5G AMERICAS

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LTE AND 5G TECHNOLOGIES ENABLING THE INTERNET OF THINGS

December 2016

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EXECUTIVE SUMMARY

LTE and 5G Technologies Enabling the Internet of Things white paper is focused on the key radio technologies specified by 3GPP that aim to create a strong ecosystem for the Internet of Things (IoT), much like the very successful global mobile broadband market built with LTE.

The term Internet of Things has been coined to describe the vision of an interconnected network of physical objects that interact with people, other physical objects and systems to benefit society in unprecedented ways. To this end, IoT is seen as the catalyst for the empowerment of everyone and everything to reach their full potential in a world that has already seen how wireless communication can improve life in every corner of the society.

This paper examines the essential aspects that encompass the development of IoT uses cases specifically enabled by cellular 3GPP technologies. An overview of IoT market drivers and requirements for IoT use cases, frames a detailed description of key radio access mechanisms that 3GPP is specifying in the context of enabling and encouraging the use of cellular connectivity to start bringing IoT services to market as early as end of this year. Constructing the foundation for IoT on LTE technology enhancements like eMTC, NB-IoT and power management mechanisms specified by 3GPP takes advantage of the well-established global ecosystem and economies of scale of LTE. Because GSM is the most deployed cellular technology and that 2G M2M connections account for the majority of M2M connections worldwide, the paper also outlines the 3GPP innovation for GSM networks, namely EC-GSM-IoT.

Additionally, this paper reviews innovations in the overall architecture and protocols for IoT, including core networks, monitoring and service exposure. Although not the primary focus of this paper, such aspects solidify the positioning of 3GPP architectures and technologies as the foundation for the design, deployment and operation of IoT use cases at global scale. Further enhancements to eMTC and NB-IoT, new features and IoT related KPIs associated with the new radio technology 5G NR are briefly described as well. A comparison, between eMTC and NB-IoT on one hand, and the proprietary non-cellular technologies on the other hand, completes the white paper.

1. INTRODUCTION

So far, the Internet of Things (IoT) has developed in two main ways. First, miniaturization, cloud solutions, faster processing speeds, and use of data analytics have allowed companies to benefit from real-time data collected from the physical environment. Second, decreasing component costs and cheaper data collection methods have altered the cost-benefit model, making IoT solutions feasible for more companies. Together, these drivers lay the foundation for continued development of new IoT products and services.

IoT is seen both as an evolution and as a superset of Machine-to-Machine (M2M). Fundamentally speaking, while M2M is built on direct communication links, IoT expands the concept to connectivity via IP networks.

While many M2M applications have already being deployed to date, the focus has been on single applications and most of the time characterized by “one device - one application”, creating closed vertical environments. In some cases, even special networks are being built for single applications. In contrast, IoT is constructed on the principles that we should enable devices to serve multiple applications, and applications to employ multiple devices.

Machine-to-Machine (M2M) communication is not a new use case for the cellular networks. Utilities, security, transportation, and even the farming industry, to the tune of 400 million devices, use existing wireless networks and platforms to communicate and to meet key business requirements. Thus far, such use cases had to have a compelling business requirement in order to overcome the technology and cost obstacles. While IoT is first and foremost about applications and devices, connectivity is the foundation on which the access of “things” to the Internet is established. With a myriad of applications in sight and even more predicted for the future, there is a huge variance in requirements on connectivity around cost, battery life, coverage, throughput, capacity, latency, security, reliability, to name a few. It is through combinations of requirements that the billions of predicted connections will be realized in practice, and the nature of applications that they serve will dictate the set of such requirements that the network connectivity must fulfill.

It has been proposed that the IoT field be segmented into massive and critical IoT, depending on the type of application to be implemented. Massive IoT, as the name implies, envisions very large numbers of connected objects, residing, for example, in buildings, agricultural fields, shipping vehicles, which report to the cloud on a regular basis and whose end-to-end cost must be sufficiently low to make business sense. Here, the requirement set is based on low-cost devices with low energy consumption, good coverage and high scalability. At the other end of the scale lie the Critical IoT applications, such as remote healthcare, traffic control and industrial control, to name a few, which will have very high demands on availability and reliability as well as very low latency. There exist, however, many use cases between the two extremes, which are already operating today on 2G, 3G or 4G connectivity.

The cellular mobile industry represents a huge and mature ecosystem, incorporating chipset, device and network equipment vendors, operators, application providers and many others. The global cellular ecosystem is governed by the 3GPP standardization forum, which guarantees broad industry support for future development. In this paper we detail the 3GPP developments known as Enhanced Machine-Type Communication (eMTC) and Narrowband IoT (NB-IoT), which are expected to offer an excellent platform for a wide variety of IoT use cases. The cellular mobile industry represents a huge and mature ecosystem, incorporating chipset, device and network equipment vendors, operators, application providers and many others. The global cellular ecosystem is governed by the 3GPP standardization forum, which guarantees broad industry support for future development. IoT value creation has many interdependencies to be successful in the marketplace including interoperability at the application and services layer.

In this paper we detail the 3GPP developments known as Enhanced Machine-Type Communication (eMTC) and Narrowband IoT (NB-IoT), which are expected to offer an excellent platform for a wide variety of IoT use cases. The 3GPP-specified eMTC and NB-IoT together with a number of unlicensed low power technologies are considered to be the wireless connectivity options that enable Low Power Wide Area Networks (LPWAN). A comparison with two of the unlicensed LPWA technologies is provided later on in the white paper.

To meet the new connectivity requirements of the emerging Massive IoT segment, 3GPP has taken evolutionary steps on both the network side and the device side. The key improvement areas addressed in 3GPP up to Release 13 are: device cost, batter life, coverage and support for massive numbers of IoT connections.

The new era of possibilities ushered in by IoT comes with high demands on security at all levels of the IoT fabric. For its part, 3GPP addresses continuous improvement in this space. Similar to present LTE networks, enhanced Machine-Type-Communication (eMTC) and Narrowband IoT (NB-IoT) support state-of-the-art 3GPP security, with authentication, signaling protection, and data encryption.

When it comes to scalability, cellular networks are built to handle massive volumes of mobile broadband traffic; the traffic from most IoT applications will be relatively small and easily absorbed. Operators are able to offer connectivity for IoT applications from the start-up phase and grow this business with low TCO and only limited additional investment and effort. Operation in licensed spectrum also provides predictable and controlled interference, which enables efficient use of the spectrum to support massive volumes of devices.

Cellular connectivity offers the diversity to serve a wide range of applications with varying requirements within one single network. While unlicensed Low Power Wide Area (LPWA) technologies are designed solely for very low-end MTC applications, cellular networks can address everything from Massive to Critical IoT use cases.

In 3GPP releases 14, 15 and beyond, standards aim at resolving existing technology and business bottlenecks such that all things that can benefit from wireless connectivity can take advantage of it. The vision of 5G is that the massive IoT market will explode with billions of devices and sensors that represent a digital representation of our real world, driven by low cost devices, long battery life, coverage everywhere, and innovative business applications. The promise of 5G is that it will be possible to realize critical IoT applications, which require real-time control and automation of dynamic processes in various fields such as vehicle-to-vehicle, vehicle-to-infrastructure, high-speed motion, and process control. Critical parameters to enable the performance required are network latency below milliseconds and ultra-high reliability and both are intrinsic components of the 3GPP work to define the new radio interface for 5G, NR. The 5G network architecture is being designed to cater for both IoT scenarios.

Overall, 3GPP standards aim at bringing innovations into the existing 4G networks and to design 5G from the start such that a growing span of IoT services can come to the market in the short term and without expensive network builds.

2. IOTMARKET DRIVERS

Much of industry participants recognize that M2M, and now IoT, represents one of the key growth opportunities for telecommunication service providers and enterprises of various sizes in the next decade. The main questions asked by industry participants in the early stages of considering to enter the field of M2M and IoT are the following: What are the key market drivers for IoT? What are market sizes for specific verticals applications?

2.1 EVOLUTION FROM M2M TO IOT

The Internet of Things (IoT), as a natural evolution of Machine-to-Machine (M2M) technology, is the interconnection of intelligent devices and management platforms that collectively enable the "smart world" around us. From wellness and health monitoring to smart utility meters, integrated logistics, and self-driving drones, our world is fast becoming a hyper-automated one. A multi-dimensional view on the evolution from M2M to IoT is provided in Figure 2.1.

Note: Going forward for the purpose of this whitepaper, the term IoT will primarily be used to cover both M2M and IoT, if not specifically noted otherwise.

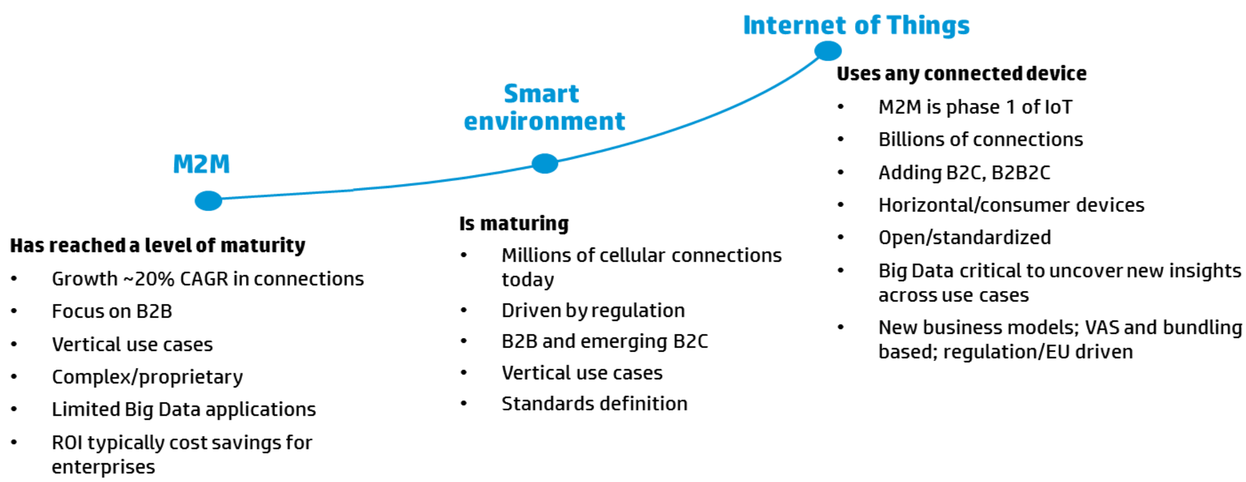

Figure 2.1. M2M to IoT Evolution.[1]

2.2 KEY IOT MARKET DRIVERS

The Internet of Things covers a tremendous number of categories of business opportunity. There are numerous interpretations of how it can be broken into various key verticals of adoption as well as horizontal considerations. Some consider five key verticals of adoption: Connected Wearable Devices, Connected Cars, Connected Homes, Connected Cities, and the Industrial IoT.

[1] *M2M insights for mobile operators*, Analysis Mason, March 2013.

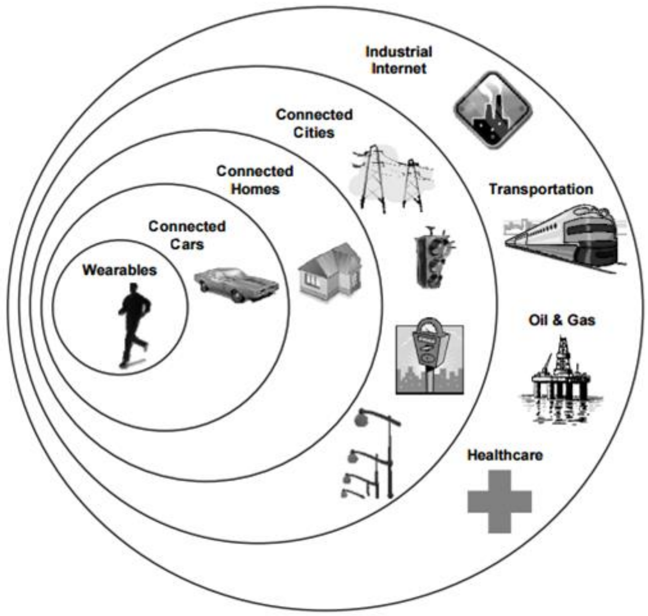

Figure 2.2. Key Verticals for the IoT.

As enterprises are exposed to an ever increasing competitive business environment it is of no surprise that from a business point of view IoT is driven by two forces:

- **Cost Savings** – Businesses are embracing the IoT to increase efficiency and improve productivity, which translate into cost savings, in key business components such as Capital Expenditure (CAPEX), maintenance, labor and energy, to name a few. For example, companies expect to save millions of kilowatts (kWh) annually across multiple data centers by deploying hundreds of sensors and control points throughout the data center, connected wirelessly.

- **Revenue Generation** – Companies are focused on IoT as a driver of incremental revenue streams based on new products and services. For example, the Connected Car service, which has been developed in partnership between mobile operators and automobile manufacturers, offers high-speed 3G or 4G connections for a monthly subscription fee. Numerous vehicle models are being built with LTE support, enabling vehicles to act as a Wi-Fi hotspot with connectivity for several devices, as well as access to the car manufacturers' service for remote vehicle access, diagnostics and emergency service. Analyst firm Analysys Mason predicts over 800 million connected vehicles by 2023.[2]

The underlying fundamental enabler that makes this happen is the technology evolution. We are now at the point in time where viable technologies are available at the same time as the concrete needs from different stakeholders are taking shape.

There have been significant technology changes that have come together to enable the rise of the IoT and this involves all connected devices, not limited to the Cellular Internet of Things (CIoT):

[2] *Analysys Mason's Internet of Things and Machine to Machine Predictions 2016*, January 2016.

- Lower cost of sensors – According to third party research firms, sensor prices have dropped significantly over the past 10 years.
- Declining cost of bandwidth – The cost of bandwidth has also declined precipitously, by a factor of nearly 40X over the past 10 years.
- Similarly, processing costs have declined by nearly 60X over the past 10 years, enabling more devices to be not just connected, but smart enough to know what to do with all the new data they are generating or receiving.
- Smartphones are now becoming the personal gateway to the IoT, serving as a remote control or hub for the connected home, connected car, or the health and fitness devices consumers are increasingly starting to wear.
- Ubiquitous cellular wireless coverage coupled with opportunity for mobility offers many vertical markets a key opportunity.
- As the IoT will by definition generate voluminous amounts of unstructured data, the availability of big data analytics is a key enabler.
- Most networking equipment now supports IPv6, the newest version of the Internet Protocol (IP) standard that is intended to replace IPv4. IPv4 supports 32-bit addresses, which translates to about 4.3 billion addresses – a number that has become largely exhausted by all the connected devices globally. In contrast, IPv6 can support 128-bit addresses, translating to approximately 3.4 x 1038 addresses – an almost limitless number that can amply handle all conceivable IoT devices."[3]
- 3GPP is addressing the standards development for the long-term future or IoT in a variety of bands and with several cellular technologies.

Figure 2.3. Market Drivers.

[3] *Goldman Sachs Global Investment Research,* September 3, 2014.

Most technology enablers are prepared to help accelerate the deployment of IoT solutions. Lower hardware costs and wireless data networks are enabling more intelligence and seamless connectivity. The market today is in a position to handle or process tremendous amounts of information that connected devices generate. The availability of big data analytics tools, combined with a growing understanding of how collective data can be used, provides an opportunity to add greater efficiency to M2M and IoT applications. End users also present the IoT driver themselves. Namely, as consumers and businesses have access to, and are used to living and working with smartphones and tablets, they are eager to adopt new applications that enrich the way they live, work, commute or shop.

The four important factors propelling the IoT forward are:

- The cost of internet-connected sensors is coming down. Many IoT devices rely on multiple sensors to monitor the environment around them. According to Goldman Sachs the cost of these sensors declined 50 percent in the decade ending in 2015.

- A lot more money is pouring into the IoT. Many large companies have begun to aggressively open IoT divisions and innovation labs. There have also been many IoT acquisitions and some innovative IoT startups, such as cloud-platform providers and smart plug makers, have received tens of millions in investment funding

- High adoption of ‘remotes’ especially smartphones, phablets and tablets that can manage the IoT are growing in market penetration. Smartphones accounted for 61 percent[4] of phones sold globally in 2015 and their share continues to rise as developing nations introduce better wireless infrastructure

- Expanded internet connectivity: The International Telecommunication Union (ITU) estimated that by 2015, 40% of the global population was connected to the internet and by 2019, roughly 57 percent will be connected. This increase in connectivity will lead to a larger base of individuals interested in purchasing IoT devices

There are three key areas that will enable the IoT market as a business driver for operators. As per research analysts Analysys Mason[5]:

We expect operators to focus on three approaches:

- ***Using M2M to generate new connectivity revenue (for example, connected cars).*** *These activities most closely align with the existing activities of M2M business units. Operators will aim to differentiate their offers and make them less susceptible to churn.*

- ***Using IoT to protect existing revenue (for example, smart homes).*** *These activities may be more closely aligned with other parts of an operator's business, for example some operators offer smart home solutions to complement their fixed broadband businesses. New connected gadgets could be used to help protect the core mobile business.*

- ***Providing platforms for vertical markets, especially where connectivity revenue alone appears to be low.*** *Healthcare is a key example of this.*

[4] *Mobile Phones Remain the Most Prolific Consumer Electronics Devices on the Planet,* CCS Insight. October 2015.
[5] *Analysys Mason’s Internet of Things and Machine to Machine Predictions 2016*, January 2016.

Various IoT industry initiatives to standardize architecture, ensure security and enable operability will accelerate the adoption of CIoT and will help the market evolve at an accelerated pace.

2.3 IOT MARKET SIZING AND FORECAST

IoT communications are set for aggressive growth for the foreseeable future. Cisco estimates that the number of connected devices worldwide will rise from 15 billion today to 50 billion by 2020. Intel is even more bullish, claiming that over 200 billion devices will be connected by then.[6] While these enormous forecasts represent all forms of wireless connectivity, with increased pervasiveness of mobile broadband, cellular connectivity is becoming even more valuable as an important access methodology for IoT.

"If there were any doubt that IoT is for real, one fact ought to dispel it: For the first time, U.S. mobile operators are adding IoT connections to their networks faster than they're adding phones," wrote Stephen Lawson, IDG News Service[7].

Although fixed and short range will be a significant part of IoT communications, cellular technology is forecasted to grow as the technology of choice for IoT applications as well. Figure 2.4 illustrates the tremendous growth of cellular M2M connections as well as the percentage that cellular IoT represents in the total IoT market.[8]

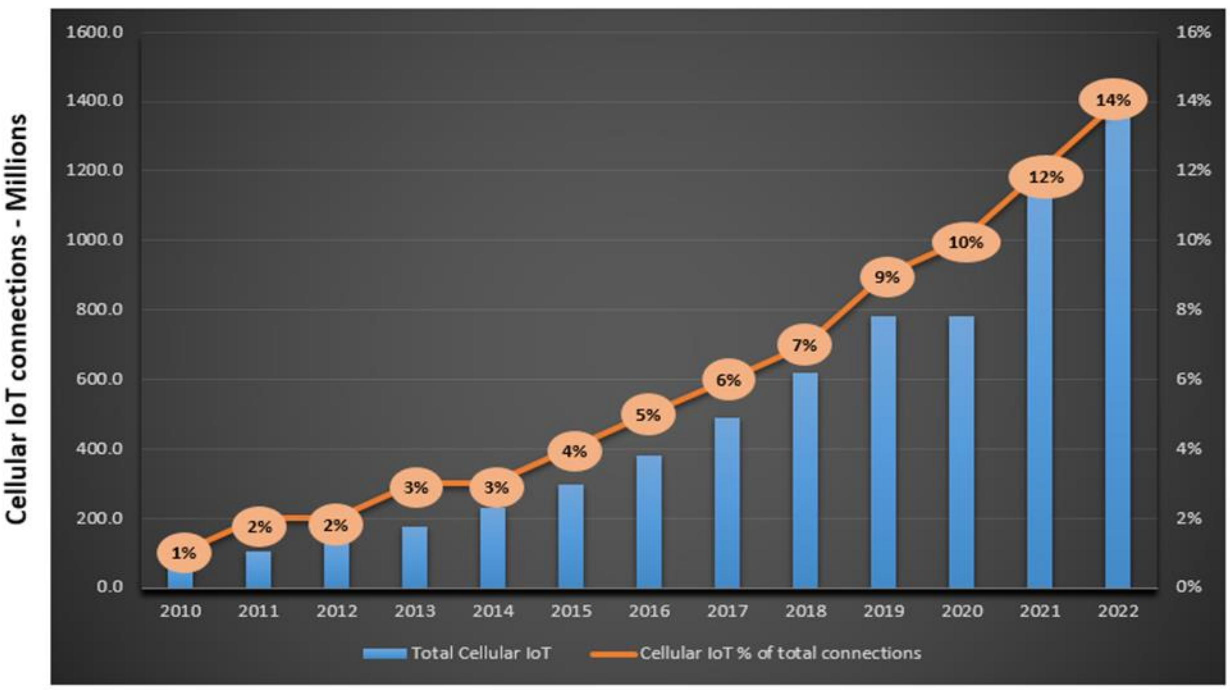

Figure 2.4. Growth of Cellular IoT Connections and Cellular IoT as Percentage of IoT Market – 2010-2022.

These forecasts are based on known and tangible deployments, opportunities and barriers for each operator and the IoT/M2M sector. They may well prove conservative if both industry players and

[6] *Internet of Things in 2016: 6 Stats Everyone Should Know,* Motley Fool. January 18, 2016.
[7] *U.S. mobile carriers added more cars than phones to their networks in the second quarter,* Stephen Lawson, IDG News, August 10, 2016.
[8] *Ericsson Mobility Report,* November 2016.

governments successfully enable a number of growth factors. This could lead to growth rates similar in the future to those witnessed over the past few years, resulting in uplift over the current trajectory forecasts of up to 50 percent. Such growth factors include low power network roll-out, increased standardization, improved regulation and greater assurance of end-to-end security. A further requirement is the development of new operator business models in the IoT/M2M space, particularly those that move beyond simply providing the mobile connectivity. The speed and sophistication achieved in each industry may vary due to specific needs of different segments, the availability of connectivity and other supporting technologies, and economic and regulatory environments in the local market.

Capitalizing on the opportunities, many innovators are swiftly adopting IoT technology in their respective industries as the new generation of devices is becoming more useful, affordable and easy to integrate. Additionally, national regulators in many industries are mandating IoT adoption as a technology enabler in achieving national socio-economic objectives.

Rapidly growing IoT adoption in different industries presents significant market opportunities for communications service providers. Mobile phones continue to be the largest category of connected devices, and in 2018 they are expected to be surpassed by the IoT, which includes connected cars, machines, utility meters, remote metering and wearables. Specifically, IoT devices are expected to increase at a compounded annual growth rate (CAGR) of 21 percent from 2016 to 2022, driven by new use cases. In total, around 29 billion connected devices are forecast by 2022, of which close to 18 billion will be related to IoT.[9]

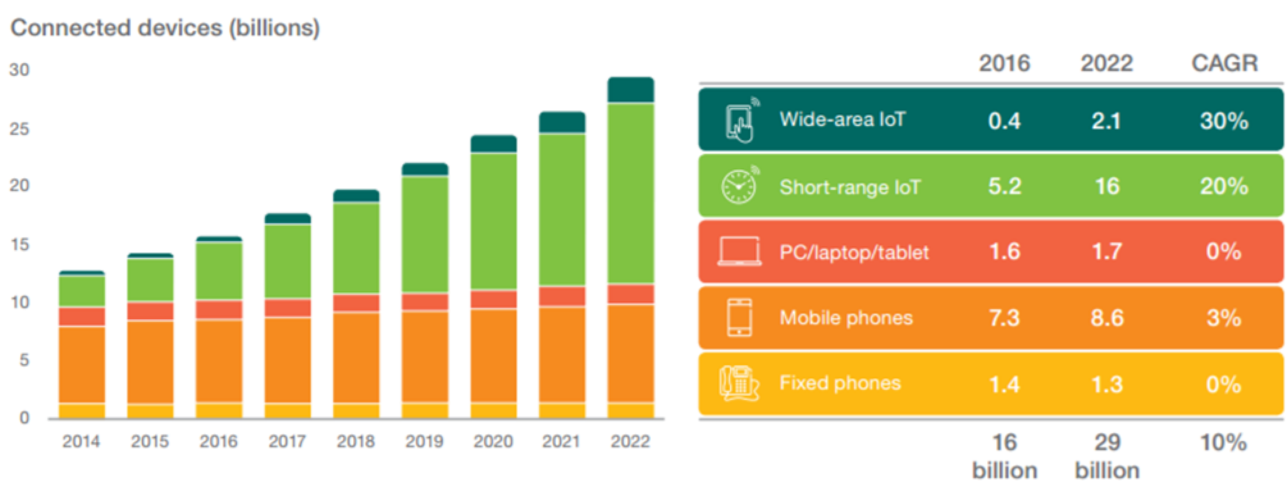

Figure 2.5. IoT Market Growth by Device Type 2015 – 2022.

As noted previously, in the U.S. some service providers are already adding more IoT connections than mobile phone connections. Cars alone are getting connected to cellular networks faster than anything else, per statistics compiled by Chetan Sharma Consulting for the second quarter of 2016. Counting all U.S. carriers, about 1.4 million cars got connected to cellular networks in the quarter, compared with 1.2 million phones and less than 900,000 tablets. IoT growth has been a long-term trend.

[9] *Ericsson Mobility Report,* November 2016.

Cisco predicts the global IoT market will be $14.4 trillion by 2022, with the majority invested in improving customer experiences. Additional areas of investment including reducing the time-to-market ($3T), improving supply chain and logistics ($2.7T), cost reduction strategies ($2.5T) and increasing employee productivity ($2.5T). The cited infographic In Figure 2.7 shows that 50 percent of IoT activity in 2022 is in manufacturing, transformation, smart cities and consumer markets.[10]

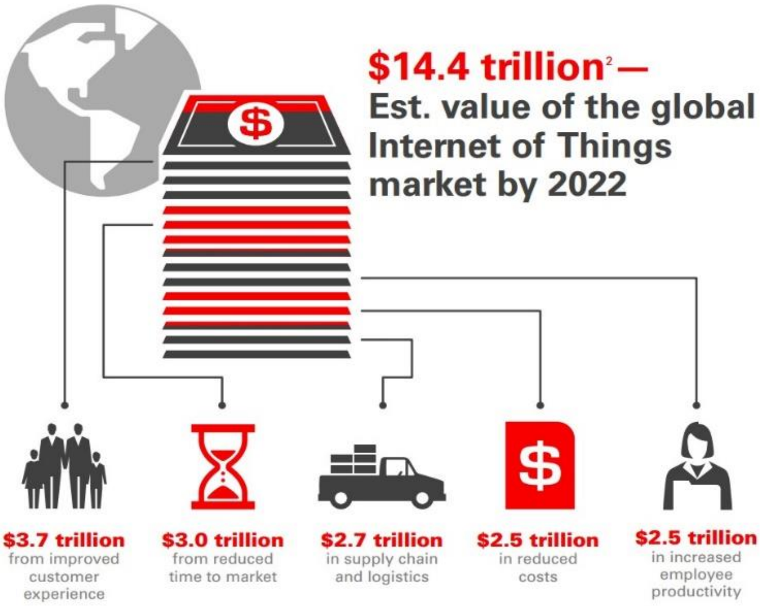

Figure 2.6. IoT Global Market Valuation 2020.[11]

The evolutionary trajectory from limited-capability IoT services to the super-capable IoT ecosystem has opened up new dimensions and opportunities for traditional communications infrastructure providers and industry-specific innovators. Those that exploit the potential of this technology to introduce new services and business models can deliver unprecedented levels of experience for existing services and, in many cases, transform their internal operations to match the needs of a hyper-connected world.

With the need to establish a model of “everything connected” no longer in doubt, the only question that needs to be addressed concerns the different patterns of distribution, timing, geography and areas of adoption. Utilities, security and transport are expected to witness maximum growth in IoT applications in the coming years.

2.4 EXAMPLE OF IOT MARKET FOR THE U.S.

The U.S. is one of the largest and most advanced IoT markets in the world and it accounted for 10 percent of all mobile connections in the U.S. in 2013. That number has grown considerably in the past few years.

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[10] *Oracle Infographic: Energize Your Business with IoT Enabled Applications*; *Embracing the Internet of Everything to Capture Your Share of $14.4 Trillion, Cisco. 2014.*

[11] Ibid.

Industry analyst Chetan Sharma provided highlights of the U.S. Mobile Market Q2 and Q3 2016.[12]

- CIoT (including connected cars) net additions exceeded phone and tablets combined (Q2)
- In Q2 2016, there were more connected cars net-additions than there were phone net-additions. For the 7th straight quarter, one leading U.S. operator added more cars than phones and tablets combined
- In Q3 2016, a leading U.S. operator reached 10M connected car subscriptions in less than 12 quarters compared to the 25 quarters it took for tablets (the first operator worldwide to do so)
- For the year, non-phone net-adds were at 71 percent share with cars and CIoT dominating (Q3)
- The first 100 million connections in the U.S. took 18 years; the last 100 million took just 6 years (Q3)

Some of the key growth drivers for the IoT market in the U.S. include:

- **Consumer demand:** As they become accustomed to digital commerce, consumers expect companies to offer personalized, real-time services. The communication service provider's role is to enable the enterprise to change its business model so it can become a service provider.
- **Semi-autonomous vehicles:** The U.S. automotive and software industries are in the vanguard of efforts to develop vehicles that are less reliant on a human driver. In February 2014, the U.S. Department of Transportation's National Highway Traffic Safety Administration announced that it will begin taking steps to enable vehicle-to-vehicle communication technology for light vehicles.
- **Health and wellness:** There is growing interest in the use of wearable devices such as wristbands to monitor activity levels and other health-related attributes.
- **International expansion:** U.S. based companies expanding abroad are likely to call on U.S. based operators to expand their IoT solutions to other markets.
- **New operating models:** As the benefits of IoT solutions become clearer, companies across the economy will increasingly adapt their operating models to be able to incorporate IoT technology quickly and efficiently.

[12] *US Wireless Market Update Q2 2016*, Chetan Sharma Consulting. August 2016 and *US Mobile Market Update- Q3 2016*, Chetan Sharma Consulting. November 2016.

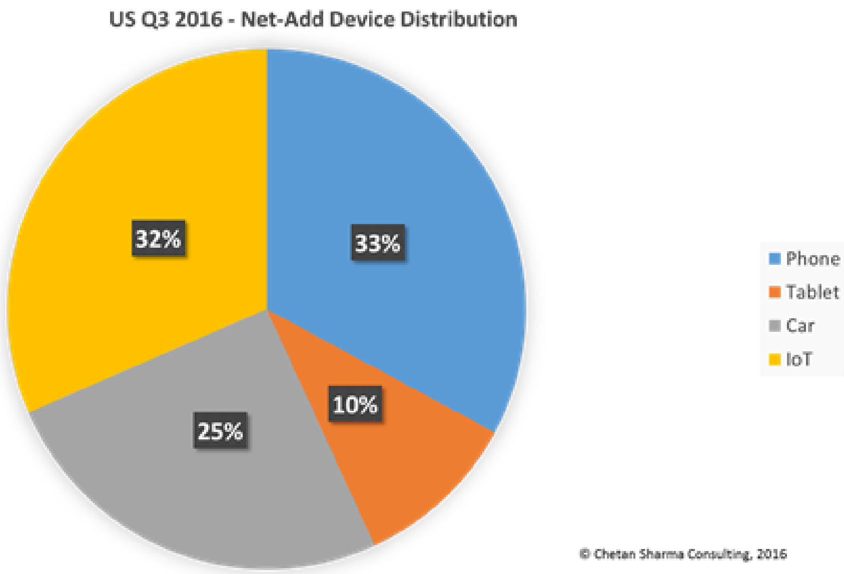

Figure 2.7. Cellular Devices by Category – Q3 2016.[13]

Sharma's quarterly report also showed how successful mobile data has become in the U.S. In the second 2016, it accounted for more than three-quarters of mobile carriers' revenue for the first time. It helps that the U.S. is No. 3 in the world for mobile data consumption per subscriber, per month, as per Sharma's insights. Only people in Finland and South Korea use more and the U.S. is first globally for countries with populations exceeding 60 million.

As noted, connected cars are a key growth component for the U.S., although most of the mobile connections are without driver interaction. Car companies are rolling out vehicles with live cellular connections, which enables monitoring the car's condition, updating software on board, and learning things that could help them improve future models. Keeping vehicles online may also reduce the need for expensive recalls. Consumers have been slow to start using the cell services in their cars since they already have a network connection through their cell phones; this can even provide a pipeline for vehicle data through IoT device-and-app combinations.

Connected cars aren't the only use of Cellular IoT. There are also more advanced services, like fleet management and tracking of shipping containers, plus smart-city applications like connected lights and parking meters. And the trend extends beyond the U.S. The country's biggest carriers offer international IoT services, and a handful of other big operators around the world are also building up major IoT operations.

3. IOT REQUIREMENTS

The IoT paradigm aims at facilitating the interaction between "real world" objects and information technologies, offering sensing and control possibilities. This enables the provisioning of an increasing number of IoT services in different areas such as manufacturing, mining, healthcare, monitoring, traffic control, etc. Each of these services with different requirements has been evolving accordingly with the technological capabilities.

[13] *US Mobile Market Update – Q3 2016*. Chetan Sharma Consulting. November 2016.

3.1 GENERIC REQUIREMENTS

The provisioning of IoT services requires objects with a mobile, flexible and ubiquitous connectivity to the network that only radio access can provide. The first obvious option has been to connect more expensive devices, such as cars or industrial machinery, in which the business case made sense due to the availability of enough electrical power and the small cost of modems compared with the object's overall cost.

The first evolution of MTC technology has been aimed at increasing the number of possible scenarios by focusing on device cost reduction since 3GPP Rel-10. In fact, this need was already foreseen in 3GPP some years before, the Rel-7 document TR22.868 (Jun 2006) already states: "It appears that there is market potential for M2M beyond the current 'premium M2M market segment,' i.e., the market segments that are currently using M2M."

The same low cost requirement was also addressed more than a decade ago by other forums and standardization bodies, as: ZigBee, Z-wave, European projects as e-sense, etc., all of them using ultra low power devices, and therefore centered in the provisioning of mesh networks which address four main challenges foreseen for massive deployment of IoT services:

1. **Low cost devices**, needed to be integrated, not only in a single chip modem, but also with sensors & actuators in everyday objects, including wearables

2. **Energy efficient system**, that will allow the maximum autonomous operation of IoT devices with reduced battery size. This requirement is obviously also related with the full system Total Cost of Ownership (TCO), as battery replacement is directly related with system OPEX

3. **Ubiquitous coverage** in the deployed scenario. Network deployment may guarantee a high degree of both outdoor and indoor coverage, and mesh networks with self-organizing routing was in the core of these technology for enabling zero-touch new nodes deployments

4. **Scalability**, considering the high number of devices that may be deployed in ultra-dense scenarios such as city centers, and the expected exponential growth of connected devices

These basic requirements were initially addressed with the combination of Short Range Devices (SRD) and mesh network. SRD addressed ultra-low power usage, and therefore low cost and energy efficiency, while mesh networking addressed the flexibility to extended coverage over indoor and outdoor (provided an adequate number of network coordinator nodes are deployed) as well as system scalability.

However, routing complexity and the need of powered (always on) Coordinator/Gateway nodes (and its OPEX maintenance) for IP connectivity, finally limited very much the commercial deployment of multihop mesh networks based on SRD.

In order to overcome this bottleneck, and thanks to the improvement in chip technology allowing single chip integration of higher power modems (including Power Amplifier (PA) and other Radio Frequency (RF) parts), a new approach to match the four mentioned IoT challenges, known as Low Power Wide Area (LPWA), was adopted several years ago. The basic idea is move back to a star connectivity, increasing the cells coverage by means of new modulation technologies in which the complexity and energy requirements are centralized as much as possible in the base station. This star approach provides a very cheap network Operating Expense (OPEX) as no coordinator nodes are needed near final devices, with highly simple deployment very well suited for operators and infrastructure owner's companies.

To achieve the previously listed challenges with a LPWA approach, several radio performance parameters may be degraded, as they are not needed in some of the foreseen IoT services:

- **Throughput**, usual scenarios require only connections of a few kbps or less
- **Packet length**, message will be very short with only a few Bytes
- **Activity cycle**, very short activity periods, overall much lower than 10% of the time
- **Latency**, values will depend on the services, but some of them have very relaxed requirements, with only small number of connection each day
- **Sessions Handovers**, may also not be required in most of the scenarios

3.2 3GPP REQUIREMENTS STUDY

Standardization in 3GPP addressed the challenge of improving MTC by accelerating improved MTC performance in the last releases, including Rel-12 LTE UE Cat.0 and Rel-13 UE Cat M1 which are further explained in Chapter 4. But beyond MTC evolution, the so called 'clean slate approach' for matching more massive IoT deployments integrated in the 3GPP technology also took place based on the Rel-13 Technical Report TR45.820 (March 2015) "Cellular System Support for Ultra Low Complexity and Low Throughput Internet of Things."

This Technical Report TR45.820 is targeted to be completed in the LPWA arena with a technology fully implementable in 3GPP nodes and architecture, and providing objectives beyond current state-of-the-art IoT connectivity requirements, with the following key performance indicators:

- **Reduced complexity (Challenge 1: Low cost devices)**

  Complexity is directly related with devices cost, even when other considerations may be taken into account, as the possible increases in cost due to Intellectual Property Rights (IPR) and the foreseeable cost reduction due to standardization (associated with large manufacturing volumes). The aim beyond the complexity measurement established in TR45.820 is to achieve an IoT full-modem chip with prices below US$3. Below these values, the modem cost may not be the main influencer in the overall cost of a device with consideration also for the battery, case and sensors/actuators included.

- **Improved power efficiency (Challenge 2: Energy efficient system)**

  The aim is to extend battery life of IoT devices. The measurement adopted in 3GPP is the time a device can be connected using 5 Wh (Watt-hours) of battery life in different scenarios. These scenarios that need to be considered are all the possible combinations of four traffic models (50 bytes each 2 hours, 200 bytes each 2 hours, 50 bytes each 24 hours and 200 bytes each 24 hours) and three possible coverage situations with coupling losses of 144 decibels (dBs), 154 dBs and maximum achievable value. The target established is to achieve at least 10 years of battery life in all the scenarios.

- **Improved indoor coverage (Challenge 3: Ubiquitous coverage)**

  The goal is to provide deep indoor coverage, as well as coverage in basements, from already deployed macro base stations. The value established as a target is to increase the Maximum Coupling Loss (MCL) up to 164 dB between the base station and the User Equipment (UE). This 164 dBs represents an increase of 20 dBs compared with any MCL for any device standardized up to Rel-12 in 3GPP. This coverage extension should provide the delivery of at least 160 bps data rate for both the Uplink (UL) and Downlink (DL).

- **Support of massive number of low throughput devices (Challenge 4: Scalability)**

Table 3.1 shows the assumptions of device density per cell for the most demanding urban scenario.

Table 3.1 Scalability and Device Density per Cell.[14]

Household Density per Sq km	Inter-site Distance (ISD) (m)	Number of devices within a household	Number of devices within a cell site sector
1517	1732 m	40	52547

Latency is another Key Performance Index (KPI) that has been considered, but as a more service-specific requirement. Due to the nature of other IoT requirements, most of them achievable by means of relaxing data throughput, latency has been established with a relaxed value of 10s.

Other requirements such as communications security, coexistence with already deployed 3GPP systems and usage of assigned frequency bands are also part of the value-added with the adoption of IoT technologies developed in 3GPP.

Currently 3GPP is developing IoT enhancements for Rel-14 that will provide the following additional features that may be useful in some services:

- **Enhanced positioning**: Observed Time Difference of Arrival (OTDOA) and potentially Uplink Time Difference of Arrival (UTDOA) for NB-IoT technologies are being specified. Positioning with node identity is the most basic service that can be provided without the need to include any sensor to the final device
- **Multicast:** needed for the provisioning of some services such as software upgrades in dense populated areas without individually addressing all the UEs
- **Mobility and service continuity enhancements**: lowering UE required power consumption in some specific cases
- **Lower UE power classes (NB-IoT only):** 14dBm transmitter requirement for further reduced UE complexity and cost
- **Voice support (eMTC only):** Support of voice services

[14] TR45.820

The evolution of IoT requirements towards 5G have also been studied not only in the New Radio (NR) Study Item currently open in 3GPP, but also in several research projects, such as the METIS II (under the EU Commission supported 5G-PPP framework).

3GPP NR requirements or target values for so-called massive Machine Type Communications (mMTC) scenarios are currently under development in the TR 38.913 "Study on Scenarios and Requirements for Next Generation Access Technologies."

mMTC, enhanced Mobile Broadband (eMB) and Ultra-Reliable and Low Latency Communications (URLLC) are the three basic families of scenarios for which requirements will shape the future 3GPP NR solutions for 5G solutions.

3.3 VERTICAL REQUIREMENTS

Obviously, apart from the generic requirements, common to all IoT services, presented in the previous sections, the specific needs for each of the wide variety of services under consideration may differ.

From an operator point of view, there are different requirements estimations, depending on the operator role and ambition. As an example, in the METIS II project the "Massive distribution of sensors and actuators" use case provides, the views on requirements for future 5G developments are shown in Table 3.2.

Table 3.2. Refined scenarios and requirements, consolidated use cases and qualitative techno-economic feasibility assessment.[15]

Availability	**99.9%**
Device density	**1 000 000 devices/km^2**
Traffic volume per device	**125 bytes message per second**
Battery life	**10 years (assuming 5 Watts-hour battery and restricted traffic model)**

Due to the high number of possible IoT services, the variety of uses cases with different requirements is enormous. In Table 3.3, some of the most relevant use cases in terms of a clear business case and their likelihood to be exploited in the next few years are summarized.

[15] METIS II Deliverable D1.1 2016-01-31.

Table 3.3. Prospective Use Cases for IoT.

Sector	Use Case	Top Requirements
Industry	High Volume (e.g. mining)	Range, Coverage, Reliability, Cost
Agriculture	Dynamic (e.g. animal tracking)	Battery, Range, Coverage, Reliability, Cost
	Static (e.g. irrigation of fields)	Battery, Range, Coverage, Reliability, Cost
Utilities	Powered (e. g. Electricity)	Indoor, SLA, Reliability
	Not Powered (e.g. Water/Gas)	Indoor, SLA, Reliability
Logístics	Management & Tracking (e.g. Fleet)	Easy Install., Mobility, Coverage, Cost
	Basic Monitoring (e.g. shipment conditions, warehouse)	Battery, Easy Install., Mobility, Coverage, Cost
Smart Cities	Dynamic Systems (e.g. Traffic Management)	SLA, Coverage, Reliability
	Basic Sensoring (e.g. air pollution)	SLA, Coverage, Reliability
Payments	TPV	Indoor, Interoperability, SLA, Reliability
	Fraud Detection	Indoor, Interoperability, SLA, Reliability
Wearables (incl. e-Health)	Continuous Tracking (e.g. Diabetes)	Indoor, Battery, Mobility, SLA, Coverage, Reliability
	Spot Tracking (e.g. steps tracking)	Battery, Easy Install., Mobility
Security	High Volume (e.g. video)	Indoor, Throughput, Security, SLA, Reliability

	Low Volume (e.g. presence detection)	Indoor, Security, SLA, Reliability
Connected Cars	Integrated solution (e.g. traffic management)	Easy Install., Mobility, Coverage, Cost
	Basic Monitoring (e.g. location)	Easy Install., Mobility, Coverage, Cost
Buildings (incl. Home)	Complex Solution (e.g. energy management)	Indoor, Security, SLA, Reliability
	Basic Solution (e.g. presence/ air pollution)	Indoor, Security, SLA, Reliability
IoT Complex Systems	Autonomous Car or Drones Ecosystems	Battery, Security, Range, SLA, Coverage, Reliability

Depending on the specific service, and the values achievable with the four main challenges of IoT as already presented, different requirements should be considered, such as:

- Traffic patterns (throughput and active cycles)
- Identity/Security needs
- Ease of Installation
- Mobility
- Service Level Agreement (SLA)
- Reliability
- Possible sector regulations

Requirements for the large variety of IoT applications is vastly different. 3GPP is working to develop a set of global standards to ensure that the challenges are successfully met with values that will accommodate the myriad of services and applications that our connected future will present.

4. KEY 3GPP IOT TECHNICAL SOLUTIONS

Long Term Evolution (LTE) is globally established and the fastest growing wireless standard, expected to reach 75 percent of the world's population coverage by 2021.[16] LTE, originally introduced in 3GPP Release 8, was developed to provide faster mobile broadband access, offering a generational performance leap over 3G. The core LTE technology has evolved over time to adapt to the ever-changing market requirements, ensuring network longevity. LTE-Advanced evolved in 3GPP Releases 10, 11 and 12 to better optimize the mobile broadband experience, enabling gigabit-class throughput with the introduction of advanced techniques, such as Carrier Aggregation (CA) and higher-order Multiple-Input Multiple-Output (MIMO). While some IoT applications can benefit from the improvements introduced in LTE-Advanced (e.g.

[16] *Ericsson Mobility Report*. June 2016.

High Definition (HD) security cameras), many IoT devices require optimizations for a far reduced set of functionalities.

3GPP has defined the following LTE features in Rel-12 and Rel-13 to address the IoT requirements:

In Rel-12-

- MTC introduces category 0 UE to reduce device complexity
- Power Saving Mode (PSM) reduces power consumption when UE does not need to send or receive data

In Rel-13-

- Rel-13 eMTC introduces category M1 UE with complexity reduction and coverage enhancements to at least 155.7 dB Maximum Coupling Loss (MCL)[17]
- NB-IoT introduces category NB1 UE which further reduces complexity and extends coverage to 164 dB MCL[18]
- extended Discontinuous Reception (eDRX) optimizes battery life for device-terminated applications
- network architecture and protocol enhancements for IoT are introduced

Figure 4.1 shows the scalability of LTE to meet a wide range of connectivity requirements including IoT.

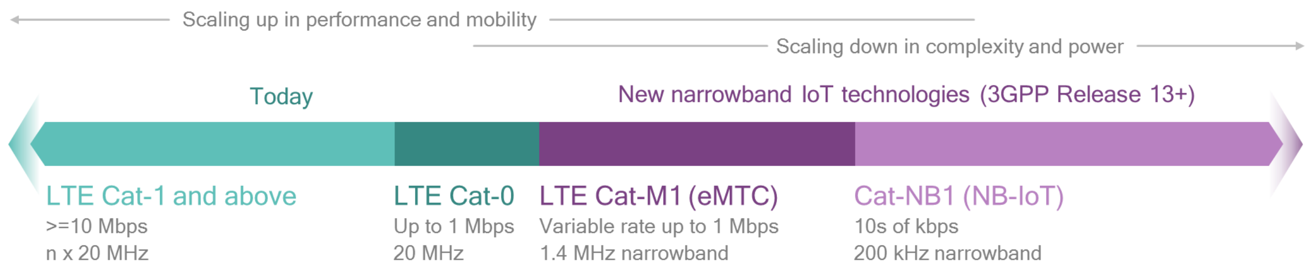

Figure 4.1. Scalability of LTE to Meet a Wide Range of Connectivity Requirements.

Rel-13 work items on both eMTC and NB-IoT were completed by 3GPP in June 2016. Due to strong market demand, it is expected that eMTC and NB-IoT will have a compressed timeline from standardization to commercialization. Cat-M1 and Cat-NB1 modules are expected to be available in early 2017. LTE networks can also be upgraded to support eMTC and NB-IoT, possibly through a software upgrade. eMTC and NB-IoT commercial launch is expected to start in 2017.

4.1 3GPP REL-12 MACHINE-TYPE COMMUNICATIONS

In Rel-12, a new UE category – UE Category 0 – is introduced to address the low cost/complexity aspects of the design goal. The following UE capabilities have been defined:

- Reduced data rate with maximum Transport Block Size (TBS) of 1000 bits for unicast and 2216 bits for broadcast

[17] MCL targets are not directly comparable due to different underlying assumptions.

- New Frequency Division Duplex (FDD) half-duplex type with relaxed switching time
- Single-receive antenna with reduced data rate capability
- Optional Multimedia Broadcast Multicast Services (MBMS) support with Physical Multicast CHannel (PMCH) Transport Block Size (TBS) of 4584 bits

The following provides a further description of the features specified for the Rel-12 low complexity MTC UEs:

- Downlink channel bandwidth for the data channel in the baseband is reduced (although only through implicit restriction), while the control channels are still allowed to use the carrier bandwidth
- Uplink channel bandwidth and bandwidth for uplink and downlink RF remains the same as that of non-MTC LTE UE
- For broadcast traffic, there is no explicit restriction on the resource allocation size for MTC UEs
- For unicast traffic, there is only implicit restriction on the resource allocation size due to the max TBS limitation (1000 bits in uplink and downlink)
- The maximum TBS for Category 0 UEs is 1000 bits for unicast transmission on PDSCH
- The maximum TBS is 2216 bits for broadcast data types referenced by System Information – Radio Network Temporary Identifier (SI-RNTI), Paging – RNTI (P-RNTI) and Random Access – RNTI (RA-RNTI)
- If a UE indicating Category 0 is scheduled with DL transmissions exceeding these limits then the prioritization between these DL transmissions within one TTI is left up to the UE implementation
- The number of soft buffer bits for unicast was specified as 25344
- A low complexity MTC UE may support eMBMS, in which case it must support a TBS size for MBMS reception of 4584 bits

Category 0 provides one step towards the goal of reduced complexity and cost for IoT use cases. New categories (Category M1 and Category NB1) have been defined by later 3GPP Release 13 that further reduce the complexity/cost while improving the coverage and battery life for IoT use cases. Thus, many operators choose to go directly to Rel-13 eMTC and/or NB-IoT by skipping Category 0 deployments.

4.2 3GPP REL-12 POWER SAVE MODE

Power Save Mode (PSM) is a new low-power mode that allows the device to skip the periodic page monitoring cycles between active data transmissions, allowing the device to enter a deep-sleep power state. However, the device becomes unreachable when PSM is active; therefore, it is best utilized by device-originated or scheduled applications, where the device initiates communication with the network. Assuming there is no device-terminated data, an LTE IoT device can remain in PSM state for as long as about 10 days, with the upper limit determined by the maximum value of the Tracking Area Update (TAU) timer. During the PSM active state, the Access Stratum (AS) at the device is turned off, and the device would not have to monitor page messages or perform any Radio Resource Management (RRM) measurements.

Moreover, PSM enables more efficient low-power mode entry/exit, as the device remains registered with the network and its Non-Access Stratum (NAS) state maintained during PSM, without having the need to spend additional cycles to setup registration/connection after each PSM exit event. Examples of applications that can take advantage of PSM include smart meters, sensors, and any IoT devices that periodically push data up to the network. PSM is applicable to Cat-0, Cat-M1 and Cat-NB1 devices.

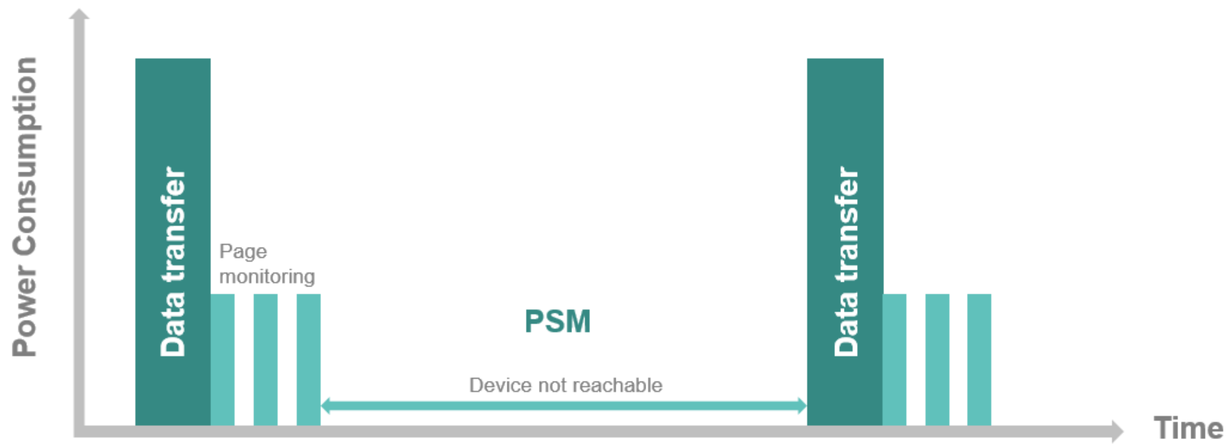

Figure 4.2. Rel-12 Power Save Mode (PSM).

One challenge with PSM is the ability to support device-terminated traffic, as the UE is unreachable when it is in PSM state. The device would become reachable to the network as the Tracking Area Update (TAU) timer expires, which can introduce significant latency for device-terminated traffic. While periodic TAU can be configured to occur more frequently to match the UE's delay requirement, such configurations would result in additional signaling overhead from unnecessary periodic TAU procedures and increased device power consumption. To address this shortcoming of PSM, extended Discontinuous Reception (eDRX) is introduced in 3GPP Rel-13, which will be described in a later section.

4.3 3GPP REL-13 EXTENDED COVERAGE - GSM

Given the extensive global footprint and broad eco-system available for Global System for Mobile Communications (GSM) networks, GSM represents a compelling alternative for IoT growth. Extended coverage GSM IoT (EC-GSM-IoT) is a standard-based Low Power Wide Area (LPWA) technology. It is based on enhanced General Packet Radio Service (eGPRS) and designed as a high capacity, long range, low energy and low complexity cellular system for IoT communications. The optimizations made in EC-GSM-IoT that need to be made to existing GSM networks can be made as a software upgrade, ensuring coverage and accelerated time to-market. Battery life of up to 10 years can be supported for a wide range use cases.

As standardized, it includes key additional enhancements including support for eDRX, reduced idle mode procedures, and QoS admission control. Full multiplexing of legacy GPRS/EGPRS Packet Switched channels are enabled by the EC-GSM-IoT specification. An example configuration with 1 Broadcast Control CHannel (BCCH) carrier supporting legacy Circuit Switched (CS) services, legacy Packet Switched (PS) services, and EC-GSM-IoT is shown in Figure 4.3.

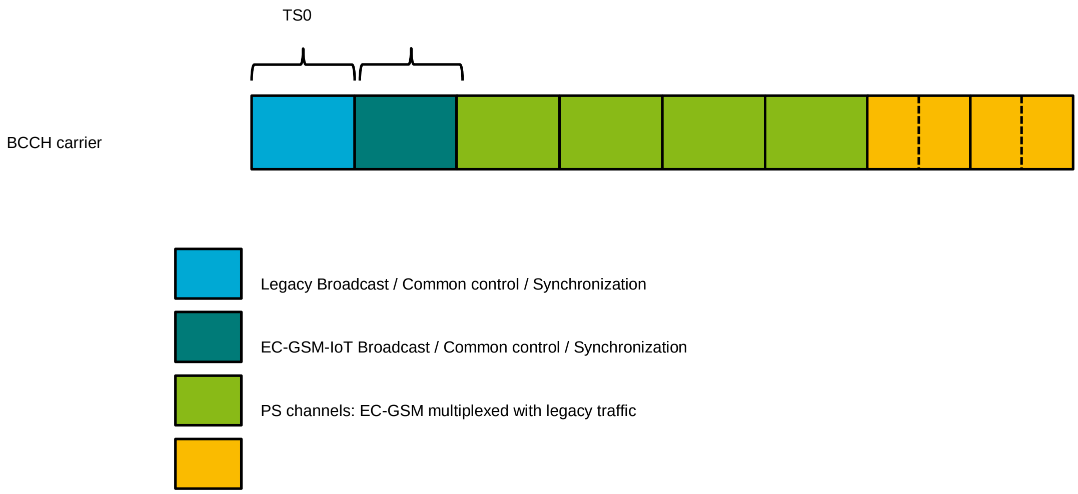

Figure 4.3. Example of an EC-GSM-IoT Channel Configuration.

For EC-GSM-IoT, all new logical channels supporting Extended Coverage are called EC-channels. EC-channels apply to EC-Shared CHannel (EC-SCH), EC-Broadcast Control CHannel (BCCH), EC-Access Grant CHannel (AGCH), EC-Paging CHannel (PCH), EC-Packet Data Traffic CHannel (PDTCH) and EC-Packet Associated Control CHannel (PACCH). EC-AGCH and EC-Packet Grant CHannel (PGCH) are designed using a 2-burst block format, while EC-PACCH is still using the current 4-burst block format. The FCCH can be kept unchanged and can still serve users in 20 dB extended coverage, with an extended acquisition time. Packet Timing Control CHannel (PTCCH) (continuous Timing Advance) is not supported or needed in EC-GSM. Initial TA is expected to be sufficient and can be optionally used on EC-PACCH.

A lower output power class will also be specified at 23 dBm to allow a more cost effective implementation, which implies a 10 dB coverage extension on the UL due to the 10 dB reduction in maximum output power.

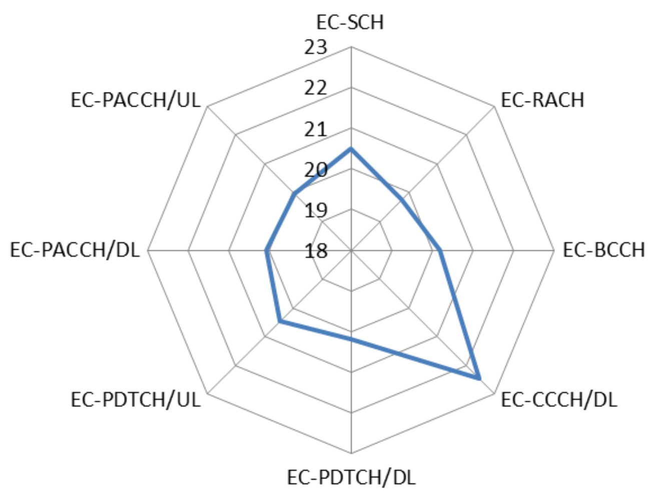

Figure 4.4 EC-GSM-IoT extended Coverage.

The minimum EC-PCH/EC-AGCH block is a 2-burst block, allowing up to 16 EC-PCH blocks and 20 EC-AGCH blocks in one 51 multifare. The EC-Random Access CHannel (RACH) is also mapped onto TS1 in the UL, leading to collision of different coverage classes on the same resources.

Extended coverage: L2 (16 times) and L3 Hybrid Automatic Retransmission reQuest (HARQ) (4 times) repetitions are used to reach 20 dB extended coverage compared to legacy GPRS. For data traffic channels, a combination of blind repetitions and incremental redundancy (HARQ type II) are used for an effective use of spectrum. The 20 dB coverage extension is reached by the use of the current 33 dBm GSM MS power class.

In summary, as GSM is most widely deployed wireless standard, it is further enhanced to support IoT requirements. EC-GSM-IoT is a simple and fast approach to support a massive number of IoT applications that require low data rates.

4.4 3GPP REL-13 ENHANCED MACHINE-TYPE COMMUNICATIONS

In 3GPP Rel-13, LTE category M1 UEs are introduced by the eMTC (enhanced Machine-Type Communications) technology, as a direct extension from category 0 UEs from Rel-12 MTC. The key objectives are reduction of device complexity and cost, extended coverage and long battery life. The standard work of eMTC was completed in Q1 2016.

Even though Category 0 devices support reduced peak data rates on DL and UL, they still need to support all specified LTE system bandwidth from 1.4MHz to 20MHz, utilizing 6 to 100 Resource Blocks (RB), and the wideband control channel spanning over the total bandwidth. eMTC operation is limited to 1.08MHz (6RBs) that can coexist in a wider, general-purpose LTE system. As a result, Cat-M1 devices only need to support 1.08MHz for both baseband and RF, which allows further reduction of the complexity and cost over Cat-0.

Cat-M1 devices have limited throughput of up to 1Mbps in both downlink and uplink. The maximum Transport Block Size for common control messages is reduced from 2216 bits of Cat-0 to 1000 bits (i.e., the same as for unicast data). The reduced peak data rates allow for both processing and memory savings in the device hardware. Additional complexity saving is achieved by reduction in the number of DL Transmission Modes (TM) and relaxed requirements on radio link quality measurements and reporting.

While Cat-0 devices need to support maximum transmission power for the UL at 23 dBm (200mW), Cat-M1 devices have the options to support 23 dBm or 20 dBm power classes. 20 dBm max transmission power allows the Power Amplifier (PA) to be integrated as opposed to dedicated PA, which would enable lower device cost. The reduction in the UL coverage from lower transmission power can be compensated by the coverage enhancement techniques introduced by eMTC.

By leveraging existing LTE numerology, eMTC can be deployed to operate within a regular LTE carrier (up to 20 MHz) and coexist with other LTE services. The bandwidth reduction for Cat-M1 requires a new control channel (i.e., MTC Physical Downlink Control Channel (MPDCCH) to replace the legacy control channels (i.e., Physical Control Format Indicator CHannel (PCFICH), Physical Hybrid Automatic Retransmission Request (ARC) Indicator CHannel (PHICH), and PDCCH), which can no longer fit within the narrower bandwidth. Cat-M1 devices leverage legacy LTE synchronization signals (e.g., Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) and Primary Broadcast CHannel (PBCH) in the center 1.08MHz of the LTE carrier, and introduce new system information (SIB1-BR).

eMTC network can configure multiple narrowband regions – 6 Physical Resource Blocks (PRBs) each – anywhere in the LTE carrier for narrowband Physical Downlink Shared CHannel (PDSCH) and MPDCCH for data scheduling. By supporting frequency and time multiplexing between IoT and non-IoT traffic, a LTE network can achieve scalable resource allocation and provide flexible capacity to meet the IoT demand. Cat-M1 devices can perform frequency retuning to a specific narrowband region, and frequency hopping to achieve frequency diversity across the entire LTE carrier. Random Access CHannel (RACH) also fits into the narrowband region addressed by MTC_SIB1-BR. Figure 4.5 provides a pictorial representation.

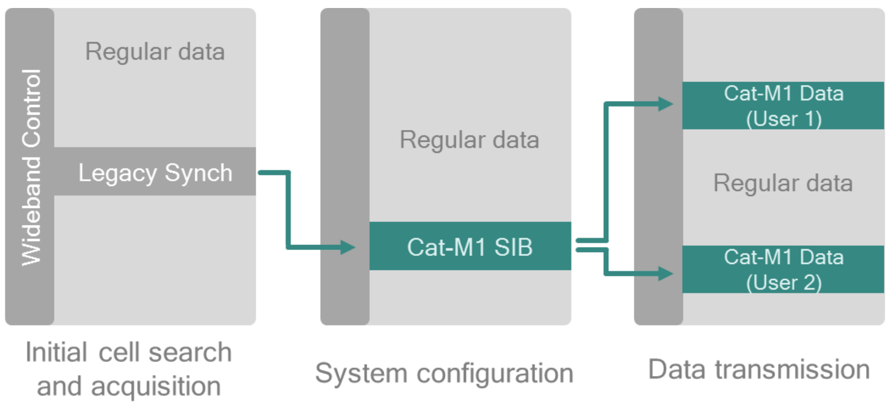

Figure 4.5. Cat-M1 (eMTC) Can Operate in Narrowband Regions Within a Regular LTE Carrier.

To extend coverage to IoT devices deployed deep indoors or in remote locations, eMTC offers 15dB of increased link budget and improved the Maximum Couple Loss (MCL) from 140.7dB of LTE baseline to 155.7dB or higher. All channels and messages needed for eMTC are designed to meet the MCL objective.

The key enabler for enhanced coverage is Transmission Time Interval (TTI) bundling and repeated transmissions, based on the tradeoff between coverage and transmission data rates and latency. TTI-bundling is available for LTE uplink in earlier releases, but the amount of bundling is further extended in eMTC. The TTI-bundling is also introduced in Rel-13 eMTC to Physical Random Access CHannel (PRACH) and downlink channel/messages, such as Physical Downlink Shared CHannel (PDSCH), MTC Physical Downlink Control CHannel (MPDCCH), Physical Broadcast CHannel (PBCH) and MTC Traffic CHannel System Information Block (MTC_SIB). For downlink and uplink data traffic channels, bundling size is determined via persistent assignments, which are established during the connection setup and can be updated through event driven feedback. A relaxed asynchronous Hybrid Automatic Retransmission reQuest (HARQ) timeline is also introduced with bundling for downlink and uplink.

eMTC enables long battery life with the goal to support 10 years of operation with a 5 Watt-Hour battery for certain IoT traffic patterns and coverage needs. Improved power efficiency of Cat-M1 devices is achieved by narrower bandwidth operation from both baseband and RF. Reduced processing requirements such as lower data rate and power efficient channel feedback also decrease power consumption. Enhanced DRX (eDRX) feature is introduced in Rel-13 to further improve the battery life.

In summary, Cat-M1 (eMTC) delivers data rates up to 1Mbps utilizing only 1.08MHz bandwidth. eMTC supports full-duplex FDD, half-duplex FDD and TDD modes, and it can be deployed in any LTE spectrum. Cat-M1 can also support voice (through Voice over LTE (VoLTE) and full-to-limited mobility, and is designed to fully coexist with regular LTE traffic (Cat-0 and above).

4.5 3GPP REL-13 NARROWBAND-IOT

While LTE Cat-M1 (eMTC) enables the broadest range of IoT capabilities, LTE Cat-NB1 (NB-IoT) scales down further in cost and power for low-end IoT user cases. NB-IoT is ideal for low-throughput, delay-tolerant use cases with low mobility support, such as smart meters, remote sensors and smart buildings. NB-IoT work began at 3GPP in the GSM/EDGE Radio Access Network (GERAN) to address re-farming of 200 KHz GSM spectrum for IoT. Later it moved to 3GPP RAN with extended scope to support LTE in-band and guard-band deployments, in addition to standalone deployment. The NB-IoT work item in 3GPP was completed in June 2016.

Cat-NB1 uses 180 kHz bandwidth and supports stand-alone, guard-band and in-band operation. NB-IoT is currently specified for FDD, although some 3GPP member companies have expressed interest in specifying TDD operation in future releases. The narrowband operation reduces the RF and baseband complexity and cost while further reducing power consumption. NB-IoT supports in-band deployment by utilizing a single RB within a normal LTE carrier. It can be deployed in a LTE carrier's guard-band utilizing unused resource blocks while still minimizing interference with neighboring carriers. In standalone mode, NB-IoT can be deployed in re-farmed spectrum from GERAN systems utilizing standalone 200 kHz carriers. Thus, NB-IoT provides flexible deployment options to operators (Figure 4.6).

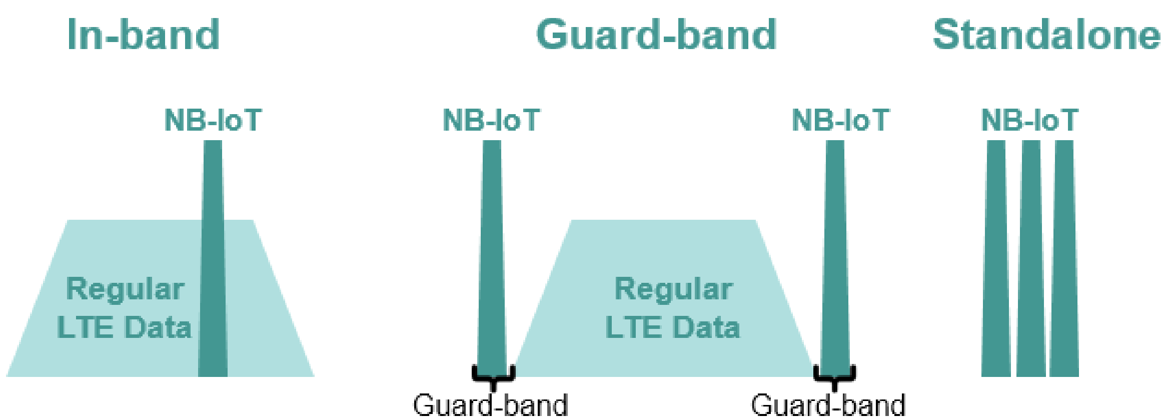

Figure 4.6. Cat-NB1 (NB-IoT) Flexible Deployment Options.

A new set of channels and signals are introduced for NB-IoT to accommodate the narrow bandwidth. These range from synchronization signals (NB-PSS and NB-SSS), broadcast and access channels (NB-PBCH and NB-PRACH), control channels (NB-PDCCH) to data channels NB-Physical Uplink Shared CHannel (NB-PDSCH) and NB-Physical Uplink Shared CHannel (NB-PUSCH).

Peak data rates for NB-IoT are further reduced to limit the device complexity and cost. Downlink peak data rates are limited to about 32 kbps for in-band scenario and 34 kbps for standalone deployment, while uplink peak data rates are limited to about 66 kbps for multi-tone transmission and 16.9kbps for single-tone. To reduce the UE receiver complexity, NB-IoT downlink supports only Quadrature Phase Shift Keying (QPSK) modulation for Narrowband Physical Downlink Shared CHannel (NPDSCH) with single Transmission Mode (TM) and Tail Biting Convolutional Codes (TBCC), while maintaining legacy LTE Orthogonal Frequency Division Multiple Access (OFDMA) numerology of 15 kHz subcarrier spacing. Uplink operation allow multi-tone transmission based on Single-Carrier Frequency Division Multiple Access (SC-FDMA) with 15 kHz tone spacing for higher data rate, and introduce single tone transmissions with 15 or 3.75 kHz tone spacing for power gain. Uplink modulation schemes include QPSK for multi-tone transmission and phase-rotated QPSK and Binary Phase Shift Keying (BPSK) modulation for single-tone transmission that can reduce Peak-to-Average-Power-Ratio (PAPR) and decrease RF chain complexity.

Cat-NB1 devices only need to support half-duplex FDD. This allows the device to implement a simpler RF switch instead of a full duplexer that is more complex and costly. Like Cat-M1 (eMTC), the Cat-NB1 UE receiver is reduced to a single antenna, and the maximum uplink transmission power can be reduced to 20 dBm (100mW) to allow the Power Amplifier (PA) to be integrated. Other complexity reduction techniques include Cat-NB1's limited support for voice (VoLTE or circuit switched services) and mobility. Cat-NB1 devices do not support connected mode mobility in the form of handovers. Instead, the mobility is supported in the idle mode through cell selection and re-selection.

NB-IoT further extends coverage beyond eMTC (Cat-M1) to up to 164 dB MCL that can reach IoT devices deployed in challenging locations. NB-IoT trades off uplink spectral efficiency and latency to effectively increase coverage without increasing output power that will negatively impact the device battery life. Key enabler techniques, noted in Figure 4.7, for deeper coverage include:

- **Redundant transmissions:** Transmitting the same transport block multiple times in consecutive sub-frames (TTI bundling) or repeatedly sending the same data over a period (repetitive transmission) can significantly increase the probability for the receiver (cell or device) to correctly decode the transmitted messages.
- **Single-tone uplink:** Similarly, a Cat-NB1 device can utilize single-tone uplink (3.75 kHz or 15 kHz sub-carrier spacing) to further extend coverage and spectral efficiency, trading off peak data rate (limiting to 10's of kbps).
- **Lower-order modulation:** By utilizing QPSK instead of 16-Quadrature Amplitude Modulation (QAM), the SINR (Signal to Interference plus Noise Ratio) threshold reduces significantly, trading off modulation efficiency (fewer bits per symbol).

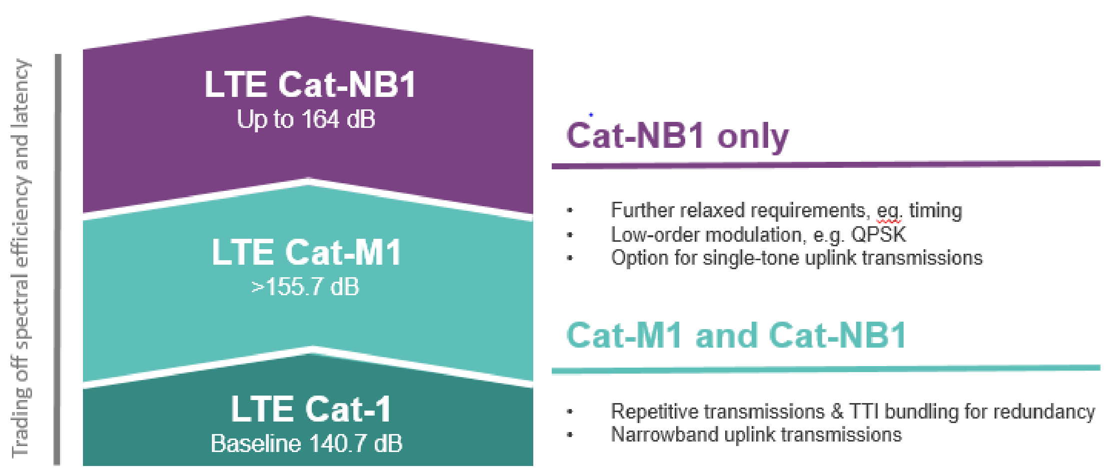

Figure 4.7. Advanced Techniques to Extend LTE IoT Coverage.

NB-IoT also allows simplified network and signaling support to handle IoT traffic more efficiently. Details are described in a later section.

In summary, LTE Cat-NB1 (or NB-IoT) further reduces device complexity and extends coverage to address the needs of low-end IoT use cases. Cat-NB1 uses narrowband operation in LTE-FDD, delivers maximum throughputs of 10's kbps, and supports more flexible deployment options: LTE in-band, LTE guard-band, and standalone. To further enhance coverage, it trades off certain capabilities to achieve extra gain over Cat-M1. Figure 4.8 compares cat-M1 and cat-NB1 device capabilities, while Figure 4.9 summarizes the high-level complexity difference of the two new LTE IoT UE categories.

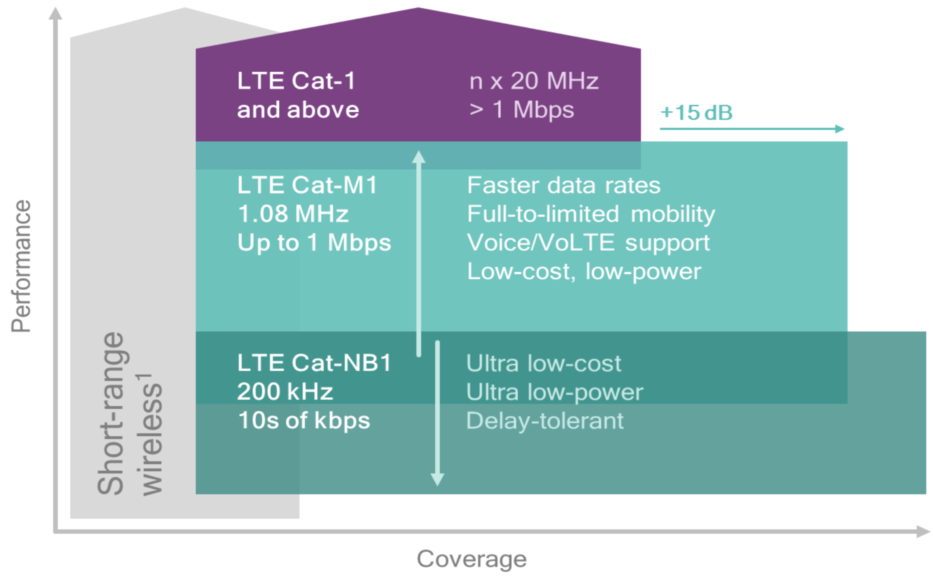

Figure 4.8. LTE IoT – Cat-M1 and Cat-NB1 Devices.

	LTE Cat-1 (Today)	LTE Cat-M1 (Rel-13)	LTE Cat-NB1 (Rel-13)
Peak data rate	DL: 10 Mbps UL: 5 Mbps	DL: 1 Mbps UL: 1 Mbps	DL: ~30 kbps UL: ~60 kbps
Bandwidth	20 MHz	1.4 MHz	200 kHz
Rx antenna	MIMO	Single Rx	Single Rx
Duplex mode	Full duplex FDD/TDD	Supports half duplex FDD/TDD	Half duplex FDD only
Transmit power	23 dBm	20 dBm or 23 dBm	20 dBm or 23 dBm

Higher throughput, lower latency, full mobility

Figure 4.9. Reducing Complexity for LTE IoT Devices.

4.6 3GPP REL-13 EXTENDED DISCONTINUOUS RECEPTION

While Rel-12 Power Saving Mode (PSM) can effectively reduce power consumption for device-originated or scheduled applications, its usage for device-terminated applications may result in unnecessary signaling and power consumption. Rel-13 introduces Extended Discontinuous Reception (eDRx) which enables enhanced connected mode and idle mode discontinuous reception (C-DRX and I-DRX) to further enhance device-terminated use cases, i.e. devices can be paged by the network. eDRX is applicable to both Cat-M1 and Cat-NB1 devices, and provides additional power savings in addition to those realized through reduced device complexity.

eDRx optimizes battery life by extending the maximum time between control channel monitoring/data reception from the network in connected mode to 10.24 seconds, and time between page monitoring and tracking area update (TAU) in idle mode up to 430.69 minutes for Cat-M1 and up to about 3 hours for Cat-NB1. As a note, legacy LTE idle mode DRX cycle is limited to at most 2.56 seconds; it allows the network and device to synchronize sleep periods, so that the device can check for network messages less frequently. The DRX cycle depends on the required latency, so eDRx is optimized for device-terminated applications. Use cases such as asset tracking and smart grid can benefit from the lower power consumption realized through the longer eDRx cycles. In addition to reduced power consumption, eDRX can also reduce signaling load compared to legacy DRX and/or PSM.

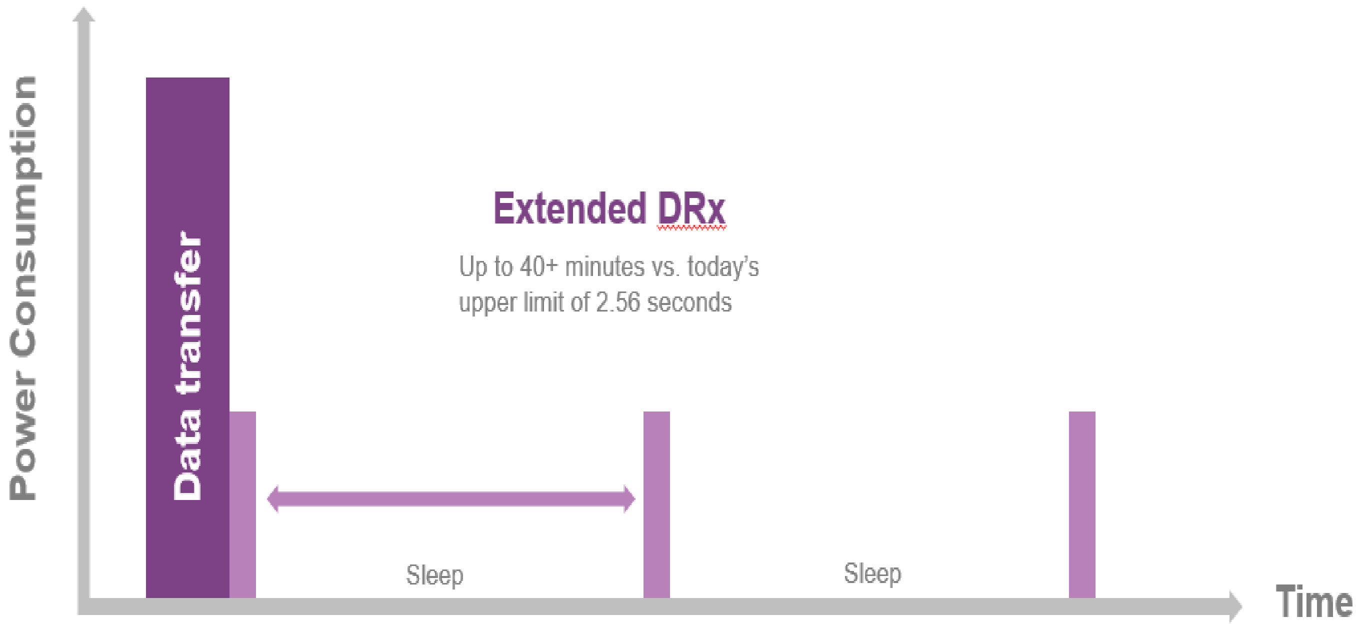

Figure 4.10. eDRX Idle Mode Extends Sleep Cycles for LTE IoT Devices.

4.7 3GPP REL-13 NETWORK ARCHITECTURE AND PROTOCOL ENHANCEMENTS

Beyond the air interface improvements, 3GPP Release 13 provides a few enhancements on network architecture and protocols for IoT. These enhancements include:

- Dedicated Core Networks (DECOR)
- Architecture Enhancements for Services capability exposure (AESE)
- Optimization to support High Latency Communication (HLCom)
- Group Based Enhancements (GROUPE)
- Monitoring Enhancements (MONTE)
- Architecture Enhancements for Cellular Internet of Things (CIoT)

Dedicated Core Networks (DECOR)

3GPP networks will continue to support a vast number and types of MTC devices. These classes of devices have different requirements from traditional devices because of issues like special traffic characteristics, availability, and congestion management.

In an effort to provide cost effective features for operators in support of different UE classes for MTC, 3GPP has introduced separate Dedicated Core Networks (DCN) consisting of specialized core network functionality designed to meet the specific requirements of MTC devices. MTC devices in these dedicated networks share the same characteristics and are selected based on operator configuration and subscription details. The architectural enhancements defined by 3GPP in this context are known as DECOR.

From a core network functionality standpoint, of the dedicated core network consists of a number of specialized elements such as Mobility Management Entities (MME), Serving GPRS Support Nodes (S4-SGSN), Serving Gateway (SGW) and Packet Data Network Gateway (PGW).

The fundamental objectives of DECOR are to define pertinent subscription information which could be used to select a DCN (MME, SGW, PGW) that is specialized to serve a set of UEs and to maintain the UEs in such DCN. The dedicated core network is selected based on the subscribed usage type of the UE, but also on local policy. When a UE first attaches to the network, if the Core Network selected by the Radio Access Network is not adapted to the UE, the network redirects the signaling to the appropriate DCN. While moving, the UE remains in the same DCN thanks to the structure of its temporary identifier. In roaming situations, the PGW in the home network is selected using the subscribed usage type. In addition, if the subscribed usage type has a standard value, the MME and SGW in the Visited Public Land Mobile Network (VPLMN) can be selected based on the subscribed usage type and local policy.

Architecture Enhancements for Services Capability Exposure (AESE)

The objective of the AESE work in 3GPP is to define stage 2 architecture enhancements so that the 3GPP system-provided service capabilities can be exposed via an Applications Programming Interface (API) specified by the Open Mobile Alliance (OMA), by another standards body, or by the network operator. This feature specifies how a third-party application can access features and data in the 3GPP system, and how the 3GPP system would expose 3GPP service capabilities in a secure manner. The benefits of this feature include:

- enhanced trouble shooting
- addressing customer care concerns, and
- a viable option for third parties to directly access 3GPP network capabilities

It should be noted that an Applications provider could also be an M2M service provider, a third party application provider, or a Mobile Network Operator (MNO). Thus, MNOs can not only monetize the data and capabilities of their 3GPP network by providing those capabilities to third parties, but also develop their own applications and thus provide additional services to both external customers and internal network management.

The AESE architecture is captured in 3GPP TR 23.708:

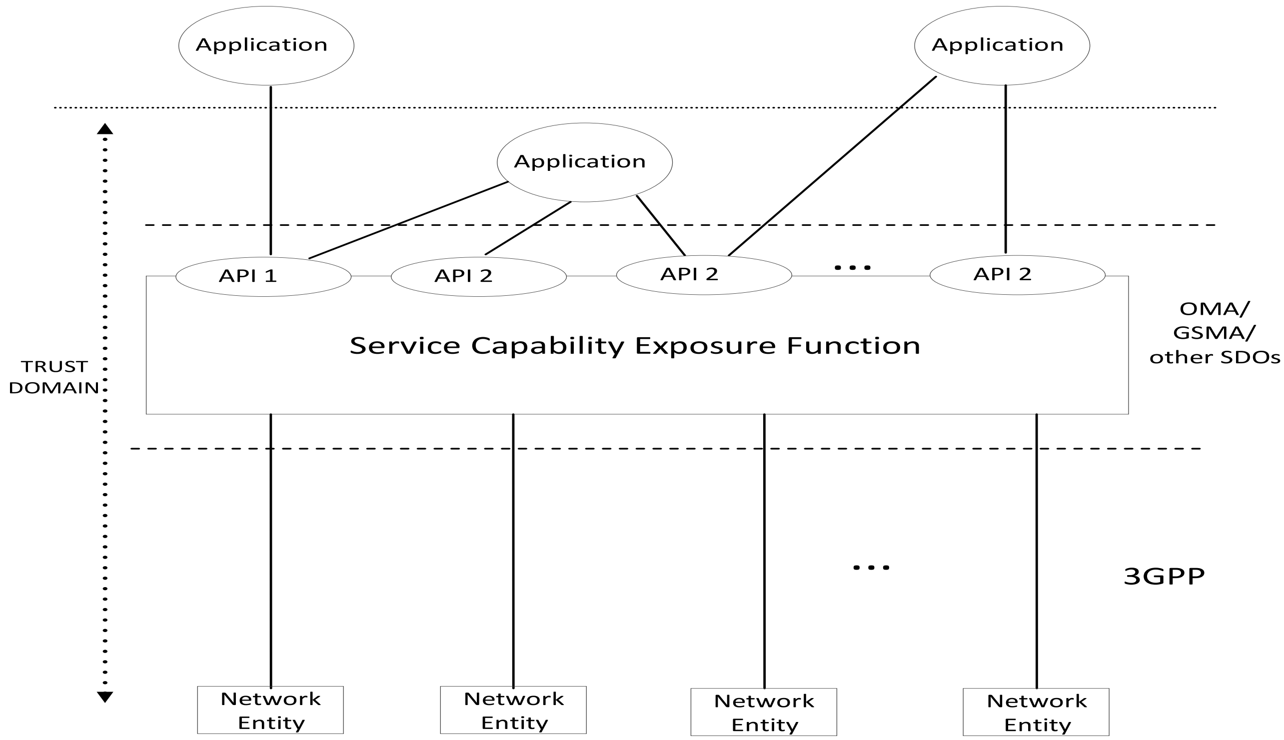

Figure 4.9. AESE Architecture.

This AESE Architecture (depicted in Figure 4.9) introduces the Service Capability Exposure Function (SCEF) in order to securely expose the services and capabilities with the 3GPP network interfaces. The "Network Entity" boxes represent the Home Subscriber Server (HSS), MME, PGW, PCRF, charging and security functions, etc., and the lines connecting each Network Entity to the Service Capability Exposure Function (SCEF) are standardized 3GPP interfaces. Thus, the SCEF can access the capabilities of the Network Entities in an MNO's 3GPP network.

The APIs at the top of the SCEF can be defined by Open Mobile Alliance (OMA), GSM Association (GMSA), other standards bodies, or by the MNO. The APIs will provide access to the SCEF which stands as a guard on access to the capabilities of the MNO network. Note that the applications that access the SCEF via these APIs can be both inside and outside of the MNO's network, allowing for a wide spectrum of services to be supported.

Optimization to Support High Latency Communications (HLCom)

M2M/IoT devices have the ability to communicate with a number of applications and other devices. These devices may be constrained sensors or meters designed to have low-cost, low-energy, and low-mobility, or, depending on application use, they may also have additional capabilities. Battery operated devices with infrequent data communication needs are designed to go to sleep and go offline by invoking battery savings functionality. Depending on the power saving method that is used, the UE applying power saving may not be reachable for a number of hours/days. There are millions, if not billions of these devices in the market today. Since a UE that applies power saving mechanisms is not reachable by paging, the network needs some methods to cope with the downlink packet that cannot be delivered to the UE during its sleep cycle.

Scenarios, such as downlink packet transmission to UEs that are applying the power savings function, and coordination of maximum latency between the application and the network, are considered. One such method to handle MTC/IoT devices that are not reachable for longer periods of time due to power saving is called High Latency Communication (HLCom), which is specified in stage 2 level in 3GPP TS 23.682. HLCom allows the Core Network to buffer the DL messages during the long sleep cycle of a device that is applying power save functions. Alternatively, the Core Network entity (MME or SGSN) that is aware of the UE sleep cycle may inform the Application Server (AS) of the next foreseen paging opportunity when the UE would be available for paging. Application Server may also subscribe to UE monitoring events to find out about UE reachability.

Group Based Enhancements (GROUPE)

The GROUPE feature provides the ability to address multiple UEs with a single action. For example, having the ability to trigger a group of devices through a single action is extremely important in MTC applications. Group-based triggering could be used to wake up a set or subset of terminals for a given application. In addition to triggering, the GROUPE feature includes group-based policing and group-based addressing.

The mechanisms laid in place in Release 13 for the GROUPE feature take advantage of the AESE architecture and use functionalities through two primary paths: the first being via the HSS and MME, and the second being via the PGW. The building blocks accomplished in Release 13 not only provide a first set of functionality, but can also be used to add new functionalities in the future with small impact.

If the network operator would like to enforce certain policies using, for example, Quality of Service (QoS), they would likely use the ability to set or modify a Group-based policy. All UEs belonging to a given Group would have that Group noted in the HSS subscription record. If all of those UEs are attached to the same PGW, that PGW can receive and enforce policies related to that Group, such as maximum data throughput per unit time (e.g., “total Group uplink traffic shall be no more than 10KB per 24 hours”).

For Group-Based Addressing, the MNO may configure the use of MBMS to optimize a message volume when a large number of MTC devices need to receive the same message. A broadcast message can be sent within a particular geographic area and only MTC devices of the target Group would be configured to receive the broadcast message and recognize the message. The savings in avoiding accesses to the network from the many UEs in such a Group can provide significant savings to the MNO and allow further monetization of the MNO’s investment in MBMS resources.

Monitoring Enhancements (MONTE)

In a previous 3GPP release, the Monitoring feature was added with the intention of monitoring MTC devices, UE and user subscription-related events. Such events are related to specific events, event detection and event reporting to authorized users, whereas these events could be for example, used by the applications for logging purposes. With Release 13 enhancements, there is a desire to allow the network to can detect these events. The feature provides a mechanism for the 3GPP network to support:

- Detecting an activated MTC feature where the behavior is not in alignment with the intended purpose
- Detecting association changes between the Mobile Entity (ME) and the Universal Subscriber Identity Module (USIM) – “Was the SIM inserted in a different device?”
- Reporting loss of connectivity of a UE
- Reporting communication failure with the UE

- Reporting geographic or location changes

The network would therefore, report such events to the Service Capability Exposure Function (SCEF) defined in the AESE feature. The SCEF could then provide a variety of services to third parties, such as M2M operators, based on the MONTE feature and using the APIs of the AESE architecture. If the MNO provides the SCEF function that is the focus of this monitoring capability, a variety of services can be built to monetize existing data and capabilities of their 3GPP network.

Architecture Enhancements for Cellular Internet of Things (CIoT)

Based on a recently completed work in 3GPP, a number of architecture enhancements have been standardized in the CIoT area.[18] The key issues are to: fulfill requirements for ultra-low complexity and low throughput; provide efficient support of infrequent small data transmission by minimizing network signaling; to support delivery of non-IP and IP data; to support efficient Paging area management for CIoT and the ability to select both CIoT Dedicated Core Networks and Authorization of use of coverage enhancements. Further enhancements have been incorporated into 3GPP Release 14. CIoT Enhanced Packet System (EPS) Optimizations comprise several enhancements:

- Support of NB-IoT radio that is optimized for CIoT use case (but CIoT runs also on WB-E-UTRAN)
- Control Plane CIoT EPS Optimization
- User Plane CIoT EPS Optimization
- Attach without PDN connectivity
- Non-IP Data Delivery (NIDD)
- Alternative small data paths either via SGW-PGW or via SCEF
- Interaction with devices using power saving mechanisms

Since CIoT has been specified as an extension of EPS functionality, the normal EPS architecture applies, as specified in 3GPP TS 23.401. Both the device and the network nodes can be upgraded to support one or some of the CIoT EPS optimizations. However, a so-called C-SGN single box deployment option has also been defined. It does not change the CIoT functionality at all, but it provides an alternative to embedded deployment where the selected CN nodes are updated to support CIoT EPS Optimizations. In standalone C-SGN deployment, the same functionality is mapped in single-box Core Network, as specified in Annex L of 3GPP TS 23.401. C-SGN deployment must internally support the functionality of MME and S-GW.

[18] 3GPP TS 22.368 v13.1.0, "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Service requirements for Machine-Type Communications (MTC); Stage 1 (Release 13). December 2014.

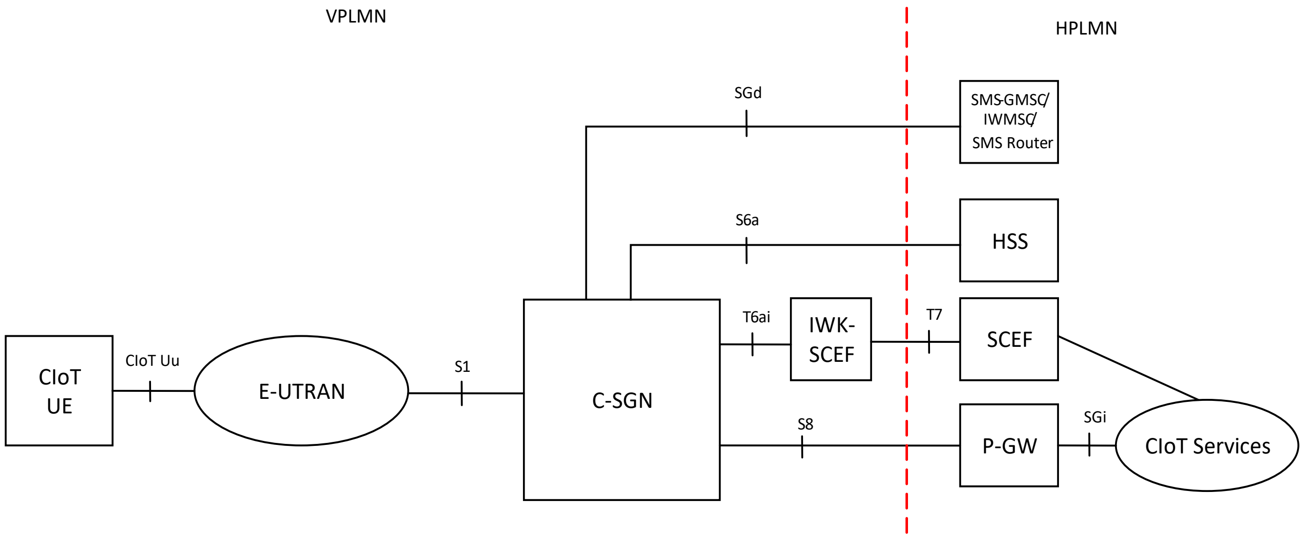

Figure 4.10. CIoT Architecture with Single-Box C-SGN.

It is not necessary for all implementation to support all of the above mentioned CIoT EPS Optimizations. In order to achieve compatibility, the device attaching to the network indicates the CIoT functionality that it intends to use in the UE requested CIoT EPS Optimizations. The serving network may negotiate these based on subscriber information, network capabilities and local policy, before indicating the network supported CIoT EPS Optimization back to the device. The network's selection becomes the CIoT feature set for that UE in the registered PLMN.

The CIoT EPS Optimizations cover a wide variety of use cases ranging from pure telemetry-type infrequent and small one-shot measurement applications to more big data oriented streaming of multimedia or e.g. software downloading to update the device SW. Control Plane CIoT EPS Optimization avoids the need for data bearer assignment by encapsulating user data payload into Non-Access Stratum signaling messages for ultimate efficiency in the telemetry use case. Also, User Plane traffic has been optimized for higher efficiency than in traditional EPS. The key aspect here is the capability to suspend an existing Radio Resource Control (RRC) connection to resume the same connection later. The message exchange to resume is faster and more compact than setting up a new connection. This capability suits also bigger bursts of data as data bearer is used.

5. FUTURE ENHANCEMENTS INTO 5G

The vision of 5G is that the massive IoT market will explode with billions of devices and sensors that represent a digital representation of our real world and that it will be possible to realize critical IoT applications, which require real-time control and automation of dynamic processes in various fields such as vehicle-to-vehicle, vehicle-to-infrastructure, high-speed motion, and process control. The 5G network architecture is being designed to cater for both IoT scenarios.

Overall, 3GPP standards aim at bringing innovations into the existing 4G networks and to design 5G from the start such that a growing span of IoT services can come to the market in the short term and without expensive network builds.

5.1 3GPP REL-14 LTE ENHANCEMENTS

A significant number of M2M/IoT features and enhancements are being considered for Release 14 where the 5G standards begin. Such enhancements and key areas of concentration consist of low latency, reduced UE complexity and spectrum efficiency. These M2M and NB-IoT systems will soon be able to take advantage of radio optimization allowing for possibly lower cost chipsets, power consumption optimizations for the device, and a better way of handling small data.

3GPP Release 14 is slated to include several high-ranking enhancements for M2M and NB-IoT such as:

- General Enhancements to MTC: E.g., Positioning, VoLTE, High Data Rate
- Enhancements of NB-IoT
- NB-IoT RF requirement for coexistence with CDMA
- UE to Network Relays for IoT and wearables
- Enhancements for LTE Device to Device and UE to Network Relays for IoT and wearables
- Study on the need for multiple APNs
- Lawful Interception
- Enhanced DECOR
- Rel-14 extensions for CIoT
- Group based enhancements in the network capability exposure functions
- New band support for Release 14 NB-IoT
- New Services and Markets Technology Enablers

This section provides a brief description of M2M and NB-IoT Enhancements as specified in 3GPP Release 14.

Enhancements to MTC

Even though Cellular Internet of Things (CIoT) provides a significant opportunity to operators in the mobile community, there is still a desire for improvements and enhancements. In Rel-14, further enhancements in the areas of positioning, multicast, mobility, data rates, and VoLTE will be undertaken.

Since device positioning and tracking are understandably important in several IoT operations, it is necessary to review, study and improve machine-type-communications related to reception and transmission time difference measurement. The feature will also take into consideration the UE complexity and power consumption for the Observed Time Difference of Arrival (OTDOA). Specifically, 3GPP RAN4 and RAN1 will weigh in and improve upon a number of measurements pertaining to location. These groups will see how to improve upon position location based on parameters using the Enhanced Cell ID (E-CID) and taking into consideration the reference signals received power (RSRP) and the reference signals received quality (RSRQ). As noted previously, OTDOA will be examined as well as the E-CID for the UE Rx-Tx time difference measurement. The new features in OTDOA include multiple PRS configurations for resource utilization improvement and PRS frequency hopping for positioning accuracy improvement. RAN4 is working on the corresponding performance.

3GPP RAN2 will take the lead and will work with 3GPP RAN1 to improve upon the following:

- Support multicast downlink transmission (e.g., software updates, group message delivery). 3GPP will extend Rel-13 Single Cell Point-to-Multipoint (SC-PTM) to support multicast transmission for eMTC
- Provide additional enhancements supporting narrowband operations (e.g., MPDCCH and coverage enhancements)

3GPP RAN4 is slated to review and develop full standard support for inter-frequency measurements for eMTC and for VoLTE enhancements; RAN1 and RAN2 will lead the task to see how improvements can be made on this study item in support of eMTC.

Furthermore, for higher data rates, 3GPP RAN1, RAN2 and RAN4 will specify the improvements. Parameters taken into consideration for improving or obtaining higher data rates are noted as specified in RP-161321.[19]

- Specify HARQ-ACK bundling in CE mode A in HD-FDD

- Larger maximum Transport Block Size (2984 bits for 1.4 MHz MTC UE and 4008 bits for 5 MHz MTC UE)

- Larger maximum PDSCH/Physical Uplink Shared Channel (PUSCH) bandwidth in connected mode at least in CE mode A in order to enhance support e.g., voice and audio streaming or other applications and scenarios. RAN1 will introduce higher-capability MTC UE to support higher data rates. This higher-capability MTC UE can support bandwidth of up to 5 MHz and maximum data rates of 4 Mbps in uplink and downlink. Furthermore, non-band-limited UE (i.e., UE category 1 and above) operating in coverage enhancement mode in Rel-14 will be able to utilize up to 20 MHz of bandwidth

- Support up to 10 DL HARQ processes in CE mode A in HD-FDD

Lastly, VoLTE enhancements for eMTC devices will also be undertaken. The goal is to enhance VoLTE coverage for half-duplex FDD and TDD devices. Potential enhancements include introducing new repetition factors and adjusting timing relationships and scheduling delays.

Enhancements of NB-IoT

Narrowband IoT has become a standard in 3GPP Release 13 and it specified requirements for improved indoor coverage, delay sensitivity for the device and support for extremely large numbers of low throughput devices. The market for IoT has increase dramatically allowing for 3GPP Rel-13 NB-IoT functionality to support non-real-time voice and to extend ultra-low cost into the IoT market. Use cases for NB-IoT include applications such as smart buildings and cities, asset tracking, utilities agriculture and environment monitoring. Based on market-driven expectations, machine type communications are in much demand by

[19] New WI proposal on Further Enhanced MTC (RP-161321, Ericsson. June 2016).

operators and governments from a global standpoint. In response to this reaction, NB-IoT will be enhanced to extend support into several 3GPP LTE features, such as: location positioning and multi-cast.

Rel-14 will also add support for Positioning, Multicast, Non-Anchor Physical Resource Block enhancements, and Mobility and Service Continuity Enhancements:

- **Positioning:** the introduction of E-UTRAN Cell Identifier (E-CID) core requirements would be evaluated for:
  - E-UTRAN Cell Identifier (E-CID): The introduction of E-CID core requirements would be evaluated for Reference Signal Received Power / Reference Signal Received Quality (RSRP/RSRQ) measurement and UE Rx-Tx time difference measurement
  - OTDOA: New narrowband positioning reference signal will be defined for OTDOA positioning in eNB-IoT with the considerations of positioning accuracy, UE complexity and power consumption. The detailed solutions and corresponding feature enhancements are still in 3GPP discussion.
  - UTDOA: The UTDOA support in eNB-IoT will be under the conditions of using existing NB-IoT transmission and meanwhile available for Rel-13 UEs.
- **Multicast:** Requirements are being considered to extend Rel-13 Single Cell Point-to-Multipoint (SC-PTM) to support multicast downlink transmission (e.g. firmware or software updates, group message delivery) for NB-IoT and if necessary, additional support for narrowband operations may include support of NPDCCH and coverage enhancements.
- **Non-Anchor Physical Resource Block (PRB):** These enhancements which support transmission of NPRACH on a non-anchor NB-IoT PRB, and paging on a non-anchor NB-IoT PRB. This will increase the random access and paging capacity for NB-IoT.
- **Mobility and service continuity enhancements:** These enhancements are slated to be considered in Rel-14, allowing for enhancements to connected mode mobility in an effort- to improve service continuity and avoid Non-Access Stratum (NAS) recovery for both Control Plane (CP) and User Plane (UP) solutions without the increasing of UE power consumption.
- **New Power Class(es):** New classes will be evaluated and will specify, if necessary, a new UE power class with a level of 14dBm. Upon evaluation, and if appropriate, signaling support will be developed to support the lower maximum transmit power that is suitable for small form-factor batteries (e.g., wearables).

Lastly, Rel-14 will also introduce larger maximum transport block sizes (1352 bits in the downlink and 1800 bits in the uplink) and support up to 2 HARQ processes in both uplink and downlink. This will allow Rel-14 UE to support higher data rates, which will reduce latency as well as power consumption.

NB- IoT RF Requirement for Coexistence with CDMA

Several high priority bands were approved in 3GPP Rel-13 for NB-IoT; the bands approved were 1, 2, 3, 5, 8, 12, 13, 17, 18, 19, 20, 26, 28 and 66. 3GPP RAN4 is working to finalize requirements for NB-IoT RF. Since this is a competitive technology, consideration had to be given to address the challenges and the coexistence with other technologies in the market today, in this case CDMA. 3GPP evaluated inter-operator coexistence related to CDMA and NB-IoT and the following conclusions were reached:

- Rel-13 NB-IoT BS Adjacent Channel Leakage Ratio (ACLR) requirement is stringent enough to guarantee the protection for CDMA systems, and no additional requirement is required

- Rel-13 NB-IoT BS Adjacent Channel Selectivity (ACS) requirement is stringent enough to guarantee the coexistence with neighboring CDMA systems, and no additional requirement is required

- Rel-13 NB-IoT UE ACS requirement is stringent enough to guarantee the coexistence with neighboring CDMA systems, and no additional requirement is required

3GPP notes that in Rel-13 NB-IoT UE RF requirement can provide around 49dB ACLR with an edge separation of 385 kHz, which guarantees the coexistence with neighboring CDMA systems, and no additional requirement is needed.

Basically, the results of this study indicate that Rel-13 NB-IoT BS and UE requirements can satisfy the coexistence with legacy CDMA systems and that no additional requirements are needed.

Further Enhancements for LTE Device-to-Device (D2D) and UE to Network Relays for IoT Wearables

Wearable technology is not only a trend, it is a viable technology because of its usage diversity. Wearable technology could be a watch that keeps track of heart beats, calories, steps, or banking and financial transactions, along with health monitors that keep track of sleep patterns, heart rhythms and vital signs. For these reasons, as well as others, there is a lot of interest in using LTE technology to connect and manage wearable devices.

In Release 13, 3GPP has introduced ProSe UE-Network relay functionalities for public safety usage only. It mainly supports extending the network coverage between the out of coverage UE (Remote User Entity) and the Network via the Relay UE. However, the core network has no visibility of the Remote UE (i.e., no subscription management of the Remote UE via Relay), and there is support for end to end QoS between the Remote UE and Network via the Relay UE. In Release 15, usefulness of ProSe UE-Network relay functionalities has found its way to the consumer electronics market. It can be used to lower the power consumption of the wearable when these wearables can access the network via ProSe UE-Network relay functionalities at the nearby handset (UE). To ensure successful adoption by the consumer products (wearables), the Rel-13 ProSe UE-Network relay functionalities must be enhanced with the support of management of the remote UEs for charging or security, QoS, session continuity, etc.

Both RAN2 and SA2 have an ongoing study item on how to develop a general L2 relay (denoted as Evolved ProSe UE-to-Network Relay) and how Evolved ProSe Remote UE is in or out of E-UTRAN coverage is able to interact with the network via Evolved ProSe UE-to-Network Relay. This work is expected to impact UE, evolved NodeB (eNB), and core-network nodes.

Rel-14 extensions for Cellular Internet of Things

3GPP Release 14 adds the following capabilities to CIoT:

- GPRS support for Non-IP small data via SCEF

- Authorization of use of Coverage Enhancement

- Reliable communication service between UE and SCEF

- Inter-RAT mobility to and from NB-IoT
- Re-use of existing multicast/broadcast architecture
- Re-use of Location services architecture for Control Plane CIoT EPS Optimization
- Inter UE QoS for NB-IoT Control Plane Optimization
- CN overload control for data transfer via Control Plane CIoT EPS Optimization

GPRS support adopts the selected CIoT EPS Optimizations Non-IP small data and the interface to SCEF also to GPRS environment. Both were supported in EPS already in the initial CIoT Release 13.

Also, Coverage Enhancement (CE) was supported already in Rel-13, but Rel-14 adds the capability to selectively authorize it to only those users who have subscribed to the CE service. Reliable communication between UE and SCEF adds acknowledgements to detect loss of messages. Inter-RAT mobility between NB-IoT and other 3GPP RATs can be supported from Rel-14 onwards. Multicast/broadcast and location services work tasks define workarounds to handle the conflict of MT services and very long unreachability periods of devices that apply long power saving sleep cycles. For the sake of service quality, it is important to distinguish in overload situation high priority applications from "toys" that are applying CIoT, and to prioritize the most important devices. And finally, Control Plane overload control is about protecting the serving MME from overload caused by excessive traffic volume from devices applying Control Plane CIoT EPS optimization. A new tool for backing off UE in control plane is designed for this purpose.

Lawful Interception

Consideration to Lawful Interception may be given to enhanced support for IoT devices as well as V2X.

In some countries, lawful interception would apply only if a human user is involved in a communication. In some other countries, lawful interception may apply even if no human is involved such as an IoT communication. Therefore, depending on regional requirements, the ability to perform lawful interception of an IoT communication may have to be incorporated into the network architecture that supports IoT communication.

Lawful interception requires the network to isolate communication traffic involving the target and deliver the same to the law enforcement agencies. The interception and delivery of IoT shall be transparent to all those who are not authorized to have the knowledge of that particular lawful interception. Those unauthorized people may include, participants of communication, other Law Enforcement Agencies (LEA), unauthorized Communication Service Providers (CSP) personnel of the same Pubic Land Mobile Network (PLMN) and all CSP personnel of other PLMNs. Interception capabilities performed within a PLMN shall not be dependent on functions provided by other PLMNs or devices.

Lawful interception may apply to VPLMN and HPLMN. Both VPLMN and HPLMN shall be able to provide the lawful interception rather independently. The lawful authorization given to VPLMN and HPLMN are separate and independent of each other.

Typically, the identities used to isolate the target communication can be any of the following:

- International Mobile Equipment Identifier (IMEI)
- International Mobile Subscriber Identity (IMSI)

- Mobile Subscriber Identity Software Defined Network (MSISDN)
- Media Access Control Address (MAC Address)
- Static IP Address
- Session Initiation Protocol (SIP) Telephone (TEL) Uniform Resource Identifier (URI)

The 3GPP LI specifications (TS 33.106, TS 33.107 and TS 33.108) define the stage 1, stage 2 and stage 3 requirements of LI capabilities The LI capabilities for IoT communications is yet to be specified in the 3GPP LI specifications.

Study on Need for Multiple Access Point Names

3GPP completed its study of the need for Multiple Access Point Names (APNs). The study considers use cases for automotive, in-vehicle user equipment and the provision of an international M2M service for business customers and provides the following solutions:

- **UICC based solution.** As the study indicates, this requires a new feature to allow for the storage and the use of multiple APNs in the USIM. The new feature will not impact RAN or Core Networks. The UICC based solution will not have an impact on legacy Over The Air (OTA) platforms as these platforms can be reused to update the list of APNs and any additional information/fields.

- **Device Management based solution.** This solution offers the ability to handle multiple devices utilizing a defined set of interfaces towards the service management layer. The device management layer provides a buffer to the service management layer from trust-type relationships in the network (e.g., relationships between the UICC and the service provider, the UICC and the network operator, as well as the UICC and the device). For clarity, these relationships are illustrated in the M2M end-to-end high-level architecture (Figure 5.1).

- Network based solution. It was determined that this solution can be achieved by using a single APN with previously document mechanisms for legacy networks. In addition, due to the availability of a variety of mechanisms documented in TR 22.802, it was noted that not only could these requirements be met by utilizing only one APN; but, if only one application is active at a specific time, various connectivity requirements of the automotive use case can be achieved using multiple APNs. However, only one APN can be active at a given time.

- APN provisioning based solution. Based on the study, this solution is like the UICC-based solution in addition, this solution reuses OMA DM which is an already defined management object relative to the APNs. In addition, previously defined OMA DM relationships are noted e.g., OMA DM bootstrap from the UICC is already defined, etc. This solution has no impact on the OMA DM specification nor the 3GPP specifications.

This Release 14 study takes into consideration Machine-To-Machine UEs; it may also take into account a more generic set of UEs.

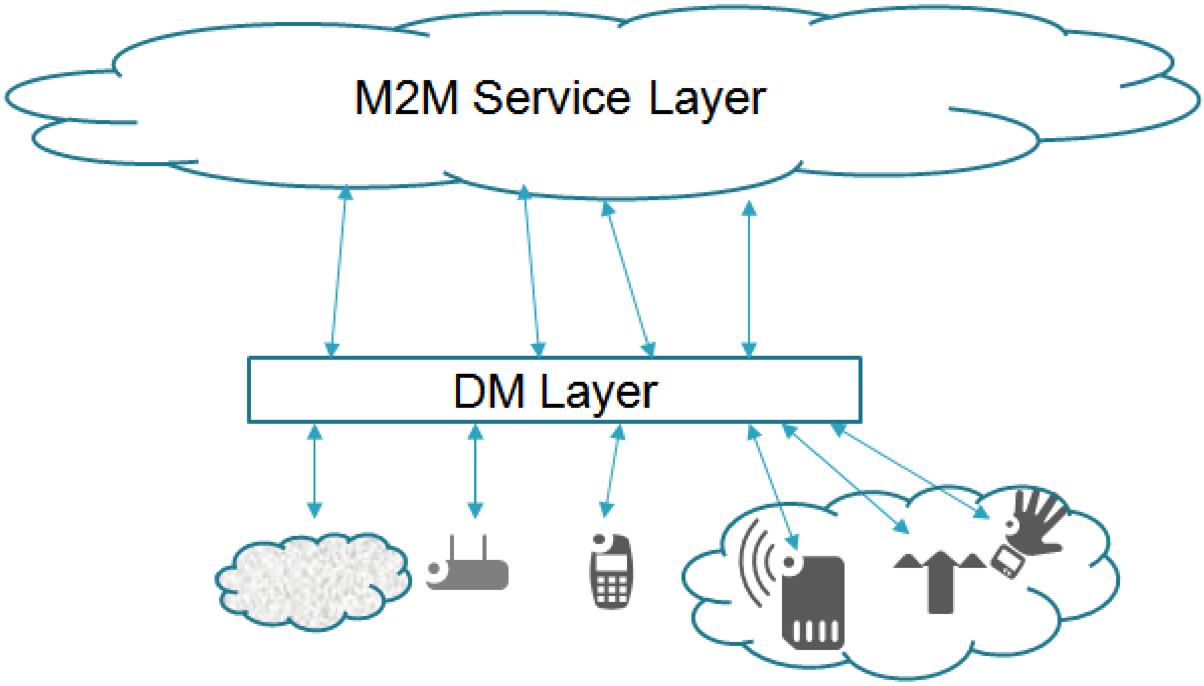

Figure 5.1. M2M end to end high level architecture.[20]

Enhanced Dedicated Core Networks (eDECOR)

As previously mentioned, 3GPP has introduced in Release 13 the concept of separate dedicated core networks (DCN), each DCN consisting of specialized MME(s), SGW(s) and PGW(s) designed to meet the requirements of these different devices in a costly efficient manner. In Release 14, 3GPP has enhanced this feature in order to eliminate the random DCN selection by the Radio Access Network (RAN), which could lead to selecting an inappropriate DCN that will then need to re-route the UE signaling towards an appropriate DCN. This has been achieved by enabling the Core Network to provide the UE with the PLMN-related DCN identity derived from the UE subscribed usage type at its first attachment to a VPLMN. The UE stores the DCN identity corresponding to the PLMN, and the UE provides that DCN identity to the network when it connects again to the PLMN, so that the RAN can use this information to route the UE signaling to an MME that can serve the UE. The UE may also be configured with Default DCN identity to eliminate potential re-routing of the signaling by the core network at the very first attachment to a PLMN. Per DCN load-balancing between MMEs of a pool of MMEs has also been specified.

Group Based Enhancements in the Network Capability Exposure Functions

The 3GPP system owns operational information on devices/subscribers and their service status that may be valuable for third parties to base applications upon and to enhance trouble shooting/customer care. Exposure of such 3GPP system internal information or services, denoted as 3GPP capability exposure, was defined in Release 13 using a new functional entity called SCEF (see the section for AESE). With the SCEF, the 3GPP capability exposure to third parties can be securely made. Release 13 also defined network capability exposure functions as part of work items including Monitoring Enhancements (MONTE).

[20] 3GPP TR 22.802 v14.0.0, “Study of need for multiple Access Point Names (APNs).

Except for the group message delivery function, all functions use per-UE network signaling. The per-UE network signaling gives significant burden to the 3GPP network and third parties using the SCEF, as the number of UEs, e.g. IoT devices, proliferates. Such burden can be reduced if these functions, other than group message delivery function, are enhanced in the viewpoint of group-based approach since IoT devices are expected to share a meaningful portion of their characteristics, which can be identified by, e.g. communication pattern, and group-based enhancements make very good sense in terms of practicability.

With the motivation described above, 3GPP investigated whether per-UE basis network capability exposure functions defined as part of MONTE work item can benefit from being performed based on a per-group basis. Protocols of interfaces among third party server, SCEF, and HSS are enhanced to enable group-based signaling.

New Band Support for Release 14 NB-IoT

In Release 14, NB-IoT support has been added to the following Bands:

- Bands 11 (Japan)
- 25 (US)
- 31 (SA and Europe)
- 70 (US)

New Services and Markets Technology Enablers

As part of Rel-14, 3GPP has undertaken numerous studies relevant to 5G. At the service requirements level, these studies include TR 22.891, *Feasibility Study on New Services and Markets Technology Enablers*, which includes over 70 use cases for new opportunities in the next generation of telecommunications systems. These use cases cover a range of new markets from the Internet of Things (IoT) to factory automation, drone control, vehicular communications and control, and tactile internet as well as new services, such as temporary service in a crisis, information caching and distribution, and device theft prevention and recovery. The study, which was completed May 2016, also addressed many system improvements, such as resource efficiencies, support for various access technologies, network slicing and network flexibility. Based on several industry white papers, the overarching objective defined a new system that can efficiently and effectively support multiple service dimensions. Figure 5.2 illustrates the proposed enhancements.

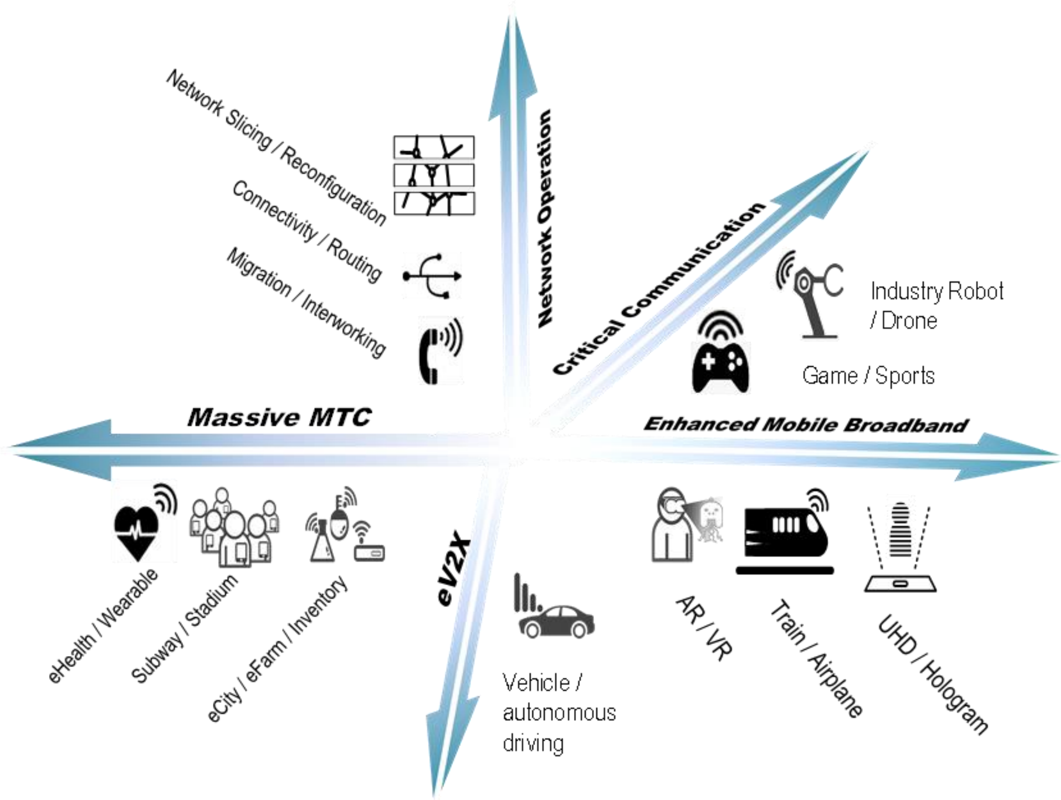

Figure 5.2. New Service Dimension.

These use cases were further developed in the following four secondary studies: TR 22.861, *Feasibility Study on Massive Internet of Things*, TR 22.862, *Feasibility Study on Critical Communications*, TR 22.863, *Feasibility Study on Enhanced Mobile Broadband*, and TR 22.864, *Feasibility Study on Network Operation*. These secondary studies, which were completed May 2016, became the basis for the Rel-15 normative requirements currently being captured in TS 22.261, Service requirements for next generation[21] new services and markets. These requirements are expected to complete March 2017. An additional study, TR 22.886, Study on 5G V2X Services, is ongoing and the expected normative requirements will also be included in the Rel-15 TS 22.261.

5.2 IOT IN 3GPP NEW RADIO (NR)

Expanding on Rel-13/14 IoT standards, 5G aims at refining the requirements and key performance indicators (KPIs) associated with key 5G IoT use cases[22] (see figure 5.3). Additional details will include such attributes as carrier frequency, aggregated system bandwidth, network layout / Inter-Site Distance (ISD), Base Station (BS) / UE antenna elements, UE distribution/speed, and service profiles.

- For Massive Machine-Type Communications (mMTC), 5G Forum desires to establish the KPIs for an urban coverage scenario with large cells with continuous and ubiquitous coverage. The target for connection density should be 1 000 000 device/km2 in urban environment

[21] 3GPP is developing a brand name for the next generation system. The title will be updated once 3GPP determines the name.
[22] 3GPP TR 38.913 V0.4.0 (2016-06) Technical Report - Study on Scenarios and Requirements for Next Generation Access Technologies.

- For Critical MTC use cases with Ultra-Reliable and Low Latency Communications (URLLC), detailed Specifications will help achieve the following KPIs:

    - Reliability: the baseline reliability is evaluated as the success probability of transmitting X bytes within 1 ms, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 Service Data Unit (SDU) ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a specified channel quality (e.g., coverage-edge). 5G specifications need to help achieve a success probability of $1\text{-}10^{-5}$ for X bytes (e.g., 20 bytes) with a user plane latency of 1ms

    - Latency: For 5G networks, the desired latency for user plane should not exceed 0.5 ms for UL and 0.5 ms for DL. Furthermore, if possible, the latency should be low enough to support the use of the 5G access as a wireless transport technology. To help the baseline, the eMBB requirement for user plane latency should be 4 ms for UL and 4 ms for DL

- For Enhanced Vehicle-to-Everything (eV2X) use case, 5G specification should meet the following KPIs while delivering a use plane packet of size [300 bytes]:
    - Reliability = $1\text{-}10^{-5}$, and user plane latency = [3-10 msec], for direct communication via sidelink and communication range of X meters
    - Reliability = $1\text{-}10^{-5}$, and user plane latency = [2] msec, when the packet is relayed via the BS

- Battery Savings and UICC power optimization for MTC: 5G will help determine if a new mechanism is needed for the UICC and will define requirements based on those findings. This will include recommendations on the optimum context specifically related to the duration of the power savings period; in addition, the recommendation will note any interaction with other mechanisms as well. For mMTC, UE battery life in extreme coverage shall be based on the activity of mobile originated data transfer consisting of 200bytes UL per day followed by 20 bytes DL from MCL of 164 dB, assuming a stored energy capacity of 5 Wh. Under these conditions, the target for UE battery life should be beyond 10 years; 15 years is desirable.

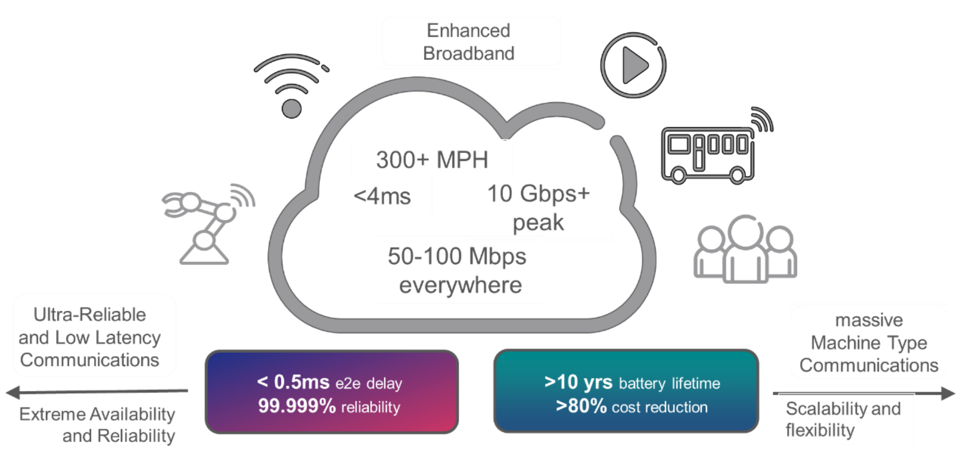

Figure 5.3. 5G Specifications for Key IoT Use Cases.

6. BENEFITS OF 3GPP IOTSOLUTIONS VS. NON-CELLULAR SOLUTIONS

While 3GPP has defined LTE-based solutions for IoT that will extend to future 5G technologies, there are a few other non-3GPP defined LPWA (Low Power Wide Area) IOT technologies. In this section, eMTC and NB-IoT technologies are compared to LoRa and SigFox, two representatives of non-3GPP LPWA IOT solutions.

The most notable difference is that eMTC and NB-IoT technologies are defined by 3GPP, the global standardization organizations supported by a mature global ecosystem. Other LWPA technologies are either defined by non-3GPP organizations or are proprietary and also lack the scale of the 3GPP ecosystem. The other key difference is that LTE IoT technology supports a wide range of high to low data rates with different mobility capability and therefore can address the wide range of IoT use cases. On the contrary, SigFox and LoRa support only very low data rates with very limited mobility that restricts their use cases.

Moreover, eMTC and NB-IoT leverage world-wide LTE network deployment that would enable ubiquitous coverage and save the cost of network operation. Non-3GPP technologies such as LoRa or SigFox require deployment and maintenance of a dedicated network that would add cost to the end users. NB-IoT also provides better link budget than SigFox or LoRa. Coupled with dense LTE network deployment, eMTC and NB-IoT would enable reach to IoT devices in remote locations.

LTE IoT technologies use licensed spectrum that includes existing LTE bands or re-farmed bands (e.g., GSM carriers). Licensed spectrum offers protection from other interference and ensures reliability and QoS. In addition, LTE operators can allocate spectrum resources matching the capacity need of its IoT services, which is efficient and scalable to support a large number of IoT users in a given area. SigFox or LoRa rely on unlicensed spectrum which is subjective to interference of other technologies in the same band. The unlicensed spectrum in the low band typically has limited bandwidth and potentially severe regulatory limitations on both Tx power and the duty cycle of its operation. For example, in Europe, SigFox and Lora use the unlicensed band of 863-870 MHz, which limits the device transmission power to 25mW (14dBm) and the duty cycle of channel access to 0.1 percent or 1 percent of channel time depending on the specific sub-band occupied; this is due to the fact that SigFox/LoRa do not support Listen-Before-Talk (LBT). As a result, there are often strict limits on the number of messages per day (e.g., SigFox allows only 4 downlink messages per day) and the total number of IoT devices in a given area can be limited by the capacity.

LTE IoT solutions use the end-to-end security mechanism defined by 3GPP that has been fully proven by billions of LTE users. SigFox does not provide end-to-end security, while LoRa relies on software-based encryption which is unproven.

Looking into the future, LTE IoT technologies have a clear evolution path, including Rel-14 enhancements and the path to Narrowband 5G for Massive IoT. The future evolution of non-3GPP LPWA technologies is unknown and uncertain.

As an example, Table 6.1 summarizes a comparison of 3GPP-based IoT solutions versus non-3GPP LPWA solutions using LoRa and SigFox.

Table 6.1. Comparison of 3GPP-Based Solutions vs. Non-Cellular Solutions.

	Rel-13 eMTC	Rel-13 NB-IoT	LoRa/SigFox
Standards	Defined by 3GPP – global standardization	Defined by 3GPP – global standardization	Non-3GPP. SigFox – proprietary, LoRa – LoRa Alliance
Eco-system	Mature global ecosystem	Mature global ecosystem	Regional profiles only in EU, US, China, Australia, South Korea
Deployment Scenario	LTE inband Reuses existing network	LTE inband, guardband, standalone. Reuses existing network	Standalone. New Network and possibly site acquisition required
Network	Leverage existing LTE deployment	Leverage existing LTE deployment	Requires deployment and maintenance of overlay networks
Bandwidth	1.4 MHz	200 KHz	LoRa: 125 - 500kHz SigFox: 100Hz
Spectrum	All existing Licensed LTE bands. Exclusive usage offers reliability	All existing Licensed LTE bands. Exclusive useage offers reliability	Both: unlicensed ISM band (902 – 928 MHz ISM in US; 863-870MHz in EU) Subject to interference from other unlicensed technologies and regulatory restrictions such as Tx power and duty cycles. For example, EU ISM band limits duty cycle of non-LBT devices to 0.1% or 1% depending on the specific sub-band occupied and max Tx power to 25mW (14dBm) (applicable for LoRa/SigFox)
Data rates	1Mbps/1Mbps (DL/UL)	~30/60 kbps (DL/UL)	Lora: 300 bps – 38.4 kbps

			Sigfox: DL 100 bps/UL 600 bps (300 baud)
Scalability	Scalable in terms of number of devices and messages/day	Scalable in terms of number of devices and messages/day	Limited messages per day (SigFox: 4*8bytes DL msg/day). Not a technical issue, but from a business perspective, current SigFox business model does limit the IoT use cases that SigFox can support
Coverage Target (Realistic Conditions)	>155.7dB Coverage benefits from ubiquitous LTE deployment	164dB (5dB better than GPRS baseline). Coverage benefits from ubiquitous LTE deployment	Depends on regulatory restrictions on radiated power in unlicensed spectrum SigFox claims: Urban: 1.86 to 6.2 miles; Semi-rural: 18.6 to 31 miles; low capacity LoS: 612 miles Reality: In sparse deployment, could be 20 to 50 dBs lower than Rel13 options LoRa claims up to 157dB[23]
UE Battery Life – 2AA 50 bytes/24 hours	10 years (2AA batteries) (Exact battery life depends on traffic pattern and coverage needs)	10 years (2AA batteries) (Exact battery life depends on traffic pattern and coverage needs)	Advertised under very low data rates: SigFox: 10 years Battery life (2AA); 20 years (2.5 Ah) LoRa: 5 years (1AA) or 10-20 years for industrial battery Reality under same assumptions: SigFox 3 - years; LoRa - 40 yrs.
Mobility	Supporting full to limited mobility	Limited mobility (cell reselection only)	Limited mobility. LoRa supports mobility and roaming.

[23] Source: https://www.loriot.io/lora-lorawan-loriot.html

Security	Full support for proven end-to-end security based on 3GPP and optional protection of application traffic using GBA to bootstrap application keys from access credentials	Full support for proven end-to-end security based on 3GPP	LoRa: SW based encryption including unique keys for network, device, and applications. Application credentials used to bootstrap access keys, ensuring application traffic always protected. SigFox: security by localizing data in SigFox BSS / OSS Cloud & SigFox Servers, no –end-to-end security
Geo-positioning	Optional	Not supported in Rel-13; being added in Rel 14	Optional
Evolution	Clear evolution path to beyond Rel-13 and 5G	Clear evolution path to beyond Rel-13 and 5G	Future evolution unknown

7. CONCLUSION

An industry transformation is underway, fueled by a myriad of global developments including the continuous expansion of internet connectivity, a high adoption of mobile devices and an exploding array of innovation initiatives. Such a transformation is a natural development in the process to materialize the vision that 'anything that can benefit from an internet connection will have one' and IoT is at the forefront of this transformation.

Enabling IoT is a multi-faceted endeavor requiring not only investments in technology and business innovation, but also cross-industry collaboration to ensure that the requirements for each IoT use case are defined in a realistic way for both mass-market and critical applications, and that complexities and challenges are dealt with through a cohesive approach. As anticipated, standards play a key role in IoT as they do in all networking, and 3GPP is doing its part to enable the evolution of the cellular networks and devices in support of the ever-growing ambitions of IoT.

This technical paper aims to illustrate the details behind how key objectives of IoT will be achieved with cellular connectivity, namely, reduction in device complexity and cost, extended coverage in support of deep-indoor and remote applications, deployment flexibility, high capacity, and long battery life. The new features and enhancements defined by 3GPP for connectivity of devices and sensors to the rest of the IoT stack are explained.

The 3GPP LTE radio access and power-saving technologies described in this paper (eMTC, NB-IoT, eDRX) address a vast array of IoT applications under the umbrella of Massive IoT, such as smart meters, remote sensors, smart buildings, asset/vehicle tracking, wearables, smart agriculture, industrial monitoring and control, etc. Cellular IoT connectivity takes advantage of the well-established LTE global ecosystem, leveraging the installed base of LTE base stations, EPC and OAM, as the features specified by 3GPP for IoT only require upgrades onto the already deployed infrastructure. Like present LTE networks, eMTC and NB-IoT support state-of-the-art 3GPP security, with authentication, signaling protection, and data encryption. Lastly, it is important to point out that by deploying IoT in spectrum that is governed by the well-established principles of LTE mobile broadband (licensed and unlicensed), capacity and coverage performance targets are ensured for the lifetime of the IoT devices.

In parallel with the development of radio-access features, 3GPP is also specifying how the overall LTE/EPC architecture needs to be enhanced to handle IoT efficiently, key among such enhancements being the selection of the core network and the exposure of 3GPP service capabilities to the API in a secure manner. Furthermore, 3GPP is already considering a number of features and continuous enhancements for LTE IoT under the umbrella of Release 14. In this context, it is expected that the types and number use cases addressable with cellular connectivity will continue to expand.

The industry agrees that 5G will be the technology of choice for applications that require very high capacity as well as very low latency. 5G networks, incorporating LTE access along with new air interfaces (also known as 5G NR), will offer the coverage, bandwidth (1gbps per user), and sub-1 ms latency needed to support the time-critical applications in emergency healthcare, traffic safety, remote manufacturing and control of critical infrastructure.

The first standard development of 5G radio access is currently underway, with target completion (of Phase 1) and initial system deployment targeted for 2018. As LTE continues to be an integral part of 5G radio networks well into the future, it is important to ensure that the IoT requirements and specifications continue to evolve for both LTE and NR radio access, in parallel, which is the roadmap for 3GPP. In this context, the ability to future-proof cellular technologies like eMTC and NB-IoT is a top priority.

Whether choosing the cellular technology track (with eMTC and NB-IoT) or other wide area technologies for IoT connectivity (e.g. LoRA, SigFox) depends on a matrix of factors, which ultimately boil down to time to market and present and future economics. The 5G Americas working group for this paper advocates that the cellular track offers compelling technological advantages that will continue to boost the ability of LTE infrastructure to address the massive IoT market well into the future, with 5G joining the IoT landscape before too long.

ACKNOWLEDGEMENT

The mission of 5G Americas is to advocate for and foster the advancement and full capabilities of LTE wireless technology and its evolution beyond to 5G throughout the ecosystem's networks, services, applications and wirelessly connected devices in the Americas. 5G Americas' Board of Governors members include América Móvil, AT&T, Cable & Wireless, Cisco, CommScope, Entel, Ericsson, HPE, Intel, Kathrein, Mitel, Nokia, Qualcomm, Sprint, T-Mobile US, Inc. and Telefónica.

5G Americas would like to recognize the significant project leadership and important contributions of project co-leaders Andreea Timberlake of Ericsson and Kai Tang of Qualcomm, Vicki Livingston of 5G Americas, as well as representatives from member companies on 5G Americas’ Board of Governors who participated in the development of this white paper.

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APPENDIX A: ACRONYM LIST

Abbreviation	Meaning
3GPP	Third Generation Partnership Project
5G PPP	Fifth Generation Public & Private Partnership
ACLR	Adjacent Channel Leakage Radio
ACS	Adjacent Channel Selectivity
AESE	Architecture Enhancements for Services Capability Exposure
AGCH	Access Grant Channel
API	Application Programming Interface
APN	Access Point Names
AS	Application Server
ATIS	Alliance for Telecommunications Industry Solutions
BCCH	Broadcast Control Channel
BPSK	Binary Phase Shift Keying
BW	Bandwidth
CA	Carrier Aggregation
CAPEX	Capital Expenditure
Cat -	Category
CDMA	Code Division Multiple Access
C-DRX	enhanced Connected Mode Discontinuous Reception
CE	Coverage Enhancement
CIoT	Cellular Internet of Things
CS	Circuit Switched
CSI	Channel State Information
CSP	Communication Service Providers
D2D	Device-to-Device
dB	Decibel
dBm	decibel-milliwatts

DCN	Dedicated Core Network
DECOR	Dedicated Core Network
DL	Downlink
EC	Extended Coverage (Channels)
E-CID	Enhanced-UTRAN Cell Identifier
eDRX	Extended Discontinuous Reception
EGPRS	Enhanced General Packet Radio Service
eMB	Enhanced Mobile Broadband
eMBMS	enhanced Multimedia Broadcast Multicast Service
eMTC	Enhanced Machine Type Communications
eNodeB	enhanced NodeB
EPDCCH	Enhanced Physical Downlink Control Channel
EPS	Enhanced Packet System
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
GERAN	GSM/EDGE Radio Access Network
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMA	GSM Association
GW	Gateway
HARQ	Hybrid Automatic transmission reQuest
HARQ-ACK	HARG Acknowledge
HD	High Definition
HD-FDD	Half-Duplex Frequency Division Duplex
HLCom	High Latency Communication
HSS	Home Subscriber Server
I-DRX	Idle mode Discontinuous Reception
IMEI	International Mobile Station Equipment Identity
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
ISD	Inter-site Distance
ITU	International Telecommunication Union

kHz	kiloHer
Km	Kilometer
KPI	Key Performance Index
LBT	Listen-Before-Talk
LPWA	Low Power Wide Area
LPWAN	Low-Power Wide-Area Networks
LTE	Long Term Evolution
LTE-A	LTE-Advanced
m	meters
M2M	Machine-to-Machine
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Service
MCL	Maximum Coupling Loss
ME	Mobile Entity
METIS-II	Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society - II
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
MONTE	Monitoring Enhancements
M-PDCCH	Physical Downlink Control Channel for MTC
ms	millisecond
MSISON	Mobile Subscriber Identity Self Organizer Network
MTC	Machine Type Communications
MTC_SIB	MTC Traffic Channel System Information Block
NAS	Non-Access Straturn
NB	Narrowband
NB-CIoT	Narrowband Cellular IoT
NB-IoT	Narrowband-IoT
NB-LTE	Narrowband-LTE
NIDD	Non-IP Data Delivery
NPDCCH	Narrowband PDCCH
NPDSCH	Narrowband Physical Downlink Shared Channel
NPRACH	Narrowband PRACH

OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Open Mobile Alliance
OPEX	Operating Expenses
OTA	Over The Air
OTDOA	Observed Time Difference of Arrival
PA	Power Amplifier
PACCH	Packet Associated Control Channel
PAPR	Peak-to-Average-Power-Ratio
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PDTCH	Pocket Data Traffic Channel
PGCH	Packet Grant Channel
PGW	Packet Data Network Gateway
PHICH	Physical Hybrid Automatic Retransmission Request Indicator Channel
PMCH	Physical Multicast Channel
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
P-RNTI	Paging – Radio Network Temporary Identifier
ProSe	Proximity Service
PRS	Positioning Reference Signals
PS	Packet Switched
PSM	Power Saving Mode
PSS	Primary Synchronization Signal
PTCCH	Pocket Timing Control Channel
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Radom Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology

RF	Radio Frequency
RI	Rank Indicator
RNTI	Radio Network Temporary Identifier
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
S4-SGSN	Serving GPRS Support Nodes
SCEF	Services Capability Exposure Function
SCFDMA	Single-Carrier Frequency Division Multiple Access
SCH	Shared Channel
SC-PTM	Single Cell Point-to-Multipoint
SDN	Software-Defined Networking
SGW	Serving Gateway
SIB	System Information Block
SINR	Signal to Interference plus Noise Ratio
SIP / TEL URI	Session Initiation Protocol / Telephone Uniform Resource Identifier
SI-RNTI	System Information – Radio Network Temporary Identifier
SLA	Service Level Agreement
SRD	Short Range Devices
SRTP	Secure Real-Time Transport Protocol
SSS	Secondary Synchronization Signal
TA	Timing Advance
TAU	Tracking Area Update
TB	Transport Block
TBCC	Tail Biting Convolutional Code
TBS	Transport Block Size
TM	Transmission Mode
TR #	Technical Report #
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
URLLC	Ultra Reliable Low Latency Communications
USIM	Universal Subscriber Identity Module

UTDOA	Uplink Time Difference of Arrival
VoLTE	Voice over LTE
VPLMN	Visited Public Land Mobile Network
Wh	Watt-hour
WWAN	Wireless Wide Area Network