new neighborhood small cells network provides huge capacity gains, the extent of which depends on the small cells' penetration and other factors including the morphology of deployment. With additional spectrum and sufficient density of small cells, it is possible to reach and exceed 1000x today's network throughput.

Typical characteristic of a NSC network are that they are deployed in unplanned or semi-planned (with respect to RF interference) fashion. To enable unplanned dense small cell deployments to provide indoor and outdoor coverage requires carefully designed self-organizing network to help traditional restricted access small cell operate robustly with the existing macro-small cell network. Dense placement of small cells provides coverage

redundancy. SON techniques enable small cells to autonomously adapt their transmit power to ensure adequate coverage, thus making extensive RF planning unnecessary.

Due to the ease of deployment and the fact that customer backhaul and site premises can be leveraged, NSC networks offer tremendous economic benefits in reduced CapEx and OpEx. Just as important, this network model uses standardized small cell architecture adopted by the industry, therefore ensuring full compatibility with legacy networks and mobiles.

Table A-1: Table showing the frequency bands that can be used for backhaul

Frequency	Considerations for Outdoor Small Cells
< 6 GHz	**Licensed bands (2.5/2.6 GHz, 3.x GHz)** (often occupied with WIMAX, LTE or other government or private services). License may be expensive and limited in bandwidth (e.g. 25 MHz, 50 MHz), calling for a balance between access and backhaul. Solutions need design for directionality (e.g. beam-forming), high modulation and interference mitigation to support small cell access and street topologies. **Unlicensed bands (2.4 GHz, 5.x GHz)** provide very low cost. QoS is harder to control due to interference from e.g. Wi-Fi, Wireless ISPs. Some availability challenges due to regulatory issues (e.g., radar detection).
6-50 GHz	Licensed LOS, some bands are congested in urban areas and adoption of new bands not global. Only higher microwave bands (e.g. 24-38 GHz) offer attractive form factors for small cells.
mm-wave 57-66 GHz	Street acceptable antenna size, short hop (e.g., 1 to 2 km) and narrow beam-width requirements (< 3 degrees) allows many links to be deployed in a given region however narrow beam widths may be impacted by light pole sway. Unlicensed band typically.
mm-wave 71-95 GHz	Same as 60 GHz but is lightly-licensed. Some regulators require < 1.5 degree beam widths which generally will require link endpoints to be on solid structures such as buildings or low down on a tower so as to avoid tower sway or twist.

The combination of the above allows operators to grow their network capacity immensely while keeping the deployment costs significantly lower compared to traditional macro or HetNet deployment. At the same time, NSCs can effectively meet user needs as they are inherently deployed where the data demand is.

Clearly as the next step in HetNet evolution, NSCs complement traditional planned macro and small cell deployments and benefit both operators and users by bringing down the cost of mobile data access.

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