



LTE PROGRESS LEADING TO THE 5G MASSIVE INTERNET OF THINGS

December 2017

3GPP Enhancements Up To Release 14

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EXECUTIVE SUMMARY

Internet of Things (IoT) is an evolution from Machine-to-Machine (M2M), with the latter being a rudimentary form of connecting machines for simple tasks such as starting a vehicle remotely. IoT consists of a wide range of use cases, some of which can be fairly complicated. It is widely believed that IoT will be a key business driver for telecommunication service providers and enterprises in the coming years. More recently, the industry has created the term Massive IoT (MIoT), referring to the connection for a large number of devices and machines (potentially on the order of tens of billions) on a regular basis. Alternatively, other IoT applications which require high availability, coverage, and low latency can be categorized under Critical IoT and could be enabled by LTE or 5G. Yet a third group might be defined as 'enterprise applications' which need moderate bitrate, mobility support and use devices smarter than basic connected sensors.

With the evolution of M2M to IoT, different types of connectivity are involved. In addition to connecting more devices or machines, new value is being created by the data generated, for example through big data analytics.

According to a study by McKinsey, IoT has a total potential economic impact of up to \$11 trillion by 2025.¹ It covers numerous business opportunities, which can be classified in multiple ways. Some consider five key verticals of adoption: Connected Wearables, Connected Cars, Connected Homes, Connected Cities, and the Industrial IoT.

For enterprises, their interest in IoT is driven by multiple forces:

- Cost Savings
- Process Optimization
- Revenue Generation
- Customer Experience

On the other hand, operators have different reasons to consider IoT:

- Generation of new revenue (for example, connected cars)
- Protect existing revenue (for example, smart home solutions as a complement of existing broadband businesses)
- Providing platforms for vertical markets, especially where connectivity revenue might be low

In addition, communications service providers can now offer solutions and services to enterprises and help them benefit from mobility, cloud and IoT applications.

Forecasts show that IoT market will grow by several orders of magnitude. With a disruptive estimate, the total number of IoT devices will reach 48 billion, of which 4.6 billion will be cellular IoT devices, by the year 2020.² These represent multipliers of 41x and 28x respectively when compared to the numbers in 2014.³ These connected IoT devices include connected cars, machines, sensors, point-of-sales terminals, consumer electronics and wearables.

IoT can be divided into short-range and wide-area segments. The former is typically enabled by unlicensed radio technologies, such as Wi-Fi, Bluetooth and ZigBee. The latter consists of devices powered by cellular technologies as well as unlicensed low-power technologies, such as Sigfox, and LoRA. Although cellular

¹ *Unlocking the Potential of the Internet of Things*, McKinsey Global Institute report, June 2016.

² *Who Will Satisfy the Desire to Consumer?* Bell Labs Consulting, Nokia, 2016.

³ *Who Will Satisfy the Desire to Consumer?* Bell Labs Consulting, Nokia, 2016.

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IoT represents a small percentage of the connected devices in 2017, it is expected to grow to around 70 percent of the wide-area category by 2022.

Among the wireless technologies used for IoT, there is no single dominant technology today. However, while proprietary LPWA technologies such as Sigfox and LoRA are gaining attention, cellular-based technologies such as NB-IoT will become the dominant standard by 2020.

As the growth of IoT continues, IoT devices may surpass mobile phones and become the largest category of connected devices. Some service providers in the U.S. are already adding more IoT connections than mobile phone connections.

Along with the advancement of technologies applicable to IoT come new opportunities for traditional communication infrastructure vendors and industry-specific innovators. A wide range of services will utilize IoT. Many of such services will require deep indoor coverage. New Low-Power Wide-Area (LPWA) cellular technologies, LTE-Machine (LTE-M) and Narrowband IoT (NB-IoT) can overcome the coverage challenge.

Operators can choose from several cellular IoT technologies based on their spectrum portfolio, existing networks, and requirements of their offered services. Operators can use connectivity as a differentiator when they offer IoT services since many other companies competing in the IoT area offer no connectivity.

LTE-M is the commercial term for LTE-MTC LPWA technology published in the 3GPP Release 13 specification. Another cellular IoT technology, Narrowband IoT or NB-IoT, was also published in the 3GPP Release 13 specification. Both technologies will continue to evolve in subsequent releases. They are supported by all major mobile infrastructure, chipset and module manufacturers and can co-exist with 2G, 3G, and 4G cellular networks. As they are 3GPP-standardized and run on licensed spectrum, they offer clear advantages, such as carrier-grade security, over non-cellular IoT technologies. Commercial launch of these technologies will begin globally in 2017-2018.

The U.S. is one of the largest and most advanced IoT markets in the world. AT&T launched LTE-M services in the U.S. at mid-2017, and will launch in Mexico by the end of 2017. T-Mobile U.S. CTO Neville Ray also said the operator will deploy NB-IoT and LTE-M. Sprint has already launched a nationwide LTE Cat-1 network and is anticipating an upgrade to LTE-M in mid-2018, followed by the launch of NB-IoT.

Aside from devices, IoT platform is another important part of the IoT landscape. According to Research and Markets, the global IoT platform market will grow at a CAGR of 31.79 percent from 2017 to 2021.⁴ The large number of active IoT devices collect data through sensors and actuators and transmit the back to a centralized location. The IoT platform empowers the end-user to make informed decisions using the data. Together with design innovations in 5G architectures, cloud-native edge computing platforms ensure Industrial IoT (IIoT) applications can be run in a cost-effective manner.

Due to its importance, many companies are developing their IoT platforms. The U.S. is in a leader position in this market. However, interoperability among the different IoT platforms could become a problem. McKinsey estimates that interoperability accounts for almost 40 percent of the value potential from the IoT applications.⁵ One solution to this challenge is to have a global IoT platform standard, such as oneM2M, which unifies the global IoT community. Many global organizations and alliances are contributing to this effort. Among these organizations and alliances, oneM2M stands out as a unifying standard and can be seen as a "standard of standards". It was formed in 2012 and consists of eight of the world's preeminent standards development organizations (SDOs). The oneM2M industry standard is designed to be industry-

⁴ [Global IoT Platform Market 2017-2021](#)", report by Research and Markets. 30 May 2017.

⁵ *The Internet of Things: Mapping the Value beyond the Hype*, McKinsey. June 2015.

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vertical and vendor-agnostic. It enables connection and information exchange between heterogeneous IoT devices and IoT applications.

The generic requirements for IoT are low cost, energy efficiency, ubiquitous coverage, and scalability (ability to support a large number of connected machines in a network). To legacy operators, IoT services should ideally be able to leverage their existing infrastructure and co-exist with other services. In the 3GPP Release 13 standard, eMTC and NB-IoT were introduced. These technologies met the above generic IoT requirements. They support in-band or guard band operations. Device cost and complexity are reduced. A large quantity of IoT devices can be supported in a network. Battery life is extended. Many of the related features were covered in the 5G Americas whitepaper, *LTE and 5G Technologies Enabling the Internet of Things*.

With Release 13 eMTC and NB-IoT as a basis, enhanced mobility and Voice-over-LTE (VoLTE) are added in Release 14. In addition, broadcast and positioning are introduced.

When IoT is applied to verticals, there will be additional requirements specific to each vertical. The vast number of verticals also means there will be numerous different requirements. Some examples of such requirements are:

- Identity/security needs
- Ease of installation
- Mobility
- Reliability
- Possible sector regulations
- Analytics and charging needs

An enterprise with a strong desire for security of its data may prefer to have a private network for its IoT needs. Such a network can leverage LTE but will operate separately from operators' public cellular networks. In some cases, operators may still deploy and operate such private networks as a service to the enterprises either with unutilized licensed spectrum or unlicensed spectrum. For enterprises that want their private networks, the main requirements are:

- Independence from the public cellular network
- Dedicated and secure network equipment in the enterprise's premise
- Quality of Service (QoS) control for different equipment
- High degree of reliability

In 3GPP, IoT device categories include Cat-1, Cat-M1 and Cat-Narrowband 1 (NB1). There were multiple enhancements related to IoT made to the 3GPP standards since June 2016. Some of these enhancements extend coverage for GSM-IoT. Release 13 Extended Discontinuous Reception (eDRX) helps reduce power consumption for IoT devices. A number of enhancements in Release 13 also apply to network architecture.

Release 14 comes with enhancements to eMTC and NB-IoT that were completed in June 2017. Updates in Release 14 for eMTC include:

- Improved positioning capabilities
- Enhanced Multicast Downlink (DL) transmission
- Mobility enhancements
- Support of higher data rates, and
- VoLTE enhancements

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Updates in Release 14 for NB-IoT, many of which similar to those for enhanced Machine-Type Communications (eMTC) include:

- Improved positioning capabilities
- Enhanced Multicast DL transmission
- New band and power class support
- Mobility enhancements
- Support of higher data rates, and
- Non-anchor Physical Resource Block (PRB) enhancements

As in Release 13, there are also enhancements to the core network introduced in Release 14 to align with Radio Access Network (RAN) enhancements and to better support third party and group-based communications.

Besides LTE-Machine-Type Communications (MTC) and NB-IoT, there are other features in the LTE standard, not originally designed to be used for IoT, such as Device-to-Device (D2D), Vehicle-to-Vehicle (V2V) Charging, and Device Management which can also apply to general IoT now.

Entities that want to have their own private networks generally do not have their own spectrum. As they resort to unlicensed or shared spectrum, they still want to use a technology that offers performance and reliability similar to today's cellular technologies. MulteFire is an LTE-based cellular technology that can operate exclusively in unlicensed or shared spectrum. Interworking between MulteFire and wide-area LTE networks can be easily supported if needed. The first MulteFire standard (Release 1.0) was completed in January 2017 by the MulteFire Alliance. It leverages elements of License Assisted Access (LAA) and eLAA from 3GPP for DL and uplink (UL) respectively. The next release of MulteFire (1.1) will include enhancements targeted for IoT.

1. INTRODUCTION

The market for connected things continues to expand at an exponential rate. What started with the Machine-to-Machine (M2M) technology supporting capabilities such as smart cameras for home security and smart keys to find and start vehicles remotely has quickly burgeoned into the Internet of Things in which more and more things are designed with an interface to the internet. Many manufacturers have been quick to take advantage of this connectivity, a few examples follow. Parking apps in many cities allow drivers to find available parking and even negotiate a rate. Home health care devices have expanded beyond simple step trackers to connected scales, sleep management bedding, and monitors that automatically report changes in vitals to your doctor. Automated and connected cars are a growing industry, with self-driving vehicles being tested in cities around the globe, and automated safety features are rapidly becoming standard features in new automobiles and trucks. Even kitchen appliances come with internet connectivity, such as a smart refrigerator that keeps track of inventory and builds a shopping list as products are consumed. This list can be sent to a preferred store for easy pickup or delivery.

Current projections suggest the IoT industry to have a market value in the tens of trillions of dollars in the next ten years. As the communications network continues to improve and provide new capabilities, new markets will continue to develop and expand. This is already happening within the markets for wearables, connected cars, connected homes, and connected cities. The markets for industrial use in transportation, inventory management, factory automation is identifying new requirements to make better use of IoT. These new requirements will address cost savings, process optimization, and revenue generation, while also looking at opportunities for data analysis to improve customer experience based on the sheer number and diversity of connected devices. As this market grows, cellular network operators are positioning to provide

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not only increased support for connectivity but also enhanced services and support for vertical industries making use of IoT technologies.

With demand for connected devices increasing, and new devices being designed with connectivity in mind, the Third Generation Partnership Project (3GPP), the global industry body that creates the wireless cellular standards such as for Long Term Evolution (LTE), continues to introduce new capabilities to better support the Internet of Things. These capabilities include support for increased bandwidth, higher data rates, longer battery life, higher positioning accuracy, lower latency and increased support for third party applications and services. In addition to supporting these enhanced capabilities, the system architecture has been designed to offer greater flexibility. While some IoT service needs require high reliability and low latency, others put an emphasis on long battery life with a higher tolerance for longer latency. As IoT devices and services continue to grow, offering customizable services that meet the different requirements for specific applications becomes imperative.

3GPP Release 13 introduced enhanced Machine-Type Communications (eMTC) for Category-M1 (Cat-M1) devices and Narrowband-IoT (NB-IoT) for low end IoT devices, along with several network capabilities that together provided support for a wide variety of IoT services over LTE⁶. Release 14 focuses on enhancements in a few key areas, such as: providing better location accuracy using Observed Time Difference of Arrival (OTDOA) for both eMTC and NB-IoT; making use of multiple Positioning Reference Signals (PRFs), PRF signal hopping, dense PRS configurations, and other enhancements; providing User Equipment (UEs) with improved positioning accuracy and resource usage efficiencies; and multicast downlink (DL) transmission which send data to multiple UEs more efficiently than using individual unicast links for each UE. Data rates have been enhanced for both uplink and downlink transmissions in Release 14, providing both resource efficiencies and increased throughput for IoT device communications.

In addition to the key feature sets, Release 14 focuses on several key IoT markets, specifically connected vehicles and wearables. Both of these markets make use of the Proximity Services initially provided in Release 12. Enhancements for the IoT markets included the introduction of a relay capability that allows an IoT device that is itself not able to communicate to the mobile network to establish a relay connection through another device, such as a smartphone, that has a network connection. In a connected vehicle service, this relay capability expands the range of the inter-vehicular communication, increasing accuracy of information as well as safety. With respect to wearables, the relay capability allows, for example, a smart watch to use a lower power connection to a smart phone, saving energy while keeping the wearer online. Another enhancement to support connected vehicles is the use of a layer 2 interface for Proximity Services, which supports higher speeds, better positioning accuracy, and lower latencies, improving end users' quality of experience.

With these enhancements, Release 14 brings the LTE-based IoT technology closer to the objectives laid out for 5G Systems. Better support is provided for the number and variety of IoT devices being introduced into the marketplace, allowing operators to continue to take advantage of all that LTE has to offer as they begin to look to the future of IoT with 5G.

As industries find new uses for connected devices, they are also looking for new ways to support communications among those devices. A growing trend is in private networks, particularly for industrial use cases. For example, as factories increase the use of robotics, they are looking to private networks to provide the intra-factory communications in a secure manner isolated from the public network. At the same time, these entities are not likely to own their own spectrum, so they need to use either unlicensed spectrum,

⁶ *Wireless Technology Evolution Towards 5G: 3GPP Release 13 to Release 15 and Beyond*, 5G Americas whitepaper. February 2017.

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non-3GPP radio technology, or coordinate with a local mobile network operator to share spectrum while operating their own core network. One enabling technology that makes use of LTE-based technology is MulteFire, which is being enhanced to support the IoT capabilities provided in 3GPP Release 14.

This white paper builds upon earlier publications by 5G Americas, including *LTE and 5G Technologies Enabling the Internet of Things* published in December 2016⁷. It provides detailed explanations of the features and benefits of cellular technologies for the Internet of Things.

2. IOT MARKET DRIVERS

A majority 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. Whereas 4G has been driven by device proliferation, bandwidth hungry mobile services, and dynamic information access, 5G will also be driven by IoT applications. There will be a wide range of IoT use cases in the future, and the market is now expanding toward both Massive IoT (MIoT) deployment as well as more advanced solutions that may be categorized as Critical IoT, as shown in Figure 2.1.

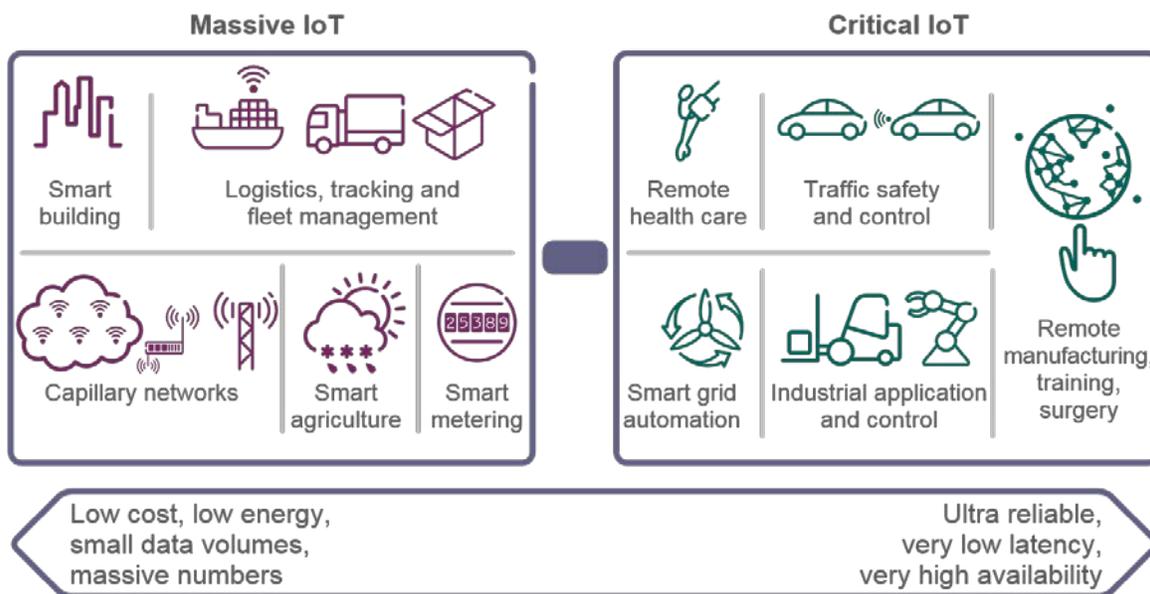


Figure 2.1. Differing Requirements for Massive and Critical IoT Applications.⁸

Massive IoT refers to the tens of billions of devices, objects, and machines that require ubiquitous connectivity even in the most remote locations, like sensors buried deep in the ground, and that report their sensing data to the cloud on a regular basis. To reach massive scale, which is defined by 3GPP as at least 1 million devices per kilometer,⁹ mobile networks must more efficiently support the simplest devices that communicate infrequently, and are ultra-energy efficient so they can deliver an extremely long ten-year battery life. The requirement would be for low-cost devices with low energy consumption and good coverage.

⁷ [LTE and 5G Technologies Enabling the Internet of Things](#), 5G Americas white paper. December 2016.

⁸ [Cellular Networks for Massive IOT](#), Ericsson white paper. January 2016.

⁹ [Leading the LTE IoT evolution to connect the massive Internet of Things](#), Qualcomm white paper, June 2017.

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Alternatively, Critical IoT applications will have very high demands for reliability, availability, and low latency which could be enabled by LTE or 5G capabilities. The volumes would be much smaller, but the business value is significantly higher. There are also many other use cases between the two extremes, which today rely on 2G, 3G or 4G connectivity.

The main questions asked by industry participants in the early stages of considering entering the field of M2M and IoT are the following: What are the key market drivers for IoT? How will we realize the 5G vision of connecting the Massive IoT and Critical IoT 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 2.2.

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.

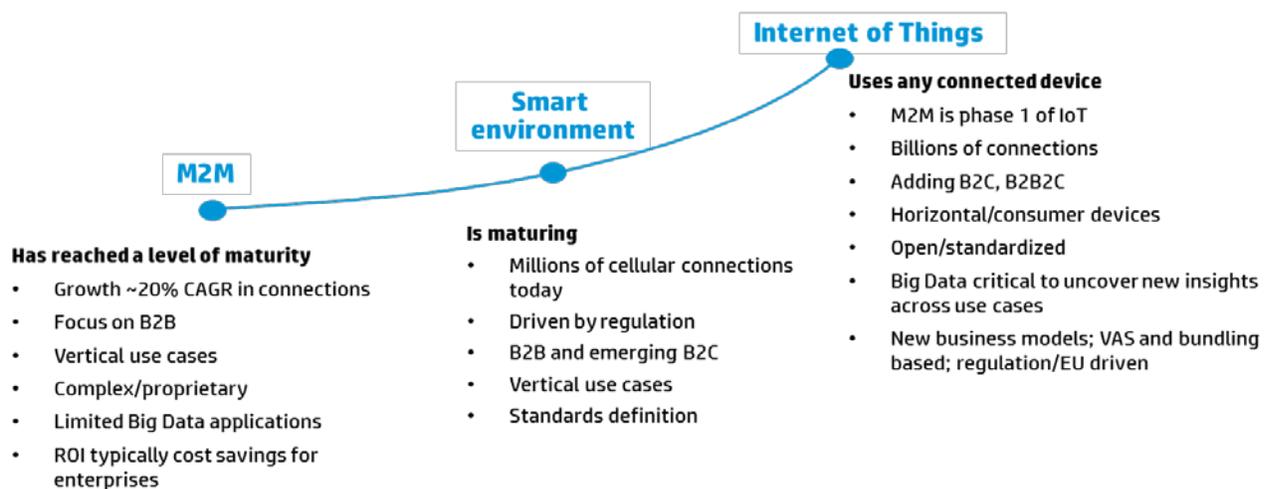


Figure 2.2. M2M to IoT Evolution.¹⁰

There is an essential difference between M2M and IoT that is fueled by the convergence of M2M communications and big data analytics: how the data is generated by all these devices and how it is used to create value. Today, we are basically still in an M2M era, with connected devices and communication technologies taking a foreground role, but things are moving fast, and IoT and big data-enabled digital transformation is happening in many places.¹¹

It must be recognized that the IoT will encompass different types of connectivity, and the access required will depend on the nature of the applications. Many IoT devices will be served by radio technologies that operate on unlicensed spectrum, that are designed for short-range connectivity with limited Quality of Service (QoS) and security requirements, or that are mainly applicable in a home or indoor environment.

There are two large IoT use case groups:

¹⁰ *M2M insights for mobile operators*, Analysis Mason, March 2013.

¹¹ *With enterprise IoT, the best is yet to come*, ReadWrite, April 2016.

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Critical use cases, for example public safety applications, have very demanding network requirements:

- Low latency
- High reliability and availability

Massive use cases, for example, smart metering, have different network requirements and highly commercial needs:

- While reliability and availability might be more or less important, extended coverage is often a must and long latency is not problematic
- Infrequent, mainly downlink, and small data packages
- Devices need to be inexpensive (i.e. simple modules)
- Device battery must last many years

A third group might be defined as 'enterprise applications':

- They might need moderate bitrate, support for mobility or even potentially include Voice-over-LTE (VoLTE)
- They use smarter devices than just connected sensors (for example Personal Digital Assistants and insurance telematics) but these must be fairly inexpensive and have a long battery life

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 concrete needs from different stakeholders are taking shape. This is the key reason for the emerging Third Generation Partnership Project (3GPP) standards – Narrowband-IoT (NB-IoT), LTE-Machine (LTE-M), Extended Coverage - GSM (EC-GSM) – in low power wide area networks (LPWAN).

Globally, M2M connections will grow from 780 million in 2016 to 3.3 billion by 2021, a 34-percent Compounded Annual Growth Rate (CAGR) and a fourfold growth in the evolution from 2G to 3G to 4G, as shown in Figure 2.3.



Figure 2.3. Global M2M Growth and Migration from 2G to 3G and 4G+. ¹²

¹² *Visual Networking Index*, Cisco, March 2017.

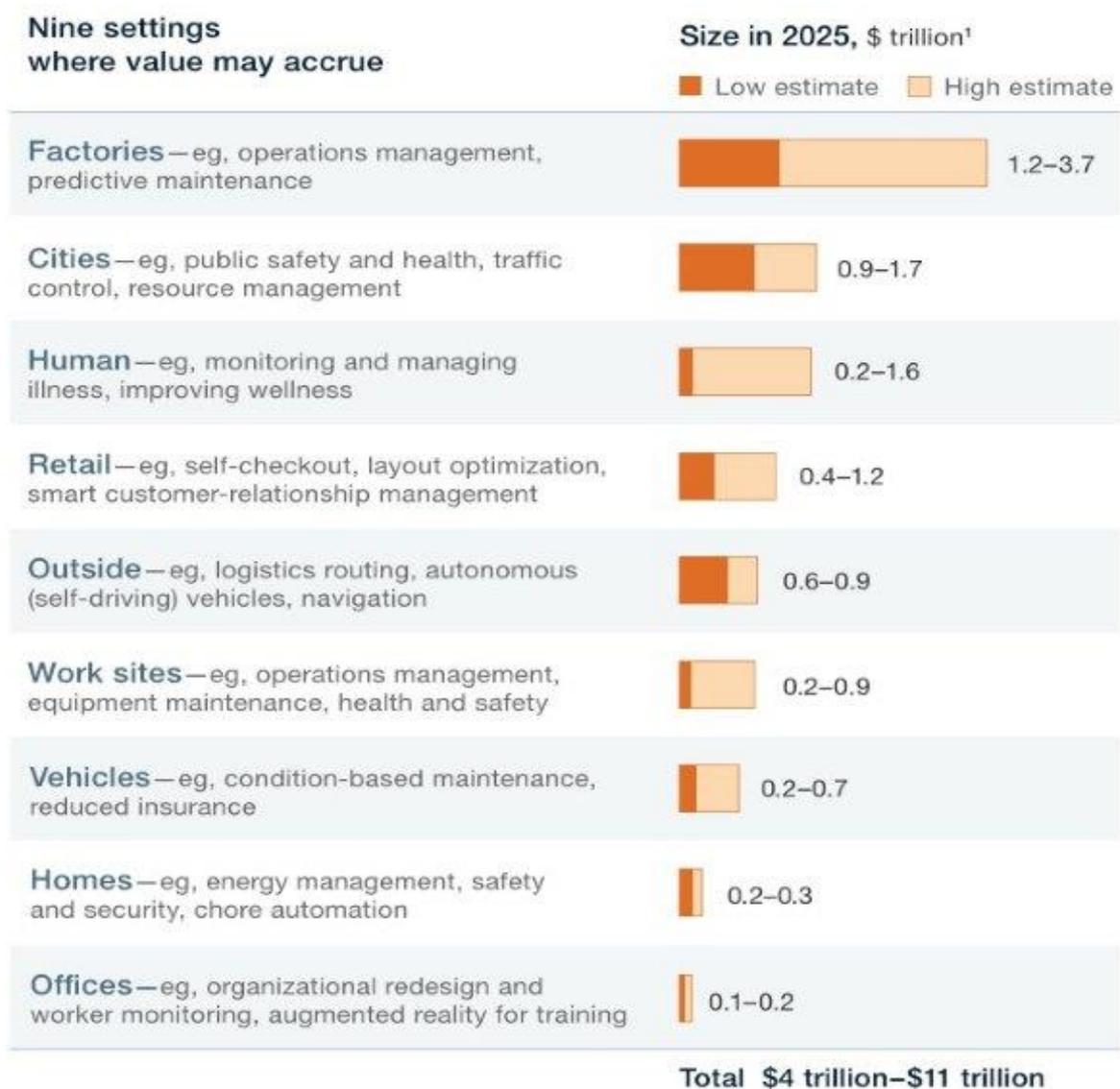
2.2 KEY IOT MARKET DRIVERS

Transformation to the age of digitization, to the IoT revolution, to the programmable world vision, or the connected world or even the networked society – these are just some of the visionary names by leading companies in the wireless industry to describe our future networks and applications. Regardless of the name, the IoT revolution offers huge potential value in terms of improved efficiency, sustainability and safety for industry and society.

According to McKinsey, the IoT has a total potential economic impact of \$3.9 trillion to \$11.1 trillion a year by 2025. At the top end, that level of value—including the consumer surplus—would be equivalent to about 11 percent of the world economy as shown in Figure 2.4.¹³

¹³ *Unlocking the Potential of the Internet of Things*, McKinsey Global Institute report, June 2016.

The Internet of Things offers a potential economic impact of \$4 trillion to \$11 trillion a year in 2025.



¹Adjusted to 2015 dollars; for sized applications only; includes consumer surplus. Numbers do not sum to total, because of rounding.

McKinsey&Company | Source: McKinsey Global Institute analysis

Figure 2.4. Economic Impact of IoT in 2025.¹⁴

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

¹⁴ *Unlocking the Potential of the Internet of Things*, McKinsey Global Institute report, June 2016.

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considerations. Some consider five key verticals of adoption: Connected Wearable Devices, Connected Cars, Connected Homes, Connected Cities, and the Industrial IoT.

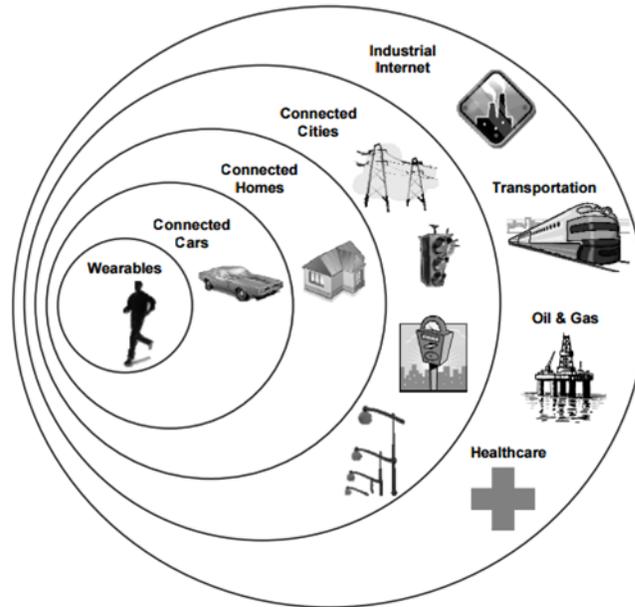


Figure 2.5. Key Verticals for the IoT.¹⁵

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 different 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 kWh annually across multiple data centers by deploying hundreds of sensors and control points throughout the data center, connected wirelessly.
- **Process Optimization** – Although in sectors like, for example, manufacturing and logistics, M2M-based ‘command and control’ applications have been used for years, the IoT brings even more transparency, traceability, and flexibility to industrial processes. The outcomes of big data analytics will help to save costs, increase quality, and raise productivity.
- **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 WiFi 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 2023,¹⁶ while Gartner forecasts revenues from connected car services to top \$42 billion by 2022.¹⁷

¹⁵ Goldman Sachs Global Investment Research, September 3, 2014.

¹⁶ Analysys Mason’s *Internet of Things and Machine to Machine Predictions 2016*, January 2016.

¹⁷ *Market Trends*, Gartner. August 2016.

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- **Customer Experience** – Many companies start using the Internet of Things to create experiences that benefit both the brand and its customers. The IoT and the data from connected devices are transforming the way they interact with their customers, by giving data-driven insights in end-user behavior, supporting real-time interaction with service desks and contact centers, refining marketing and National Provider Identifier (NPI) processes, providing predictive and proactive product maintenance, and providing more personalized service and products.

There are three key areas that will enable the IoT market as a business driver for operators. According to research analysts Analysys Mason¹⁸:

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.*

On top of these, communications service providers have an unprecedented opportunity to extend their offering of solutions and services to enterprises, as many of their business customers are looking for a technology and service partner to help them digitally transform, and benefit from mobility, cloud and IoT applications.

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

2.3 IoT CONNECTIVITY MARKET FORECAST

By all accounts the number of devices connected to the world's fixed and mobile networks through 2020 will grow by several orders of magnitude, dominated by the continuous introduction of connected things in a wide range of application environments. Figure 2.6 shows a conservative estimate in which the multiplier of the total number of devices is 12x in total and a disruptive estimate in which the total is 28x the number connected in 2014.¹⁹

The total number of IoT connected devices (not including wearables) is expected to grow from 1.6 billion in 2014 to anywhere between 20 billion (conservative view) and 46 billion (disruptive view) by 2020. Of this total, cellular IoT devices will be between 1.6 billion and 4.6 billion in 2020.²⁰

¹⁸ Analysys Mason's *Internet of Things and Machine to Machine Predictions 2016*, January 2016.

¹⁹ *Who Will Satisfy the Desire to Consumer?* Bell Labs Consulting, Nokia, 2016.

²⁰ *Who Will Satisfy the Desire to Consumer?* Bell Labs Consulting, Nokia, 2016.

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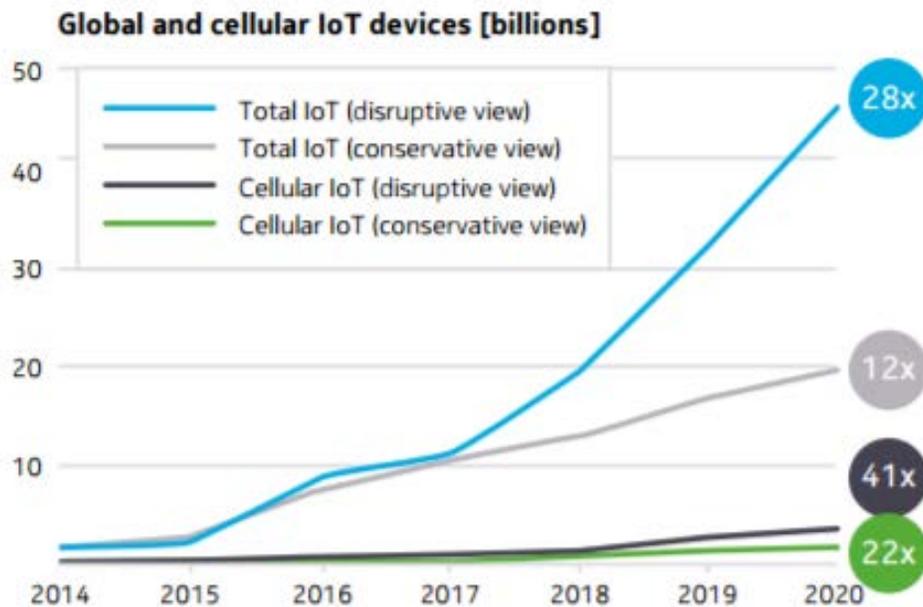


Figure 2.6. Cellular and Total IoT Devices Globally, 2014-2020.

A leading industry research firm, Gartner, forecasts that by 2020, the installed base of IoT endpoints will reach 20.4 billion units and is projected to grow at 32.9% compound annual growth rate (CAGR).²¹

IoT communications is clearly set for aggressive growth in the foreseeable future. Around 29 billion connected devices are forecast by 2022, of which around 18 billion will be related to IoT.²² Connected IoT devices include connected cars, machines, meters, sensors, point-of-sales terminals, consumer electronics and wearables. Between 2016 and 2022, IoT devices are expected to increase at a CAGR of 21 percent, driven by new use cases and business models, and supported by falling device costs.²³

In Figure 2.6, IoT is divided into short-range and wide-area segments. The short-range segment largely consists of devices connected by unlicensed radio technologies, with a typical range of up to 100 meters, such as WiFi, Bluetooth and ZigBee. This category also includes devices connected over fixed-line local area networks and powerline technologies. The wide-area segment consists of devices using cellular connections, as well as unlicensed low-power technologies, such as Sigfox, LoRa (Long Range) and Packet Reservation Multiple Access (PRMA). GSM/GPRS is the dominant technology in this segment.²⁴

²¹ *Internet of Things — Endpoints and Associated Services, Worldwide, Forecast by Gartner, 2016.*

²² *Ericsson Mobility Report, June 2017.*

²³ *Ericsson Mobility Report, June 2017.*

²⁴ *Ericsson Mobility Report, June 2017.*

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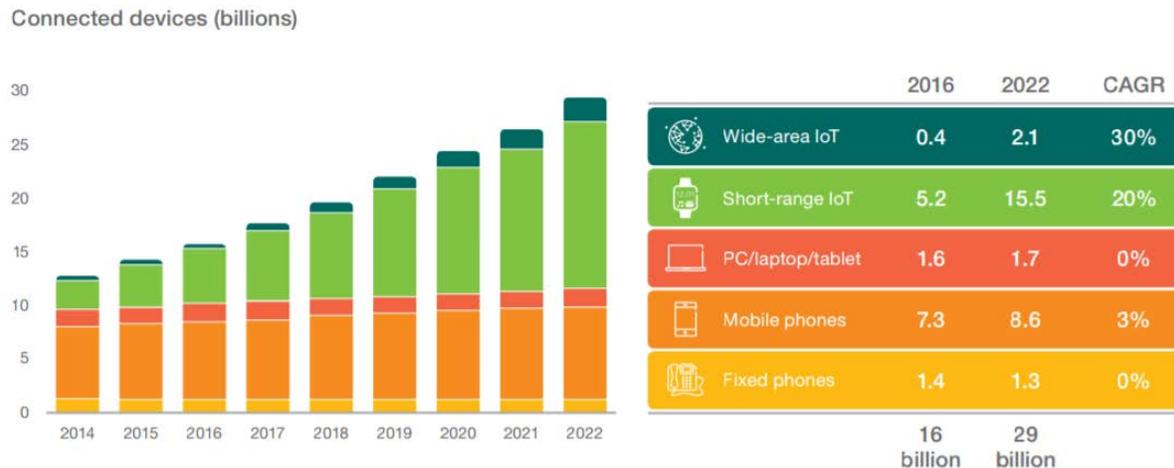


Figure 2.7. Global Connected Devices.²⁵

At the end of 2016, there were approximately 0.4 billion IoT devices with cellular connections as shown in Figure 2.7. Due to increased industry focus and 3GPP standardization of cellular IoT technologies, this number is projected to reach 1.5 billion in 2022, or around 70 percent of the wide-area category, according to another leading industry source.²⁶

Within the wide-area IoT segment, two distinct sub-segments with different requirements have emerged as were previously described: massive and critical applications. Massive IoT connections are characterized by high connection volumes and small data traffic volumes, low-cost devices and low energy consumption. Many things will be connected through capillary networks. Critical IoT connections place very different demands on the network: ultra-reliability, availability, low latency and high data throughput. Declining modem costs, evolving LTE functionality and 5G capabilities are all expected to extend the range of applications for critical IoT deployments. However, many use cases exist between these two extremes, which today rely on 2G, 3G or 4G connectivity.

Network connectivity is essential for the Internet of Things (IoT) and there are many wireless access technologies currently in use but given the wide variety of use cases, environments and requirements, no single connectivity technology and standard can adequately serve all use cases.

While Proprietary LPWA technologies, using protocols like Sigfox and LoRa, are gaining market attention, 3GPP-supported cellular-based NB-IoT is catching up and by 2020, narrowband Internet of Things (NB-IoT) will become the dominant standard for low-power, wide-area (LPWA) networks, from new entrant standard in 2016.²⁷ NB-IoT is streamlined for ultra-low throughput applications and is deployed on LTE networks.

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 2.8 illustrates the tremendous growth of cellular M2M connections as well as the percentage that cellular IoT represents in the total IoT market.²⁸

²⁵ Ericsson Mobility Report, June 2017.

²⁶ Ericsson Mobility Report, June 2017.

²⁷ IoT Communications Architecture Demystified, Gartner, August 2016.

²⁸ Ericsson Mobility Report, November 2016.

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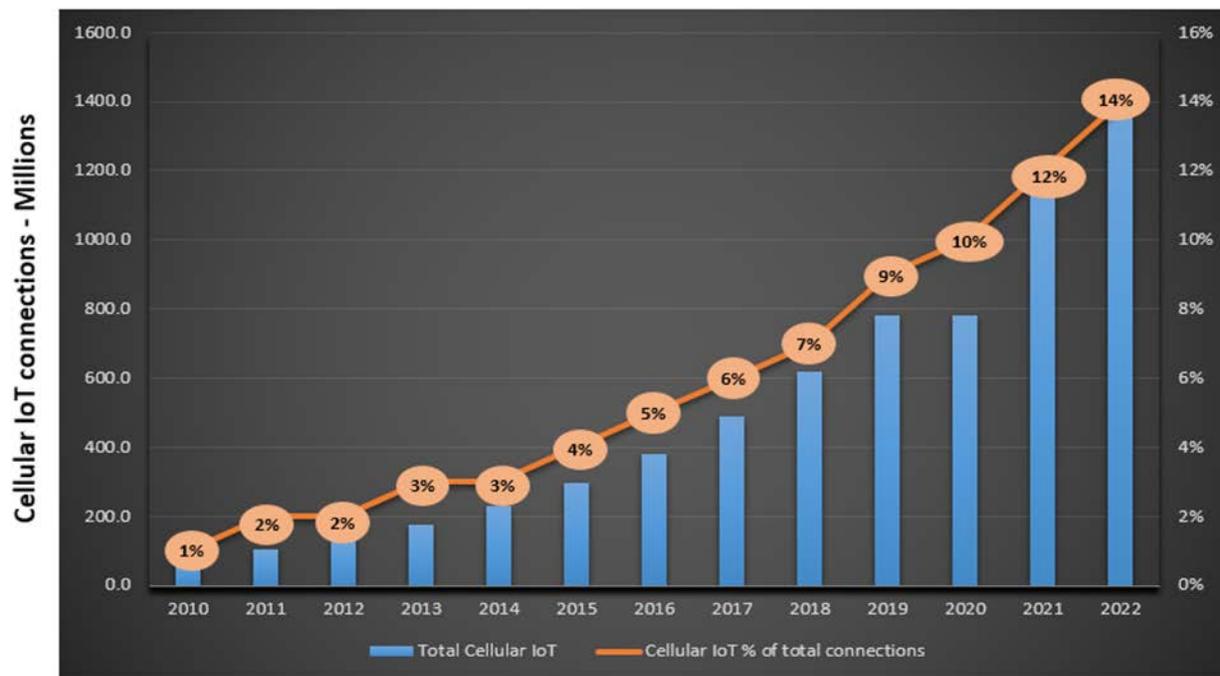


Figure 2.8. Growth of Cellular IoT Connections and Cellular IoT as Percentage of IoT Market – 2010-2022.

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 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, but 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.²⁹

²⁹ Ericsson Mobility Report, November 2016.

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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, according to 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 in the second quarter of 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 2.9 shows that 50 percent of IoT activity in 2022 is in manufacturing, transformation, smart cities and consumer markets.³⁰

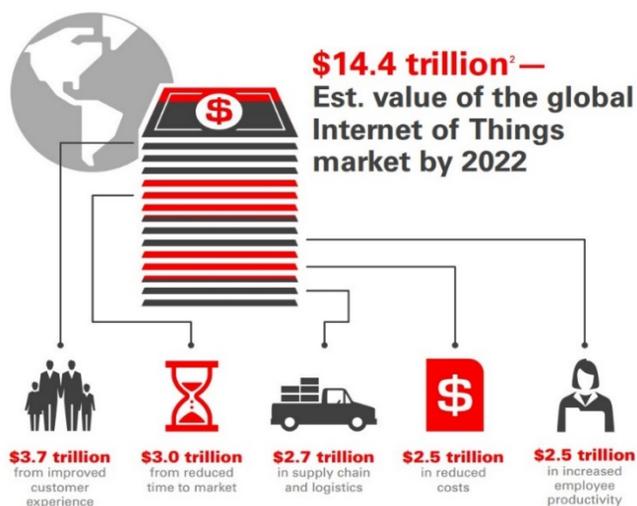


Figure 2.9. IoT Global Market Valuation 2020.³¹

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.

A wide range of IoT services are being embraced in cities. Deep indoor connectivity is a requirement for many of these services. Simulation of a realistic large-scale IoT service scenario in a city showed that up to 99 percent of devices located deep indoors could be reached with new cellular technologies for the IoT.³²

Coverage challenges for a variety of use cases can be overcome by newly standardized Low-Power Wide-Area (LPWA) cellular technologies, LTE-M and NB-IoT which are deployed on existing LTE networks.

³⁰ [Oracle Infographic: Energize Your Business with IoT Enabled Applications; Embracing the Internet of Everything to Capture Your Share of \\$14.4 Trillion, Cisco, 2014.](#)

³¹ Ibid.

³² *Ericsson Mobility Report*, June 2017.

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Category- Machine 1 (Cat-M1) supports a wide range of IoT applications, including content-rich ones. Both NB-IoT and Cat-M1 meet massive IoT coverage requirements and support a wide range of low cost devices.

2.4 OPERATOR DEPLOYMENT CONCEPTS

Different IoT devices need different connectivity services. Some only need to send a few bytes at long intervals, while others require continuous high bandwidth connectivity with low latency. Operators, therefore, need to define a strategy that describes in which segments they want to compete and which will then guide them on how to tailor services for these segments and what technologies to deploy.

Frequency licenses are a key operator asset. If the operator has available Frequency Division-LTE (FD-LTE) capacity in sub-Gigahertz (GHz) frequencies, implementing NB-IoT functionality is a natural choice. If Time Division Duplex-LTE (TDD-LTE) capacity is available, then both NB-IoT and LTE-Machines (LTE-M) are feasible. If GSM is available, Extended Coverage-GSM IoT (EC-GSM-IoT) can be deployed and if 3G is available, spectrum can be refarmed to support NB-IoT.

Correct pricing and price differentiation are essential. As the low-power wide-area (LPWA) IoT market expands, lower prices for connecting devices to the internet will support the emergence of new applications with new types of sensor.

For operators, IoT connectivity is a clear differentiator against companies like Amazon, IBM and Microsoft which all compete in the IoT arena, but offer no IoT connectivity.

As well as connectivity, operators can offer additional services such as devices and device management, as well as applications and services related to those devices. Due to the large number of different applications, operators will need to select which applications to provide for their own company strategy. This is important because applications could potentially generate the biggest share of all IoT-related operator revenues.

The first cellular IoT networks supporting massive IoT applications, based on Cat-M1 and NB-IoT technologies were launched in early 2017 and are called LTE-M or LTE for Machines.

LTE-M is the commercial term for the LTE-MTC low power wide area (LPWA) technology standard published by 3GPP in the Release 13 specification. It specifically refers to LTE Cat-M1, suitable for the IoT. LTE-M is a low power wide area technology which supports IoT through lower device complexity and provides extended coverage, while allowing the reuse of the LTE installed base. This allows battery lifetime as long as 10 years (or more) for a wide range of use cases, with the modem costs reduced to 20 to 25 percent of the current enhanced GPRS (EGPRS) modems. LTE-M IoT devices connect directly to a 4G network, without a gateway, and on batteries.

The LTE-M network is deployed with global, 3GPP standardized technology using licensed spectrum for carrier-grade security. This differentiates LTE-M from the technologies offered by other companies with non-cellular IoT solutions. LTE-M supports large-scale IoT deployments such as smart city services, smart metering, asset tracking, supply chain management, security and alarm monitoring and personal wearables.

Supported by all major mobile equipment, chipset and module manufacturers, LTE-M networks will co-exist with 2G, 3G, and 4G mobile networks and benefit from all the security and privacy features of mobile networks, such as support for user identity confidentiality, entity authentication, confidentiality, data integrity, and mobile equipment identification. Commercial launches of LTE-M networks are taking place globally in 2017-2018. As of September 2017, worldwide, there were 13 commercial NB-IoT networks

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including six in Western Europe and four in Asia Pacific, and six commercial LTE-M networks including two in the U.S. and three in Asia Pacific.³³

The U.S. is one of the largest and most advanced IoT markets in the world and as of September 2017, there were two nationwide U.S. carriers with commercial LTE Cat-M1 (LTE-M) deployments out of the six commercial LTE-M networks worldwide.

For example, AT&T launched LTE-M services in the U.S. at mid-year 2017, and will launch in Mexico by the end of the year and, combined with extended coverage with Telcel, create an LTE-M footprint covering 400 million people. AT&T's LTE-M deployment—the result of software upgrades—marks another step forward on the path to 5G and Massive IoT. AT&T launched a full new suite of rate plans with LTE-M, with monthly plans starting for as little as \$1.50 per month per device. Further discounts were available for yearly and multi-year plans, as well as volume commitments. LTE-M modules were available from AT&T's supplier for as low as \$7.50 each, including a SIM card - half the cost of the LTE Cat-1 module AT&T launched with its supplier in 2016. AT&T's current IoT starter kits with Category M14A2A modules are software-upgradeable to LTE-M with a firmware update. The LTE-M starter kit will spur developers to open the doors to IoT innovation.

Advantages of LTE-M over traditional IoT connectivity options include:

- Longer battery life (expected up to 10 years)
- Better coverage for IoT devices underground and deep inside buildings
- Reduced module size (as small as 1/6 the size of current modules)

LTE-M has been embraced by leading global carriers to build a broad base of ecosystem partners, devices and applications for global markets.

As a further example, T-Mobile U.S. C.T.O. Neville Ray said the operator will be deploying narrow-band LTE (NB-LTE) and LTE-M, although a timeline had not been announced at mid-year 2017. In January 2017, T-Mobile US unveiled two new simple, straightforward, low-cost IoT Access packs with wireless data and a Category 1 (Cat1) module to help accelerate IoT innovation and eliminate the pain of piecing together wireless IoT solutions. For applications that use little data, T-Mobile marketed that customers can get 5 MB of data per month for \$20 per year per device in the first year and just \$6 per year per device afterwards. For unlimited data at 64 kbps, T-Mobile charges \$25 per year per device. With both T-Mobile IoT Access packs, T-Mobile covered the cost of a Cat-1 module, via a bill credit from T-Mobile, up to \$16 per module.

T-Mobile has tackled some of the biggest obstacles slowing IoT innovation with solutions for IoT and M2M solutions. In 2016, T-Mobile provided customers with ways to future-proof their IoT solutions on today's LTE networks with support for Category 1 modules; extended 2G network operations to support customer transitions to LTE through 2020; was first to open the door for wireless development at the platform level with Twilio; delivered wireless solutions for retail businesses with ignite by Inseego; and, most recently launched T-Mobile SyncUP DRIVE, a new all-in-one connected car solution.

Analyst firm ABI has predicted that Cat-M technology will see strong growth beginning in 2018 as network operators become more aggressive in their deployments. The initial cost advantage of non-cellular networks is likely to dissipate as cellular operators move on their deployments.

³³ *GlobalComms Database*, TeleGeography. September 2017. [5G Americas](#).

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“Size and speed matter in the burgeoning LPWA Network market,” said Steve Hilton, analyst at MachNation. “The more devices ordered for a technology like Cat 1, the lower the per unit price per device. And most assuredly the success of this market is going to depend on extremely inexpensive devices. In addition, the sooner that LPWAN solutions are available on licensed spectrum from carriers like Sprint, AT&T, and Verizon, the less market opportunity there is for non-dedicated spectrum solutions like Sigfox and Ingenu.”³⁴



Figure 2.10. Benefits of LTE-M.³⁵

Sprint launched an LTE Cat-1 IoT network nationwide by end of July 2017, and is anticipating a further upgrade to LTE-M in mid-2018, in turn followed by the rollout of LTE Cat NB1 (NB-IoT).

2.4.1 GLOBAL IOT PLATFORMS

According to Research and Markets, the global IoT platform market will grow at a CAGR of 31.79 percent during the period 2017-2021.³⁶ According to the report, one of the major drivers for this market is the large-scale benefits of using IoT devices. An estimated 35 billion devices are expected to be a part of this connected environment by 2021. IoT devices collect data through sensors and actuators, transmitting it to

³⁴ IEEE ComSoc Technology Blog.

³⁵ IEEE ComSoc Technology Blog.

³⁶ [Global IoT Platform Market 2017-2021](#), report by Research and Markets. 30 May 2017.

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a centralized location on a real-time basis. This empowers the end-user to make informed decisions. In simple terms, the purpose of any IoT device is to connect with other IoT devices and applications (cloud-based mostly) to relay information using internet transfer protocols. The gap between the device sensors and data networks is filled by an IoT Platform. Such a platform connects the data network to the sensor arrangement and provides insights using backend applications to make sense of plethora of data generated by hundreds of sensors.

There are many IoT platforms available now that provide the option to deploy IoT applications on the go. While there are hundreds of companies and a few startups venturing into IoT platform development, some major players are way ahead of others in the competition. The U.S. is in a leadership position in the market of IoT Platforms. Among the leading companies are PTC (U.S.), Amazon Web Services (U.S.), Microsoft Corporation (U.S.), Google (U.S.), Cisco Systems, Inc. (U.S.), SAP SE (Germany), General Electric (U.S.), AT&T (U.S.), Huawei Technologies Co. Ltd. (U.S.), IBM (U.S.), Wipro (U.S.), Nokia (U.S., Finland) and HPE (U.S.) among others.

Advanced wireless network services in emerging 5G infrastructure will support a mix of Industrial-IoT (IIoT) services. According to ACG Research, without pervasive incorporation of cloud-native edge computing platforms into diverse deployment environments in the RANs, many IIoT applications will be unable to succeed. Design innovations in 5G architectures and cloud computing at the edge will be able to support those applications in a cost-effective manner. In parallel, the scale of IIoT services such as smart meter, video surveillance, and connected vehicle transport will be supported between two and three times more efficiently by employing cloud-native system designs in the core of the network service. And at the diverse endpoints supporting IIoT applications for their users, the performance and flexibility of advanced 4G and 5G networks and the elasticity and scale of the cloud application delivery platforms on which the endpoints will rely will combine to make the widespread billions of IIoT connections function together in real time in a high-performance, cloud-native ecosystem.³⁷

Traditional business models may not be adequate or relevant for the IoT ecosystem, which dictates that vendors collaborate even if historically competitors.³⁸ Models may include: 1) classic strategy of first to market; 2) Offer one part of the solution with minimal or no cost to the customer and capture revenue on other parts, for example, offer IoT enablement platform at cost and capture analytic series with XaaS model such as Security-as-a-Service or Analytics-as-a-Service; 3) helping the customer achieve an optimal and efficient business model to achieve its business Key Performance Indexes (KPIs).

A key challenge for unlocking this huge potential traditionally has been a lack of consistent standards and interoperability between the different IoT systems. McKinsey estimates that interoperability accounts for almost 40 percent of the value potential from the IoT applications.³⁹

This key challenge of interoperability may be overcome with the adoption of a global IoT platform standard, such as **oneM2M** which is working to unify the global IoT community, by enabling the federation and interoperability of the different IoT systems, across multiple networks and domains. There are plenty of standards-related activities in the IoT industry led by different alliances and consortia, and many of them are quite mature in their own respective areas and domains. Adding to this challenge of multiple standards is the IoT market's distinct fragmentation, a highly distributed value chain with a lot of proprietary IoT device implementations which makes it nearly impossible for all of these devices to actually be able to talk to each

³⁷ *Advances in IIoT Made Possible by Innovations in 5G, Virtualization and the Cloud*, report by ACG Research. 2017.

³⁸ *Internet of Things: Name of the Game Is Business Model*, blog by Robert Haim, ACG Research. 15 June 2017.

³⁹ *The Internet of Things: Mapping the Value beyond the Hype*, McKinsey. June 2015.

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other as envisaged with the Internet of Things. Some of the global organizations contributing in the IoT global platform space are the following:

AllSeen Alliance is a cross-industry consortium dedicated to enabling the interoperability of billions of devices, services, and apps that comprise the Internet of Things (IoT).

Open Mobile Alliance (OMA) specifications support the billions of new and existing terminals across a variety of wireless networks, supporting machine-to-machine device communications for IoT.

The **3rd-Generation Partnership Project (3GPP)** unites telecommunications standard development organizations to standardize cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities. Specifically, to IoT- they released the NB-IOT specification among others.

The mission of the **Institute of Electrical and Electronics Engineers (IEEE)** IoT initiative is to serve as the gathering place for the global technical community working on IoT.

The purpose of the **International Telecommunication Union (ITU)** Global Standards for IoT is to provide a visible single location for information on and development of IoT standards, these being the detailed standards necessary for IoT deployment and to give service providers the means to offer the wide range of services expected from the IoT.

The **IPSO Alliance** (IP Smart Object) promotes and supports Smart Objects, and manages an IPSO Smart Object Registry. The objective is to develop, establish, and create the industry leadership of an “IPSO Platform” that includes the definition and support of Smart Objects with an emphasis on object interoperability on protocol and data layers and of Identity and Privacy technologies.

The **Internet Engineering Task Force (IETF)** originally focused on running IP over IEEE 802.15.4 radios and has since then evolved into a much larger project, covering IPv6 adaptation layer (6LoWPAN), Constrained RESTful Environments (CoRE) to allow the integration of constrained devices with the Internet at the service level.

OCF (Open Connectivity Foundation), unified in February 2016, is an entity whose goal will be to help unify IoT standards so that companies and developers can create IoT solutions and devices that work seamlessly together.

The current IoT-related standards and technologies are highly fragmented. The fragmentation can be seen across different verticals/application domains where there is very little or no re-use of technologies. Given that multiple standards have always existed—many of them quite well established in their own areas primarily around network/device connectivity—it is not realistic to expect the ecosystem to automatically converge on a single standard considering the varied applications needs and diverse physical operating conditions for these connected devices.

Industry analyst firm UBS's research report has singled out standardization as one of the key prerequisites for the broad adoption of connected devices and claims that “adherence to a single standard will be key in enabling the success of the Internet of Things on a global basis.⁴⁰” Overall, the importance of consistent standards and IoT interoperability to the market and consumers is undeniable.

⁴⁰ *Making Sense of IoT Standards*, Harman, March 2015.

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While there are numerous alliances already underway with the intention of establishing standards conducive to the implementation of IoT, oneM2M stands out as a unifying standard for most of these initiatives. The objective of oneM2M is to avoid competing standards, duplication, and conflicts stemming from alliances and consortia tackling similar or overlapping issues. oneM2M can be seen as a “standard of standards”; it is involved in concerted efforts to bring in interoperability among architectural layers across IoT applications spanning different industry verticals. oneM2M is helping this dire challenge of fragmentation in realizing the vision of IoT and stands out as the interoperability enabler for the entire M2M and IoT ecosystem.

oneM2M⁴¹ is the global standards initiative that was formed in 2012 and consists of eight of the world’s preeminent Standards Development Organizations (SDO) viz. ETSI (Europe), ARIB (Japan), ATIS (U.S.A), TTA (U.S.A), CCSA (China), TSDSI (India), TTA (Korea) and TTC (Japan). These SDO Partners collaborate with six industry consortia (Broadband Forum, Continua Alliance, GlobalPlatform, HGI, Next Generation M2M Consortium and OMA) and has over 220-member organizations to produce and maintain globally applicable, access-independent technical specifications for a common M2M/IoT Service Layer. oneM2M is an open initiative; it actively encourages industry associations and forums with specific application requirements to participate, in order to ensure that the solutions developed support their specific needs.

oneM2M industry standard and is designed to be industry-vertical and vendor-agnostic. It takes a truly horizontal approach, enabling connection and information exchange between heterogeneous IoT devices—standards and proprietary communication—and IoT applications. Its enables federating the various components of the end-to-end solution within the complex and fragmented eco-system, from device through to application—to sit on top of ubiquitous reliably managed connectivity, enable identification, development, and roll out industry-specific use cases.

oneM2M IoT platform might comprise the following key modules:

Device and Service management

The Device and Service Management (DSM) module manages the end-to-end lifecycle of the IoT service and associated gateways/devices and sensors, which includes application registration, communication policies, and remote management of the IoT gateways/devices. It provides a Web-based GUI for all the stakeholders to interact with the IoT platform. The hierarchical customer account modeling, coupled with the Role-Based Access Control (RBAC) mechanism, enables various mutually beneficial service models such as B2B, B2C, and B2B2C models.

Network Interworking Proxy

The Network Interworking Proxy (NIP) component is a connected devices framework for managing and communicating with disparate IoT gateways/devices, and communicating over different types of underlying networks. With NIP, you get interoperability and information exchange between the heterogeneous systems deployed in the field and the uniform oneM2M-compliant resource model.

Data Acquisition and Verification

Data Acquisition and Verification (DAV) supports reliable bi-directional data communication between IoT applications and IoT gateways/devices deployed in the field. The DAV component uses the underlying NIP to interact and acquire IoT data and maintain it in a resource-oriented uniform data model aligned with oneM2M. This data model is completely agnostic to the device or application, so it is completely flexible

⁴¹ Much of the text on global IoT platforms has been compiled from www.oneM2M.org. July 2017.

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and extensible. IoT applications in turn can discover, access, and consume these resources on the north-bound side using secure oneM2M-compliant Mca (reference point to interface CSEs) interface.

Data Analytics

The Data Analytics (DA) module provides a creation, execution, and visualization environment for nearly all types of analytics including batch and real-time—based on complex event processing. It leverages the discovery of meaningful patterns in data collected from sensors in conjunction with application-specific externally imported data. The data analytics engine enables the creation of data insights that can be used for business analysis and/or monetization by sharing insights with the partners.

Data Service Cloud

The Data Service Cloud (DSC) module enables advanced monetization models, especially fine-tuned for IoT and cloud-based offerings. DSC supports mashup for new content creation providing additional insight by combining embedded IoT data with internal and external data from other systems. This additional insight can provide value to other stakeholders outside the immediate IoT ecosystem, enabling monetization of such information.

Back-end Systems

The back-end systems -- Business Support Systems / Operations Support Systems (BSS/OSS) -- module provides a consolidated, end-to-end view of devices, gateways, and network information. This module helps IoT operators automate and prioritize key operational tasks, reduce downtime through faster resolution of infrastructure issues, and improve service quality. In addition, the IoT applications can consume a subset of these OSS/ BSS from the Platform-as a-Service, thereby avoiding the need for re-developing the OSS/BSS functionalities within the applications.

oneM2M addresses the challenges of fragmentation, integration complexity, information sharing and high development cost with a horizontal-platform-based approach, providing a standardized, simplified, and unified layer as a service to various partners consuming and sharing information across various application domains. The access technology-independent horizontal platform enables reliable, end-to-end data control/exchange between M2M devices and customer applications by providing functions for remote provisioning and activation, authentication, data buffering, encryption/decryption, synchronization, aggregation, and device management. This enables rapid IoT application development using the underlying common service functions for multiple access technologies such as fixed line, cellular, WiFi, ZigBee, Bluetooth®, LoRa, NB-IoT, etcetera.

A horizontal IoT platform provides the following key benefits:

- Lower Total Cost of Ownership (TCO): Lower CAPEX with lower cost of development and deployment, and lower OPEX with scale of economies with horizontal service layer providing nearly all the common service functions
- New revenue streams: Enables new business opportunities with service offerings from cross sharing of resources and data across silos; helps address use cases and markets where cost was prohibitive earlier
- Faster time-to-value with accelerated development and deployment

The common service functions provided by the horizontal platform have been designed based on the analysis of a number of use cases across different application domains. oneM2M Release-1 and Release-

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2 specifications are already addressing interoperability for many of the common existing industry standards and technologies:

Protocol Bindings

- RESTful HTTP—release 2 (TS-0009) specifies binding of oneM2M primitives to HyperText Transfer Protocol (HTTP) method, binding of oneM2M response status codes (successful/unsuccessful) to HTTP response codes and binding of oneM2M RESTful resources to HTTP resources
- CoAP—release 1 (TS-0008) specifies binding of oneM2M primitives to CoAP messages, binding of oneM2M response status codes to CoAP Response Codes and behavior of a CoAP client and server depending on oneM2M parameters
- Message Queuing Telemetry Transport (MQTT)—release 1 (TS-0010) specifies how the oneM2M Mca (reference point to interface an AE (Application Entity) and CSE (Common Services Entity) or Mcc (reference point to interface CSEs) request and response messages are transported across the MQTT protocol
- WebSocket (TS-0020)—oneM2M is working on specifying the binding for WebSocket protocol to transport serialized representations of oneM2M request and response primitives

Management enablers

- OMA (TS-0005) specifies the usage of OMA DM and OMA Light Weight M2M (LWM2M) resources and the corresponding messages to fulfil the oneM2M management-related requirements
- Broadband Forum (BBF) (TS-0006) specifies the usage of the BBF TR-069 protocol and corresponding messages to fulfil the oneM2M management related requirements

Also, a number of other work programs have been identified in oneM2M for enabling interworking with other industry consortia/alliances, such as:

- LWM2M Interworking (TS-0024)—providing transparent transport of encoded LWM2M application objects between LWM2M endpoints and M2M Applications. It is also specifying full mapping of LWM2M objects in LWM2M endpoints to semantically enabled resources that are utilized by M2M applications. It should be noted that this interworking will also apply to ecosystems around LWM2M, for example other alliances like IPSO have created LWM2M-compatible object descriptions related to smart city applications
- Home Appliances Information Model and Mapping (TS- 0023)—describes the oneM2M defined information model for home appliances, including the description of a method on how it is mapped with other information models from external organizations which include AllJoyn, Open Interconnect Consortium (OIC), Home Gateway Initiative (HGi) Smart Home Device Template (SDT) and ECHONET (communication protocol designed to create the “smart houses” of the future)

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- Open Interconnect Consortium (OIC) Interworking (TS-0024)—providing transparent transport of encoded OIC resources and commands in oneM2M resource types between OIC devices and M2M applications
- AllJoyn Interworking (TS-0021)—oneM2M is working on identification of interworking scenarios between oneM2M and AllJoyn systems, which could result in new requirements on the oneM2M system (AllJoyn is a collaborative open source software framework that allows devices to communicate)

Adoption of oneM2M provides for seamless interoperability with all of the above standards/ technologies and benefits from the re-use of already existing solutions/technologies wherever possible. For customers, this secures their investment in having a platform that is future technology-proof.

oneM2M is based on Resource Oriented Architecture, where the real-world entities (Gateways, devices, sensors) are uniformly represented as resources, where a resource could be any component of a device/application on a device that is worth being uniquely identified and linked to. Resources are identified based on Uniform Resource Identifiers (URIs), and representations retrieved through resource interactions contained as links to other resources, so that applications can follow links through an interconnected web of resources. In addition to the hierarchical URI, oneM2M also supports a non-hierarchical URI to enable IoT applications to access and interact with resources without the need to know the topology of the underlying resource model.

A Resource Oriented Architecture simplifies the development of IoT applications by providing a uniform interface for interacting with resources and retrieving their representations, irrespective of:

- The type of the underlying gateway/device and their topology
- The type of the vertical/application domain, which could be smart cities, industrial control, home automation, connected health, intelligent transportation, etcetera
- The communication protocol used between the gateway and devices in personal area network. For for example ZigBee, Bluetooth, RFID etcetera
- The application/communication protocol used by the gateways/devices, for for example MQTT, LWM2M, CoAP or any other proprietary protocol
- The network communication technology used, for for example cellular, LoRa, WiFi, or fixed line, Applications access/interact with the resources using a simple request/response mechanism with “Create”, “Retrieve”, “Update”, “Delete”, and “Notify” commands (CRUDN), enabling discovery of access policies, device info, and resources on the devices; fetching device information by retrieving resources; controlling devices by changing resources and monitoring resources observing the changes on the properties of resources. oneM2M provides for multiple protocol bindings (HTTP, WebSockets, MQTT, CoAP, etcetera) to access and interact with this common resource model. For for example a Web-based IoT application could use RESTful HTTP-based interface

A Resource Oriented Architecture with linkable resources is one of the key steps towards building a scalable interaction model on top of the basic network connectivity for any IoT application and is a strong foundation for having a semantically enabled Internet of Things.

oneM2M provides the guidelines and security solutions for addressing the diverse security needs resulting from the delivery of cross-domain interactions and services. It defines the following high layers:

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Secure functions layer: Contains a set of security functions that are exposed at reference point Mca and Mcc (reference point to interface CSEs), such as identification and authentication, authorization, security association, sensitive data handling, and security administration

Secure environment abstraction layer: This is used by the secure functions layer and implements various security capabilities such as key derivation, data encryption/decryption for application message security, signature generation/verification, manage security credential from/to the secure environments

Secure environment layer: This layer, containing one or multiple secure environments, provides various security services related to sensitive data (SE capability, security keys, local credentials, security policies, identity information, etcetera) storage and sensitive function (data encryption/decryption) execution

The authorization function is aligned with the Resource Oriented Architecture and manages data access to authenticated entities according to provisioned access control policies and assigned roles. Access Control Policy (ACP) is defined as sets of conditions that define whether entities should be permitted access to a protected resource. Access/management for a given resource is authorized upon satisfying at least one ACP rule in one of the linked ACPs. For example, an ACP rule is satisfied if the “who”, “what” and “which” are satisfied by the requesting entity.

The system provides for a flexible model for defining the ACP allowing for associating the same ACP with multiple resources, enabling easy sharing of resources for multiple applications.

In order to fully realize the benefits of Internet of Things, we need an ecosystem where applications can collaborate and exchange data across industry domains.

The end game with IoT is to securely monetize the vast treasure troves of IoT-generated data to deliver value to enterprise applications, whether by enabling new revenue streams, reducing costs, or improving customer experience. Effective monetization of data will not be achieved with mere consumption of the IoT data—data needs to be categorized based on the value, services need to support instant interactions based on the data values, and data should be exchanged across multiple domains for maximizing the value. oneM2M enables management of IoT solutions and delivers value through monetizing the vast amounts of data generated by connected devices and making it available to enterprise-specific applications and use cases.

3. IOT REQUIREMENTS

Because IoT is aimed at connecting “machines”, there are different requirements than those for general mobile broadband. The generic requirements for IoT are low cost, energy efficiency, ubiquitous coverage, and scalability (ability to support a large number of connected machines in a network). To legacy operators, IoT services should ideally be able to leverage their existing cellular infrastructure and co-exist with other non-IoT services in the same network and spectrum.

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3.1 OVERVIEW IN 3GPP

In the 3GPP Release 13 standard, enhanced Machine-Type Communications (eMTC) and Narrowband IoT (NB-IoT) were introduced. They are complementary narrowband IoT technologies in LTE intended for different types of use cases. The generic IoT requirements are met by these technologies. They support in-band or guard band operations so operators do not need to find new spectrum to deploy these technologies. By allowing half-duplex and single antenna operation, device cost and complexity can be reduced. Efficient signaling minimizes overhead so that a large quantity of IoT devices can be supported in a network. In addition, the extended Discontinuous Reception (eDRX) reduces battery consumption for device-terminated applications and thus lengthen the battery life.

The 5G Americas whitepaper, *LTE and 5G Technologies Enabling the Internet of Things*,⁴² provides expanded information on many of these features.

3.2 3GPP RELEASE 14 REQUIREMENTS

With Release 13 eMTC and NB-IoT as a basis, more enhancements to existing features, such as mobility and Voice-over-LTE (VoLTE) support, were added in Release 14. Two key features, broadcast and positioning, were introduced. Latency and battery consumption reduction were also planned. New User Equipment (UE) categories were added to enable UEs with expanded capabilities and supporting higher data rates.

More details about the Release 14 features can be found in Section 4.2 of this paper.

3.3 VERTICAL REQUIREMENTS

Clearly, apart from the generic requirements common to all IoT services and 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 upon the operator role and ambition. As an example, in the METIS II project the “Massive distribution of sensors and actuators” use case, the following views on requirements for future 5G developments, as shown in Table 3.2 are provided.

Table 3.1. Refined scenarios and requirements, consolidated use cases and qualitative techno-economic feasibility assessment.⁴³

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)

⁴² *LTE and 5G Technologies Enabling the Internet of Things*, 5G Americas whitepaper, December 2016.

⁴³ METIS II Deliverable D1.1 2016-01-31.

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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.

Table 3.2. Prospective Use Cases for IoT.

Sector	Use Case	Top Requirements
Industry	High Volume (for example mining)	Range, Coverage, Reliability, Cost
Agriculture	Dynamic (for example animal tracking)	Battery, Range, Coverage, Reliability, Cost
	Static (for example irrigation of fields)	Battery, Range, Coverage, Reliability, Cost
Utilities	Powered (e. g. Electricity)	Indoor, Service Level Agreement (SLA), Reliability
	Not Powered (for example Water/Gas)	Indoor, SLA, Reliability
Logistics	Management & Tracking (for example Fleet)	Easy Install., Mobility, Coverage, Cost
	Basic Monitoring (for example shipment conditions, warehouse)	Battery, Easy Install., Mobility, Coverage, Cost
Smart Cities	Dynamic Systems (for example Traffic Management)	SLA, Coverage, Reliability
	Basic Sensoring (for example air pollution)	SLA, Coverage, Reliability
Payments	Total Payment Volume (TPV)	Indoor, Interoperability, SLA, Reliability
	Fraud Detection	Indoor, Interoperability, SLA, Reliability
Wearables (incl. e-Health)	Continuous Tracking (for example Diabetes)	Indoor, Battery, Mobility, SLA, Coverage, Reliability
	Spot Tracking (for example steps tracking)	Battery, Easy Install., Mobility
Security	High Volume (for example video)	Indoor, Throughput, Security, SLA, Reliability
	Low Volume (for example presence detection)	Indoor, Security, SLA, Reliability
Connected Cars	Integrated solution (for example traffic management)	Easy Install., Mobility, Coverage, Cost
	Basic Monitoring (for example location)	Easy Install., Mobility, Coverage, Cost
Buildings (incl. Home)	Complex Solution (for example energy management)	Indoor, Security, SLA, Reliability
	Basic Solution (for example presence/air pollution)	Indoor, Security, SLA, Reliability
IoT Complex Systems	Autonomous Car or Drones Ecosystems	Battery, Security, Range, SLA, Coverage, Reliability

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Depending upon the specific service, and the values different sets of requirements should be considered to meet specific IoT service needs, such as:

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

Requirements for the large variety of IoT applications are 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.

An enterprise with a strong desire for the security of its data may prefer a private network for its IoT needs. Such a network can leverage LTE but will operate separately from operators' public cellular networks, providing access only to authorized devices. In some cases, operators may still deploy and operate such private networks as a service to the enterprises as the latter often lack the experience and expertise to do so. Operators with spectrum to spare can opt to deploy a private network in one of their unutilized carriers. Alternately, they can also deploy the private network in shared or unlicensed spectrum.

In addition to the requirements listed in Tables 3.2 and 3.3, a private network will also need to support the following:

- Independence from the public cellular network
- Dedicated network equipment in the enterprise's premise with ubiquitous coverage
- QoS control for different equipment
- High degree of reliability

These requirements for private networks can be met with existing LTE features or through implementation and network planning, without any change to the LTE standard.

4. KEY 3GPP IOT TECHNICAL SOLUTIONS

LTE systems have supported CIoT since 3GPP Rel-10 with continuing enhancements added in each ensuing Release. Rel-13 introduced the following capabilities.

- eMTC category M1 UE with complexity reduction and coverage enhancements to at least 155.7 dB Maximum Coupling Loss (MCL)⁴⁴
- NB-IoT category NB1 UE which further reduces complexity and extends coverage to 164 dB MCL¹⁸
- extended Discontinuous Reception (eDRX) optimizes battery life for device-terminated applications
- network architecture and protocol enhancements for IoT are introduced

⁴⁴ MCL targets are not directly comparable due to different underlying assumptions.

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Rel-14 includes enhancements for eMTC and NB-IoT related to positioning accuracy, Multicast DL Transmission, mobility, higher data rates, and power consumption. Additionally, network architecture and protocol enhancements improve group communications.

4.1 3GPP RELEASE 13 IOT FEATURES

Rel-13 work items on both eMTC and NB-IoT were completed by 3GPP in June 2016. The following subsections include enhancements that have been made to the standards since that time.

4.1.1 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 4.1.

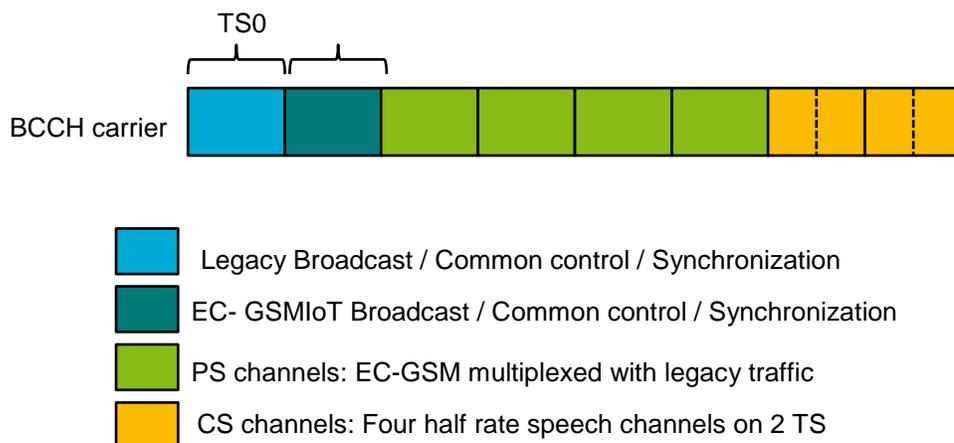


Figure 4.1. Example of an EC-GSM IoT Channel Configuration.

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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.

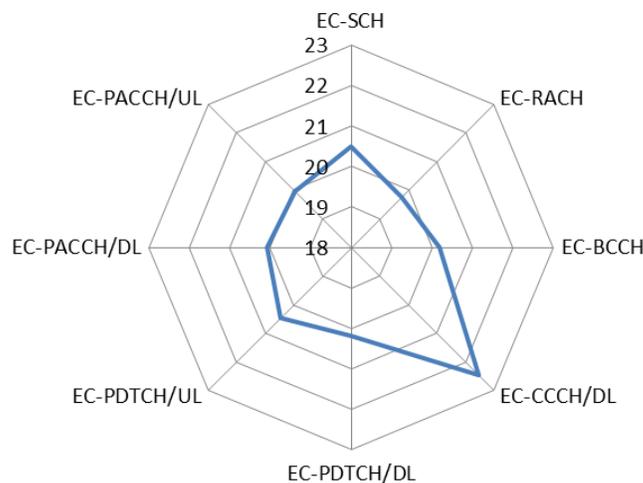


Figure 4.2 EC-GSM-IoT extended Coverage.

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.

4.1.2 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

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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 1.4 MHz to 20 MHz, utilizing 6 to 100 Resource Blocks (RB), and the wideband control channel spanning over the total bandwidth. eMTC operation is limited to 1.08 MHz (6RBs) that can coexist in a wider, general-purpose LTE system. As a result, Cat-M1 devices only need to support 1.08 MHz 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 1 Mbps 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 (for example, Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) and Primary Broadcast CHannel (PBCH) in the center 1.08 MHz of the LTE carrier, and introduce new system information (SIB1-BR).

eMTC networks 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 4.3 provides a pictorial representation.

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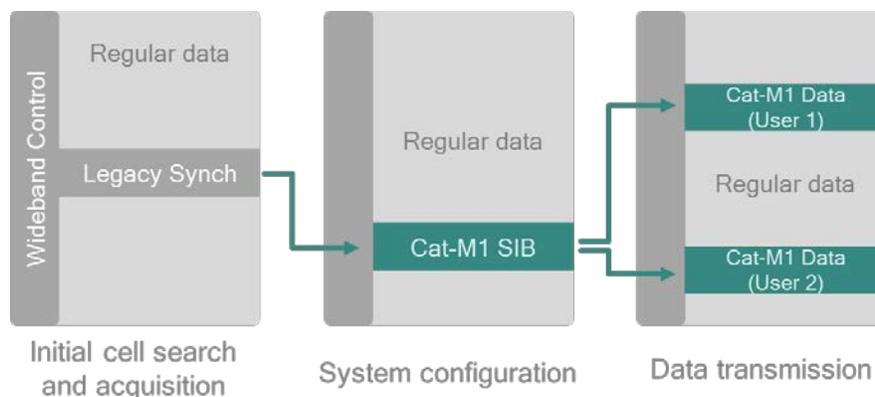


Figure 4.3. Cat-M1 (eMTC) Can Operate in Narrowband Regions Within a Regular LTE Carrier.

To extend coverage to IoT devices deployed deep indoors or in remote locations, eMTC offers 15 dB of increased link budget and improved the Maximum Couple Loss (MCL) from 140.7 dB of LTE baseline to 155.7 dB 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 1 Mbps utilizing only 1.08 MHz 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 VoLTE) and full-to-limited mobility, and is designed to fully coexist with regular LTE traffic (Cat-0 and above).

4.1.3 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.

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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 4.4).

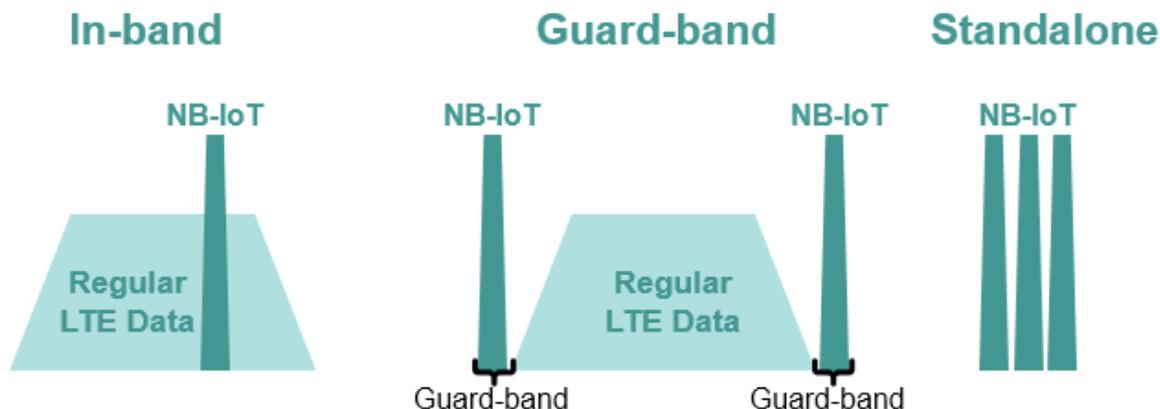


Figure 4.4. Cat-NB1 (NB-IoT) Flexible Deployment Options.

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 (NB-PDSCH) 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

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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 4.5, 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).

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

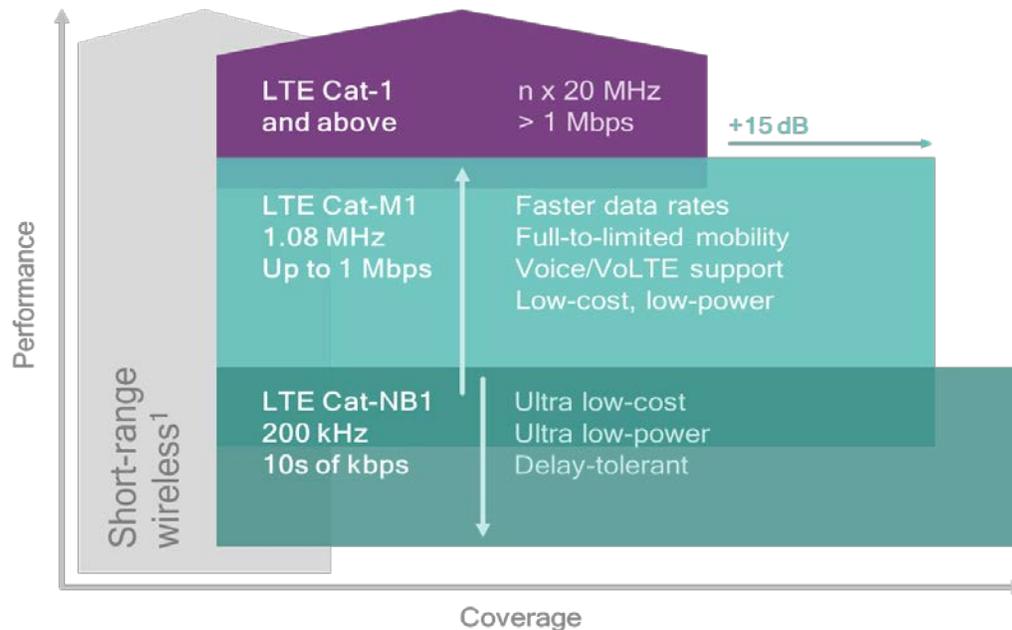


Figure 4.5. Advanced Techniques to Extend LTE IoT Coverage.

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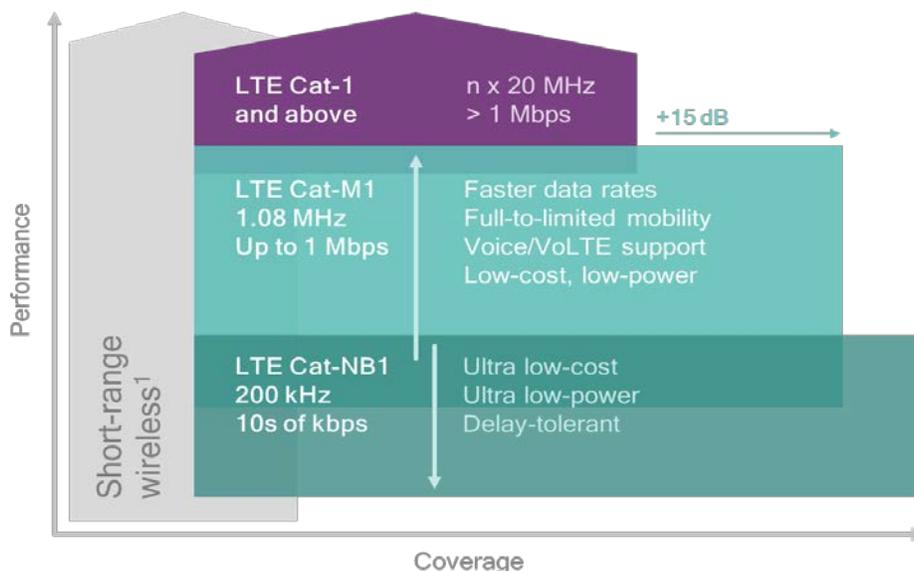


Figure 4.6. LTE IoT – Cat-M1 and Cat-NB1 Devices.

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 4.6 compares Cat-M1 and Cat-NB1 device capabilities, Figure 4.7 summarizes the high-level complexity difference of the two new LTE IoT UE categories.

	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 4.7. Reducing Complexity for LTE IoT Devices.

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4.1.4 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.

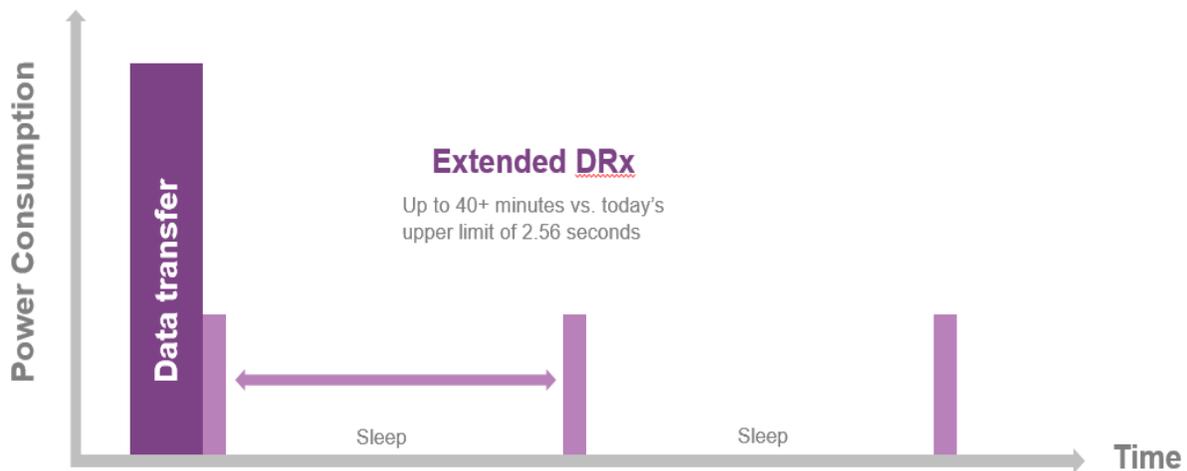


Figure 4.8. eDRX Idle Mode Extends Sleep Cycles for LTE IoT Devices.

4.1.5 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)

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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 than traditional devices because of issues like special traffic characteristics, availability, and congestion management.

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, but more generally to serve specific types of subscribers/devices (MTC devices vs smartphones, subscribers of a certain MVNO, Public Safety subscribers, etcetera). MTC devices, subscribers of a certain MVNO or Public Safety subscribers in these dedicated networks share the same characteristics and are selected based on operator configuration, UE capabilities 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, configured in the HSS, but also on local policy and on other information such as the UE capabilities and, in non-roaming case, subscription information. When a UE first attaches to the network, if the Core Network selected by the Radio Access Network (RAN) 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 UE capabilities local policy. An operator network that has deployed the DECOR feature can also accept MVNOs that have not upgraded their HSS and, in this case, the MME/SGSN selects the SGW and PGW/GGSN only based on local policy, UE capabilities and, in non-roaming cases, subscription information.

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

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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:

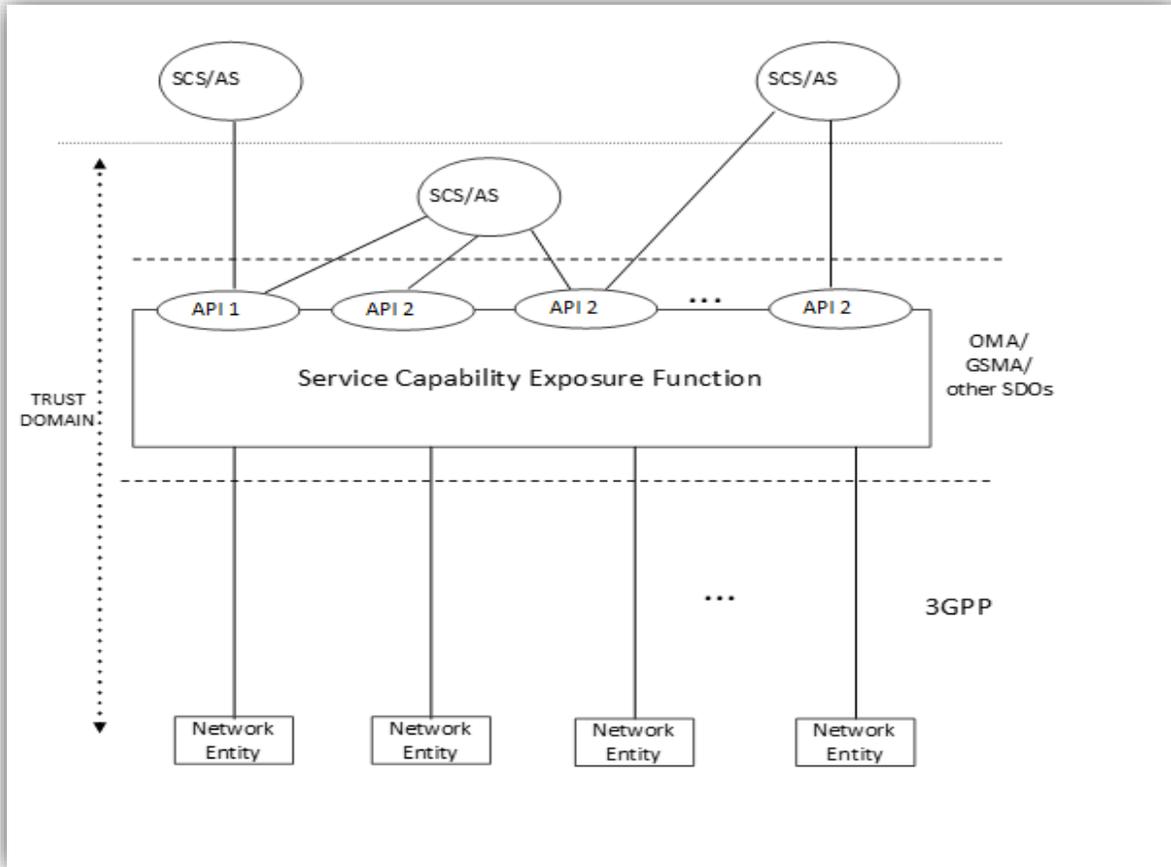


Figure 4.9. AESE Architecture.

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 to external 3rd party service provider Service Capability Server/Application Server (SCS/AS) hosting an Application(s). The "Network Entity" boxes represent the Home Subscriber Server (HSS), MME, PGW, PCRF, charging and security functions, etcetera 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 (GSMA), 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.

As part of AESE work following new functionalities were also specified:

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- Support of informing about potential network issues enhanced trouble shooting
- Resource management of background data transfer addressing customer care concerns, and
- E-UTRAN network resource optimizations based on communication patterns provided to the MME
- Support of setting up an Application Server (AS) session with required QoS, and
- Change the chargeable party at session set-up or during the session

3GPP is working to extend the AESE architecture by providing standardized interface between SCEF and SCS/AS as part of ongoing Rel-15 work on Northbound APIs for SCEF – SCS/AS Interworking (NAPS).

With the growing interest in northbound APIs, 3GPP has also undertaken task in Rel-15 to define a Common API Framework (CAPIF) within 3GPP for consistent development of northbound APIs. Intended users of CAPIF are third-party developers that may not be familiar with 3GPP networks, and their underlying complexities.

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. 3GPP architecture in 3GPP TS 23.682 models triggering as a service supported by the MTC-IWF element. To provide also the triggering service over the same common interface as the SCEF services GROUPE and MONTE (and ClOT Non-IP Data Delivery (NIDD)), an architecture option with co-located MTC-Interworking Function (IWF) and SCEF is specified in Rel-13.

The mechanisms laid in place in Rel-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 Rel-13 not only provide a first set of functionalities, but can also be used to add new functionalities in the future with small impact.

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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 (for example, “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)

The Monitoring feature was added with the intention of monitoring MTC devices, UE and user subscription-related events. Monitoring feature comprised of means that allow the identification of the 3GPP network element suitable for configuring the specific events, the event detection, and the event reporting to the authorized users, for example, for use by applications or logging, etcetera. If such an event is detected, the network might be configured to perform special actions, for example limit the UE access. The feature provides a mechanism for the 3GPP network to configure and report following events:

- 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?”
- Loss of connectivity of a UE
- Communication failure with the UE
- Reporting geographic or location changes
- UE reachability
- Location of the UE, and change in location of the UE
- Roaming status (i.e. Roaming or No Roaming) of the UE, and change in roaming status of the UE
- Number of UEs present in a geographical area
- UE availability notification after downlink data delivery failure

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.⁴⁵ 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

⁴⁵ 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.

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and the ability to select both Clot Dedicated Core Networks and Authorization of use of coverage enhancements. Further enhancements have been incorporated into 3GPP Release 14. Clot Enhanced Packet System (EPS) Optimizations comprise several enhancements:

- Support of NB-IoT radio that is optimized for Clot use case (but Clot runs also on WB-E-UTRAN)
- Control Plane Clot EPS Optimization
- User Plane Clot 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 Clot 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 Clot EPS optimizations. However, a so-called Clot-Serving Gateway Node (C-SGN) single box deployment option has also been defined. It does not change the Clot functionality at all, but it provides an alternative to embedded deployment where the selected CN nodes are updated to support Clot 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.

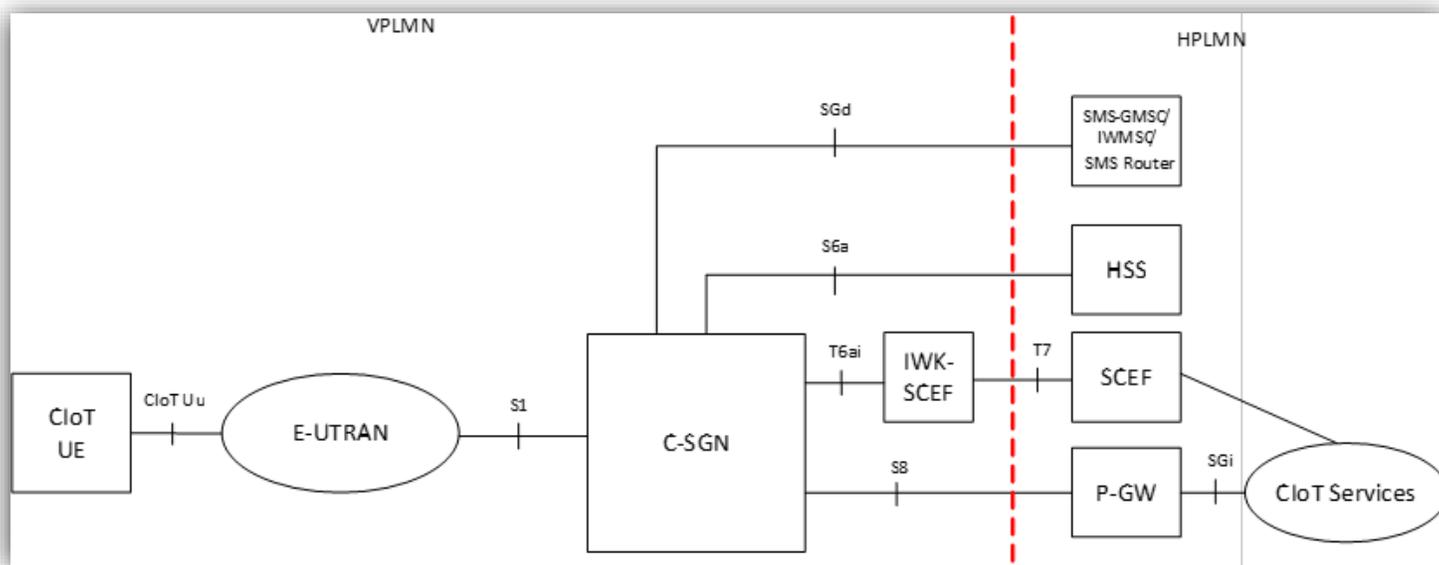


Figure 4.10. Clot Architecture with Single-Box C-SGN.

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

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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 for example 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.

Collection of charging information (in offline and online charging as well) dedicated to these CIoT Enhanced Packet System (EPS) Optimizations enhancements have been introduced, in order to provide capabilities for MNO to monetize usage of their Network for CIoT.

Collected charging information include amongst other, NB-IoT radio type, and/or Non-IP PDN type when applicable.

For small data path alternative using SGW-PGW, the existing EPC charging framework enhanced with dedicated information applies, whereas for small data path alternative using Services Capability Exposure Function (SCEF) a new charging solution is specified.

4.2 3GPP RELEASE 14 IOT FEATURES

Rel-14 work items on both eMTC and NB-IoT were completed by 3GPP in June 2017. The following subsections describe enhancements made to better support IoT devices with more refined service requirements.

4.2.1 3GPP REL-14 ENHANCEMENTS FOR EMTC (CAT-M1/M2/NON-BANDWIDTH LIMITED (NON-BL) FEATURES)

Specific updates in Rel-14 for eMTC include:

- improved positioning capabilities,
- enhanced Multicast DL transmission,
- mobility enhancements
- support of higher data rates, and
- VOLTE enhancements

4.2.1.1 Observed Time Difference of Arrival (OTDOA) Positioning

OTDOA positioning is a downlink positioning solution, in which the UE measures the Time of Arrival (ToA) of the reference signals received from multiple transmission points, and then reports the reference signal time difference to the location server for positioning purpose. OTDOA positioning has been supported for Rel-13 eMTC UEs with the restriction of RSTD measurement based on PRS bandwidth of 6 PRBs. LTE Rel-14 enhanced OTDOA positioning for further enhanced Machine-Type Communications (FeMTC) UEs with the consideration of the improvement of OTDOA positioning accuracy and resource utilization.

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The OTDOA positioning enhancement for FeMTC Rel-14 includes multiple Positioning Reference Signals (PRS) configurations, dense PRS configuration, PRS frequency hopping, PRS muting pattern enhancement and Reference Signal Time Difference (RSTD) measurement/reporting enhancement.

Multiple PRS Configurations

Until LTE Rel-13, one UE can be configured with one PRS configuration for one transmission point, where one PRS configuration includes only one PRS bandwidth. Normally PRS bandwidth of one transmission point would be same as LTE system bandwidth. However, the OTDOA positioning accuracy of some FeMTC UEs might be impacted due to its limited bandwidth of 1.4 MHz. In this case, dense PRS configuration for lower PRS bandwidth while sparse PRS configuration for higher PRS bandwidth would be expected for resource utilization improvement. Since one eNB might have both traditional UEs and FeMTC UEs, LTE Rel-14 introduced up to 3 PRS configurations for one transmission point and meanwhile one UE can be configured with up to 3 PRS configurations for one transmission point, where each PRS configuration could have its own PRS configuration parameters.

Dense PRS Configuration

In LTE Rel-13, the periodicity of PRS occasion (i.e. PRS periodicity) could be configured with 160 milliseconds (ms), 320 ms, 640 ms or 1280 ms, and one PRS occasion could have 1, 2, 4 or 6 PRS subframe(s). LTE Rel-14 introduced a PRS-only beacon which transmits PRS only. To efficiently use a PRS-only beacon, the configurable PRS periodicity could be from 1 ms to 159 ms besides existing 160 ms, 320 ms, 640 ms and 1280 ms, and the configurable number of PRS subframes per PRS occasion could be from 1 to 160 PRS subframes, where the number of PRS subframes per PRS occasion could not exceed associated PRS periodicity. FeMTC Rel-14 inherits such dense PRS configuration.

PRS Frequency Hopping

As mentioned previously, the measurement bandwidth of some FeMTC UEs might be 1.4 MHz. To improve the frequency selective gain, the feature of PRS frequency hopping is introduced in LTE Rel-14. If PRS frequency hopping is configured, the PRS frequency hopping would happen within 2 or 4 PRS frequency hopping bands. The first PRS occasion of the first PRS occasion group starts after the beginning of System Frame Number (SFN) =0 is located at the center of the system bandwidth. The frequency band of each subsequent PRS occasion is indicated by high-layer signaling. One PRS occasion group has 2, 4, 8, 16, 32, 64 or 128 PRS occasions. Please note that Rel-14 only supports PRS frequency hopping with PRS bandwidth of 6 Physical Resource Blocks (PRBs) for FeMTC UEs.

PRS Muting Pattern Enhancement

In the existing LTE Rel-13, the PRS muting pattern length is 2, 4, 8 and 16. In LTE Rel-14, the PRS muting pattern is extended to 2, 4, 16, 32, 64, 128, 256, 512 and 1024. If PRS frequency hopping is not configured, then each bit in the PRS muting pattern corresponds to one PRS occasion, otherwise each bit in the PRS muting pattern corresponds to one PRS occasion group.

Multipath RSTD Measurement Reporting

Compared to traditional single-path RSTD measurement reporting, one FeMTC UE can report the information of RSTD measurement with multiple paths as shown in Figure 4.11 so that the location server has rich information to distinguish the correct path for OTDOA positioning accuracy improvement.

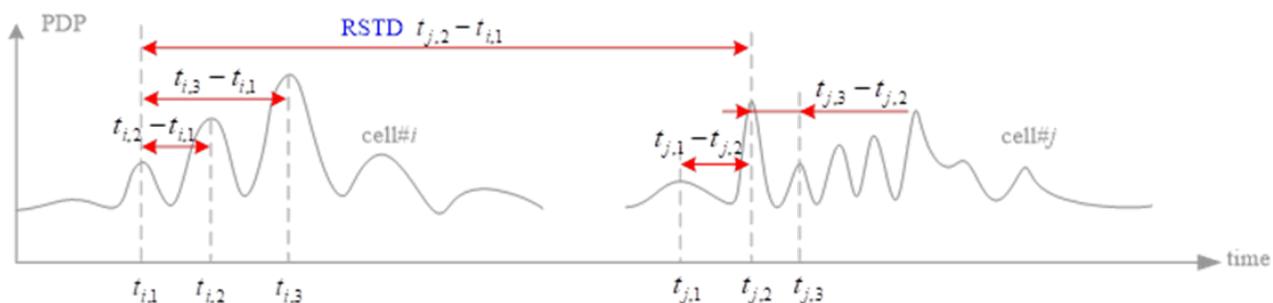


Figure 4.11. Multipath RSTD Measurement in OTDOA Positioning.

RSTD Measurement Reporting with Higher Resolution

LTE Rel-14 introduced the higher-resolution RSTD reporting where the reporting range is from $-15391 T_s$ to $15391 T_s$ with $0.5 T_s$ resolution. The UE shall report a reference quantity based on Table 9.1.10.3-1 in TS 36.133 and a relative quantity Δ_{RSTD} defined in Table 9.1.10.4-1 in TS 36.133 so that the difference between the measured RSTD quantity and the lower bound of the corresponding range from Table 9.1.10.3-1 is between Δ_{RSTD} and $\Delta_{RSTD} + resolutionStep$.⁴⁶

4.2.1.2 Multicast DL Transmission

Multicast downlink (DL) support is beneficial for IoT use cases as it provides a means to send the same information to a set of UEs using less network resources than unicast, such as massive firmware updates and group message delivery.

To minimize specification changes, multicast support for eMTC is based upon the LTE Single Cell Point-to-Multipoint (SC-PTM) feature. LTE SC-PTM uses two logical channels, the Single Cell Multicast Control Channel (SC-MCCH) and the Single Cell Multicast Transport Channel (SC-MTCH).

The SC-MCCH logical channel contains the SC-PTM configuration message and is used to carry information such as the list of Multimedia Broadcast Multicast Service (MBMS) sessions in serving/neighbor cells and MBMS sessions scheduling parameters; it is transmitted periodically. The SC-MTCH logical channel is used to carry MBMS sessions. Each MBMS session is transmitted on a separate SC-MTCH, where a unique group identification is assigned to each MBMS session. Note that SC-PTM applies only to eMTC UEs in Radio Resource Control idle (RRC_IDLE) mode.

At the physical layer, both SC-MCCH and SC-MTCH logical channels are transmitted by the PDSCH which is scheduled by the PDCCH; these channels can be repeated to reach UEs that are in poor coverage.

⁴⁶ 3GPP TS 36.133, 3GPP; Technical Specification Group Radio Access Network; E-UTRA; Requirements for support of radio resource management (Release 14), V14.4.0, June 2017.

4.2.1.3 Miscellaneous: Mobility Enhancements, Support of Higher Data Rates and VoLTE Enhancements

While not as extensive as the enhancements for positioning and multicast DL transmissions, eMTC enhancements for mobility management, higher data rates and VoLTE, all increase support for wider variety of IoT devices.

Mobility Enhancements

Even though Cellular-IoT (CIoT) provides a significant opportunity to operators in the mobile community, there is still a desire for improvements and enhancements. Release 14 contains further enhancements in the areas of positioning, multicast, mobility, data rates, and Voice over LTE (VoLTE). Such enhancements and key areas of concentration consist of low latency, reduced User Entity (UE) complexity and spectrum efficiency.

Support of Higher Data Rates

In Rel-14 a new UE category (Cat-M2) has been introduced with support of higher data rates by using wider RF bandwidths, larger TBSs and more Hybrid Automatic Retransmission reQuest (HARQ) processes. This new UE category can support a maximum bandwidth of 5 MHz for both the downlink and the uplink, along with a maximum transport block size (TBS) of 4008 bits in the downlink and 6968 bits in the uplink. In addition, it can also optionally support 10 HARQ processes instead of 8. This new UE category has higher complexity than Cat-M1 UEs but is still considered low-cost. It can be used to support multimedia IoT applications such as voice and video.

In addition to introducing a new UE category, Rel-14 Cat-M1 UEs capabilities are also enhanced; the maximum TBS has been increased to 2984 bits in both downlink and uplink. These larger TBSs can be supported by using higher coding rates.

On the other hand, Rel-13 legacy LTE UEs (non-Bandwidth Limited UEs) can operate in coverage enhancement mode by behaving like eMTC UEs and limiting bandwidth to 1.4 MHz. In Rel-14, the legacy UE can use up to 20 MHz for the downlink and 5 MHz for the uplink. This is because, in the downlink, the peak rate can be increased by using more bandwidth (since power is divided among all PRBs). However, this is not true in the uplink since the UE can choose to transmit using all available power in only PRB.

Table 4.1 summarizes the improvements vs Rel-13 Cat-NB1 UEs.

Table 4.1. Improvements of Cat-NB1 UEs.

	Cat-M1 (Rel-13)	Cat-M1 (Rel-14)	Cat-M2 (Rel-14)	Non-BL (Rel-14)
Maximum DL bandwidth	1.4 MHz	1.4 MHz	5 MHz	20 MHz
Maximum UL bandwidth	1.4 MHz	1.4 MHz	5 MHz	5 MHz
Maximum DL TBS	1000 bits	2984 bits	4008 bits	4008 bits
Maximum DL data rate	< 1 Mbps	≈ 1 Mbps	≈ 4 Mbps	≈ 27 Mbps
Maximum UL TBS	1000 bits	2984 bits	6968 bits	6968 bits
Maximum UL data rate	< 1 Mbps	≈ 3 Mbps	≈ 7 Mbps	≈ 7 Mbps
Number of HARQ processes	8	8	10	10

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Note that this wider bandwidth operation is supported for Cat-M2 UEs only in RRC_CONNECTED mode and enabled by the eNB. Idle mode operations reuse Rel-13 design (i.e., limited to 1.4 MHz). In addition, only the PDSCH and PUSCH can use 5 MHz bandwidth. Other channels remain limited to operating within the narrowband. This was done to minimize changes to the specifications.

Several other enhancements have also been introduced to support higher peak rates. They include supporting Hybrid Automatic Retransmission Request - Acknowledgement (HARQ-ACK) bundling and reducing guard period for retuning.

VoLTE Enhancements

An important trend for IoT is the integration of voice communication capability into the devices. Use cases include using voice as the user interface (for example, voice command over the network), supporting two-way communication (for example, for wearable devices, alarms and eHealth), and for customer service. Voice capability can be supported in an LTE network via VoLTE.

In Rel-14, VoLTE coverage using half-duplex Cat-M1 devices has been enhanced. To improve coverage, several techniques have been specified; they include introducing an additional repetition factor to help fill any gap, adjusting the scheduling delays, and enabling modulation step down to allow larger packet size to be transmitted.

4.2.2 3GPP REL-14 ENHANCEMENTS FOR NB-IOT (CAT.NB1/NB2) FEATURES

Specific updates in Rel-14 for NB-IoT include:

- improved positioning capabilities,
- enhanced Multicast DL transmission,
- new band and power class support
- mobility enhancements
- support of higher data rates, and
- non- anchor PRB enhancements

4.2.2.1 Positioning (E-CID Plus OTDOA)

In LTE Rel-14, the solutions to support NB-IoT UE positioning include Cell ID (CID) positioning, enhanced Cell ID (E-CID) positioning and OTDOA positioning.

- OTDOA positioning is a downlink positioning solution, in which the UE measures the time of arrival (ToA) of the reference signals received from multiple transmission points, and then reports the reference signal time difference to the location server for positioning purpose.⁴⁷
- CID positioning estimates the UE position based on the geographical coordinates of its serving cell, and E-CID positioning uses additional measurement information for further enhancement, for example Narrowband Reference Signal Received Power (NB-RSRP) and Narrowband Reference Signal Received Quality (NB-RSRQ) for NB-IoT UEs.

⁴⁷ Observed time difference of arrival positioning in 3GPP LTE, Sven Fischer. June 6, 2014.

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CID/E-CID Positioning

As mentioned previously, CID positioning utilizes the geographical coordinates of the serving cell for UE positioning so that its positioning accuracy relies on the cell coverage range. In the E-CID positioning, NB-IoT UE could report the measurement information of NB-RSRP and NB-RSRQ to its location server by LTE Positioning Protocol (LPP), where NB-RSRP and NB-RSRQ should be measured in RRC_IDLE mode or RRC_CONNECTED mode while UE Rx-Tx time difference should be measured in RRC_CONNECTED mode in Rel-14.⁴⁸

OTDOA Positioning

In OTDOA positioning, the distance between transmission point and UE is estimated by the measurement of the ToA of the reference signal. When the UE uses narrow bandwidth for PRS measurement, the ToA estimation accuracy of the first path will be impacted due to the lower sampling rate and uncoupled multiple paths at the UE side. So the narrow bandwidth is the main factor to limit the OTDOA positioning accuracy in NB-IoT besides the Non-Line of Sight (NLoS)-based measurement. In order to solve this issue, NB-IoT Rel-14 enables both wideband-based RSTD measurement and narrowband-based RSTD measurement. If the positioning accuracy is more important than the UE cost, then the UE could select wideband-based RSTD measurement based on the existing positioning reference signal (PRS) with the PRS transmission bandwidth of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz or 20 MHz. If the UE cost is more important and/or the positioning accuracy could be relatively relaxed, then the UE could select narrowband-based RSTD measurement based on the new defined narrowband positioning reference signal (NB-PRS) which is transmitted over one or more carriers and the bandwidth of one carrier is 180KHz. Different from other existing LTE UEs, which only support RSTD measurement in RRC_CONNECTED mode, the NB-IoT UEs in Rel-14 support RSTD measurement in IDLE mode only.

Positioning Measurement in IDLE Mode

LTE Rel-14 introduces UE positioning measurement in IDLE mode for NB-IoT. In this solution, after receiving the positioning assistance information from Evolved Serving Mobile Location Center (E-SMLC) (i.e. location server) and before starting positioning measurement in IDLE mode, the UE may finish any other activities in process, waits until the network releases or suspends the connection, and then receives an RRC connection release or suspend from the eNB due to the expiration of the inactivity timer. After finishing positioning measurement, the UE will establish the connection with MME and send the location measurement to the E-SMLC.⁴⁹

4.2.2.2 Multicast DL Transmission

Multicast DL transmission for NB-IoT targets the same use cases as eMTC; for the same reason it is based upon the LTE SC-PTM feature and uses the same logical channels as eMTC (SC-MCCH and SC-MTCH channels). As for eMTC SC-PTM applies only to NB-IoT UEs in RRC_IDLE mode.

The main difference with eMTC is related to the physical layer: for NB-IoT both SC-MCCH and SC-MTCH logical channels are transmitted by the NB-PDSCH which is scheduled by the NB-PDCCH. As a consequence, the multicast DL performances for NB-IoT may differ from eMTC ones (extended coverage, peak/sustained data rates, etcetera).

⁴⁸ 3GPP RP-171059, Status report for WI: *Enhancements of NB-IoT*, 3GPP RAN#76 meeting, West Palm Beach, USA. 5-8 June 2017.

⁴⁹ 3GPP TS 36.305, *Evolved Universal Terrestrial Radio Access (E-UTRA); UE positioning in E-UTRAN*, V14.1.0. March 2017.

4.2.2.3 New Band and Power Class Support

Support of small form-factor batteries is needed to address use cases for which IoT devices are small-sized and/or lightweight, for example wearables. Such batteries are expected to correspond to a UE maximum output power lower than the 20 and 23 dBm UE power classes already supported in Rel-13.

In Rel-14, a new UE Power Class (PC 6) has been introduced which corresponds to a UE output power of 14 dBm; PC 6 is supported by both Cat-NB1 and Cat-NB2 UE categories. Specific signaling is introduced to take into account the consequences of this lower output power, for example the need for a larger number of repetitions in the uplink or the lower RSPM measurements accuracy.

According to 3GPP specifications, operating bands for Category NB1 and NB2 were developed to operate in E-UTRA bands 1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 25, 26, 28, 31, 66 and 70. Category NB1 and NB2 UE Power Classes are specified and define the maximum output power for any transmission bandwidth within the category NB1 and NB2 channel bandwidth as specified in 3GPP TS 36.101.⁵⁰ In Release 14, eMTC and NB-IoT support has been added to the following Bands and Power Classes:

Table 4.2. UE Power Class.

EUTRA band	Class 3 (dBm)	Tolerance (dB)	Class 5 (dBm)	Tolerance (dB)	Class 6 (dBm)	Tolerance (dB)
1	23	±2	20	±2	14	±2.5
2	23	±2	20	±2	14	±2.5
3	23	±2	20	±2	14	±2.5
5	23	±2	20	±2	14	±2.5
8	23	±2	20	±2	14	±2.5
11	23	±2	20	±2	14	±2.5
12	23	±2	20	±2	14	±2.5
13	23	±2	20	±2	14	±2.5
17	23	±2	20	±2	14	±2.5
18	23	±2	20	±2	14	±2.5
19	23	±2	20	±2	14	±2.5
20	23	±2	20	±2	14	±2.5
25	23	±2	20	±2	14	±2.5
26	23	±2	20	±2	14	±2.5
28	23	±2	20	±2	14	±2.5
31	23	±2	20	±2	14	±2.5
66	23	±2	20	±2	14	±2.5
70	23	±2	20	±2	14	±2.5

4.2.2.4 Support of Higher Data Rates

In Rel-14 a new UE category (Cat-NB2) has been introduced with support for higher data rates by using larger TBSs and multiple HARQ processes. This new UE category can support a maximum Transport Block Size (TBS) of 2536 bits for both uplink and downlink; these larger TBSs can be supported by using a higher coding rate as well as a larger number of subframes (up to the same maximum number of 10) in one scheduling resource unit. In addition, it can also optionally support two Hybrid Automatic Retransmission reQuest (HARQ) processes instead of one.

⁵⁰ 3GPP TS 36101-e30, *Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception*.

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Table 4.2 summarizes the improvements vs Rel-13 Cat-NB1 UEs.

Table 4.3. Improvement in Cat-NB1 UEs.

	Cat-NB1 (Rel-13)	Cat-NB2 (Rel-14)
Maximum DL TBS	680 bits	2536 bits
Maximum DL data rate	26 kbps	127 kbps
Maximum UL TBS	1000 bits	2536 bits
Maximum UL data rate	62 kbps	159 kbps
Number of HARQ processes	1	1 or 2

Note that Rel-14 Cat-NB1 UEs support the same data rates as in Rel-13.

The timing diagrams for supporting two HARQ processes in downlink and uplink are shown in Figure 4.12, including minimum gap values.

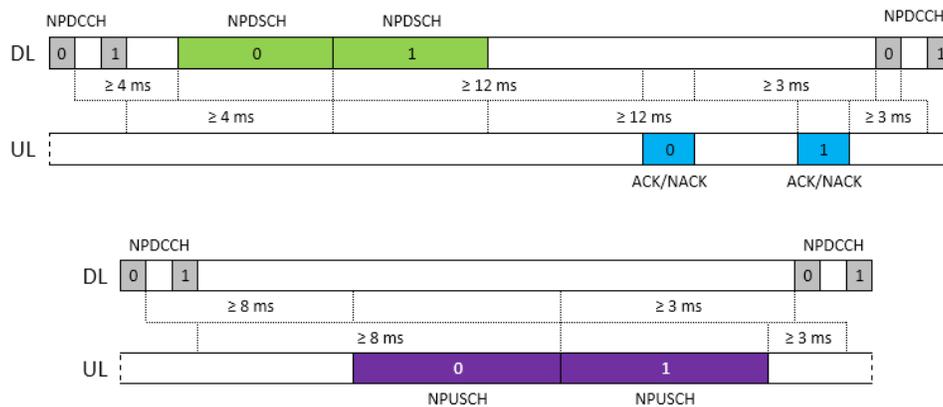


Figure 4.12. HARQ Processes in Downlink and Uplink with Minimum Gap Values.

4.2.2.5 Miscellaneous: Mobility and Service Continuity Enhancements, Non-Anchor PRBs Enhancements

Additional NB-IoT enhancements in Rel-14 include those for mobility with enhanced service continuity and utilization of non-anchor PRBs.

Mobility and Service Continuity Enhancements

Development on mobility and service continuity provided for enhancements to connected mode mobility 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.

Non-anchor PRBs Enhancements

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For NB-IoT, downlink anchor carrier refers to the carrier with Narrowband Primary Synchronization Signal (NB-NB-NPSS) / PSS / Narrowband Secondary Synchronization Signal (NB-SSS) / Narrowband Physical Broadcast Channel (NB-PBCH) and System Information Blocks (SIB) transmitted, while uplink anchor carrier refers to the carrier with Narrowband Physical Random-Access Channel (NB-PRACH). Additional NB-IoT carriers (called non-anchor carriers) can be configured to provide additional capacity. UE accesses the NB-IoT system using anchor carriers. After the UE has completed Radio Resource Control (RRC) configuration procedure, it can be moved to non-anchor carriers for data transmission and reception via RRC signaling. In Rel-13, some procedures such as paging and random access can only be performed on anchor carriers; this limits network paging/random access capacity. In Rel-14, paging and Random-Access procedures can also be supported in non-anchor carriers.

For paging, up to 16 downlink non-anchor carriers can be configured to support this procedure. This configuration is provided in the SIB. UE selects the carrier based on its UE ID. In addition, the network supports uneven paging load distribution between anchor and non-anchor carriers using weighted distribution between all carriers. For random access, up to 16 non-anchor carriers can be configured to support this procedure. UE selects NB-PRACH resource (including selection of carrier) based on a random draw by using different carrier selection probabilities for anchor and non-anchor carriers.

For both paging and random access, such uneven non-anchor carrier selection is mandatory, as Rel-13 NB-IoT UEs always use an anchor carrier to perform these procedures.

4.2.3 3GPP REL-14 NETWORK ARCHITECTURE AND PROTOCOL ENHANCEMENTS

While much of the Rel-14 IoT related enhancements focused on the radio aspects described in the previous sections, there were also some enhancements to the core network. DÉCOR, MONTE, and AESE were updated to align with enhancements in the RAN and to provide better support for 3rd party and group based communications.

4.2.3.1 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 Serving Gateway (SGW(s)) and/or Packet (PGW(s)) and optionally Mobility Management Entity (MME(s)) designed to meet the requirements of these different devices in a cost-efficient manner. In Release 14, 3GPP has enhanced this feature 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 Public Land Mobile Network (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 that PLMN, so that the RAN can use this information to route the UE signaling to an MME of the correct DCN. The UE may also be configured with a 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.

4.2.3.2 Group Based Signaling

The 3GPP system owns operational information on devices/subscribers and their service status that may be valuable for 3rd 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 3rd parties can be securely made. Release 13 also defined network capability exposure functions as part of work items including MONTE.

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, for example 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 for example communication pattern, group-based enhancements make very good sense in terms of practicability.

With the motivation described above, in Rel-14 3GPP investigated whether per-UE basis network capability exposure functions defined as part of MONTE and AESE work items can benefit from being performed based on a per-group basis. Protocols of interfaces among 3rd party server, SCEF, PCRF and HSS are enhanced to enable group-based signaling.

4.2.3.3 CIOT Extensions

An extended architecture to support Cellular Internet of Things was studied in TR 23.730. In Rel-14, as part of normative work, the following enhancements were specified.

Restriction of Use of Enhanced Coverage

The usage of Enhanced Coverage may require use of extensive resources (for example radio and signaling resources) from the network. This feature enables the operator to prevent specific subscribers from using Enhanced Coverage. The Enhanced Coverage Restricted parameter is introduced as part of the subscription data in the HSS that specifies per PLMN whether the enhanced coverage functionality is restricted or not for the UE. The MME receives Enhanced Coverage Restricted parameter from the HSS. If the UE includes the support for restriction of use of Enhanced Coverage, the MME sends the Enhanced Coverage Restricted parameter to the UE in the Attach/TAU Accept message. The UE uses the value of Enhanced Coverage Restricted parameter to determine if the enhanced coverage feature is restricted or not. The MME also provides an Enhanced Coverage Restricted parameter to the eNB via S1 signaling whenever the UE context is established in the RAN, for example, during service request procedure, attach procedure, and TAU procedure. The Restriction of use of the Enhanced Coverage is specified in TS 23.060 and TS 23.401. The support for Enhanced Coverage (i.e. CE Mode B) for both "data centric" and "voice centric" UEs is specified in TS 23.401 and TS 23.228.

The support for Enhanced Coverage Restriction Control via SCEF was also specified which enables 3rd party service providers to query status of the enhanced coverage restriction or enable/disable enhanced coverage restriction per individual UEs. The Enhanced Coverage Restriction Control via SCEF is specified in TS 23.682.

Stage-3 aspects for restriction of use of Enhanced Coverage are specified in TS 24.301, TS 23.008, TS 29.272, and TS 29.002.

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Reliable Data Delivery

The Rel-13 solution for non-IP data delivery (NIDD) via the SCEF is unreliable, i.e., there is no mechanism for the SCEF to determine if the data was successfully delivered to the UE (for example, in case of UE radio link failure, or if the UE is out of coverage) and for the UE to determine if the data was successfully delivered to the SCEF (for example, in case of T6a/b connection failure, SCEF congestion etcetera). Rel-14 introduced enhancements for reliable delivery of NIDD. Two complimentary mechanisms were specified:

- Reliable delivery by acknowledgements on a hop-by-hop basis, i.e. the link layer protocol on each interface used for NIDD uses acknowledgments and nodes apply retransmissions if needed to ensure reliable delivery;
- Reliable Data Service (RDS) between UE and SCEF. The RDS provides a mechanism for the SCEF to determine if the data was successfully delivered to the UE and for the UE to determine if the data was successfully delivered to the SCEF. When a requested acknowledgement is not received, the RDS retransmits the packet. The RDS is enabled or disabled based on APN Configuration per (Service Level Agreement) SLA. The RDS protocol is specified in TS 24.250.

Inter RAT Idle Mode Mobility to/from NB-IoT

Rel-13 does not support idle mode mobility to and from the NB-IoT RAT and if the MME identifies an attempt for RAT change to or from NB-IoT, the MME requires the UE to reattach. Rel-14 introduced the support for idle mode inter-RAT mobility to and from NB-IoT. To ensure a UE initiates tracking area updating procedure when performing inter-RAT mobility between NB-IoT and WB-E-UTRAN, the E-UTRAN shall be configured such that a Tracking Area does not contain both WB-E-UTRAN and NB-IoT cells, and the MME shall not allocate a Tracking Area Identity list that contains both NB-IoT and WB-E-UTRAN Tracking Areas.

A new subscription parameter PDN-Connection-Continuity was added to indicate, on per APN basis, how to handle the PDN connection when the UE moves between "broadband" (WB-E-UTRAN, UTRAN) and "narrowband" (NB-IoT, GPRS, EC-GSM IoT). The serving node based on the PDN-Connection-Continuity subscription parameter and on the operator policy determines whether to maintain the PDN connection or disconnect the PDN connection with/without a reactivation request. Stage-2 details are specified in TS 23.401 and TS 23.060.

Stage-3 details are specified in TS 29.272 and TS 29.274.

MBMS User Service for UEs using Power Saving Functions

MBMS Bearer Services (see TS 23.246) together with MBMS User Services (see TS 26.346) provide a means to deliver data or triggering payload over broadcast to multiple UEs at the same time. One of the key requirements is how to provide MBMS service to the UEs using power saving functions (for example Power Saving Mode or eDRX). Details of MBMS user service for UEs using power saving functions is specified in TS 23.401.

Enhancements to Location Services for CIoT

In order to support Location Services for CIoT UEs, the following enhancements to Location Services are defined:

- Deferred Location for the UE availability event
- Indication of UE RAT type and/or coverage level to Evolved Serving Mobile Location Centre (E-SMLC)

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- Support of UE positioning measurements in idle mode
- Addition of Periodic and Triggered Location for EPC
- Support of Last Known Location for a UE that are unreachable for long periods of times

Stage-2 details are specified in TS 23.682 and TS 23.271.

Inter UE QoS for NB-IoT UEs Using Control Plane Clot EPS Optimization

To allow the E-UTRAN to prioritize resource allocation between different NB-IoT UEs when some of the UEs are using the Control Plane Clot EPS optimization, the eNB may request, based on configuration, the MME to supply the eNB with the negotiated QoS profile for any UE that is using the Control Plane Clot EPS optimization. The QoS profile sent to the eNB by the MME consists of the E-UTRAN Radio Access Bearer (E-RAB) Level QoS Parameter. The eNB can use the QoS profile to assist with resource prioritization decisions between different NB-IoT UEs.

Stage-2 details are specified in TS 23.401. Stage-3 details are specified in TS 36.413.

CN Overload Control for Data Transfer via Control Plane Clot EPS Optimization

Further enhancements to handle the CN overload from data transmission via Control Plane Clot EPS Optimization were specified. Under overload conditions the MME may restrict requests from UEs for data transmission via Control Plane Clot EPS Optimization. A first option consists in a Control Plane data back-off timer returned by the MME to the UE via NAS signaling. While the Control Plane data back-off timer is running, the UE shall not initiate any data transfer via Control Plane Clot EPS Optimization. The MME shall store the Control Plane data back-off timer per UE and shall reject any further request (other than exception reporting) for data transmission via Control Plane Service Request from that UE while the Control Plane data back-off timer is still running. A second option, based on the MME requesting the eNB and using OVERLOAD START message, is to not accept RRC connection requests with RRC establishment because of "mo-data" or "delayTolerantAccess" from UEs that only support Control Plane Clot EPS Optimization.

Stage-2 details are specified in TS 23.401. Stage-3 details are specified in TS 24.301, TS 36.331 and TS 36.413.

4.3 OTHER FEATURES RELATED TO IOT

Several features supporting IoT capabilities were studied and enhanced in Rel-14. A study on Proximity Services demonstrated the benefits of a layer 2 relay function, a key functionality needed for wearables such as smart watches. The relay function allows a device that is out of range of the network to exchange signaling and data via an intermediary device that has a network connection. Another use of Proximity Services supported in Rel-14 is vehicle to everything (V2X) communications. Based on the increased interest in the autonomous car industry, several aspects of the Rel-13 Proximity Services capabilities were enhanced to support V2X traffic with the requisite quality of service (QoS). Alongside these specific feature enhancements, charging and device management capabilities were expanded to fully support the new and enhanced IoT features.

4.3.1 3GPP REL-14 FURTHER ENHANCEMENTS TO LTE D2D, UE TO NETWORK RELAYS FOR IOT AND WEARABLES

Direct discovery and direct communication were the first Proximity Services (ProSe) based on LTE specified by 3GPP in Release 12 of the standard. During that time, the focus was on addressing mission critical

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communications' requirements from Public Safety community and social-technological trend of emerging commercial, proximity-based applications.⁵¹ Release 13 introduced additional enhancements and UE-to-Network Relay was amongst the most interesting ones, giving a possibility for a so called remote UE, potentially being out of coverage of LTE network, to achieve network connectivity via another UE, serving as a relay. However, once more, the functionality was targeted for exclusive use of Public Safety applications. On the other hand, with the growing popularity of wearable devices such as smartwatches, fit-bands or network-enabled medical devices (for example heart monitors) as well as that of Internet of Things related applications, in Release 14 a new Study Item was launched (and continues in Release 15) with a goal to "study enhancements to ProSe UE-to-network relaying and to the LTE D2D framework for commercial and public safety applications such as wearable devices."⁵² The objectives of this study were more ambitious than merely analyzing how to apply Layer 3 UE-to-Network (NW) relaying, initially developed for Public Safety community, to additional use cases. It was decided to focus the study on Layer 2 relaying, which is believed to bring many benefits in comparison to the already existing framework. The accompanying work was also started in Service and Architecture (SA) Work Groups to look at higher layer aspects of L2 relaying operations as described in SP-160961.⁵³

To better understand the differences of the two frameworks, one should commence with having a closer look at the protocol stack of both solutions, as depicted in Figure 4.13 and in Figure 4.14, which are extracted from 3GPP TS 23.303 and 3GPP TR 36.746 respectively.

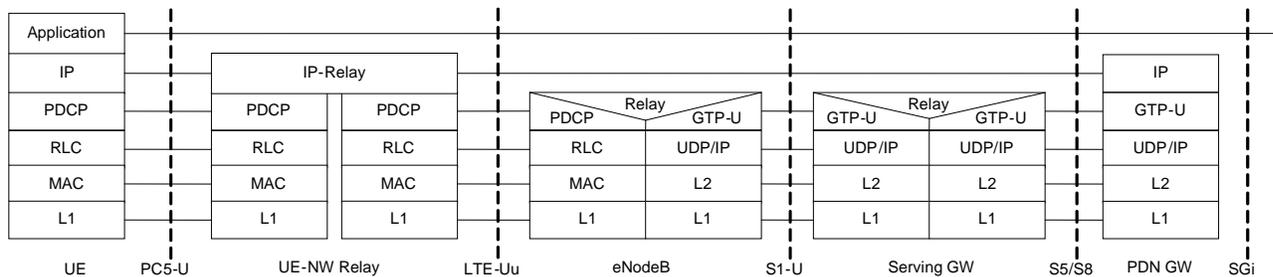


Figure 4.13. User Plane for UE-to-Network Relay.⁵⁴

⁵¹ RP-122009, *Study on LTE Device to Device Proximity Services*, 3GPP TSG RAN Meeting #58.

⁵² RP-16130, *Revision of SI: Further Enhancements LTE Device to Device, UE to Network Relays for IoT and Wearables*, 3GPP TSG RAN Meeting #72.

⁵³ SP-160961, *New Study WID: Study on architecture enhancements to ProSe UE-to-Network Relay*, 3GPP TSG SA Meeting #74.

⁵⁴ Figure 5.1.2.2-1 from 3GPP TS 23.303.

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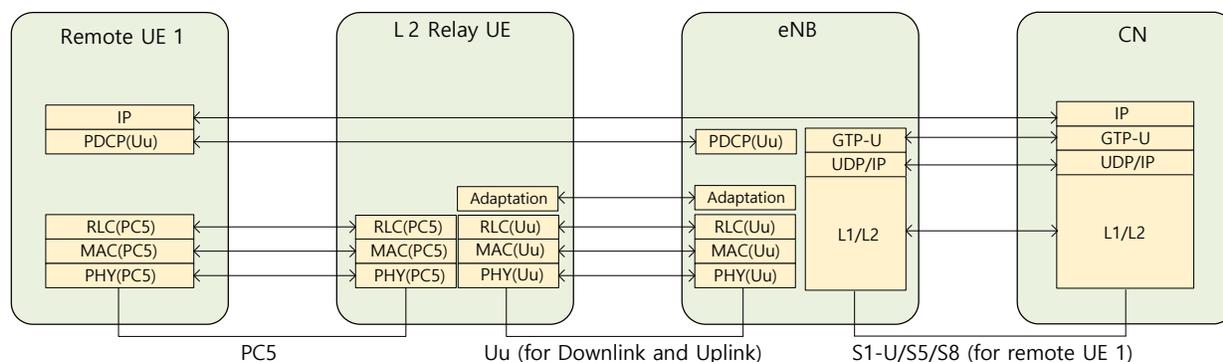


Figure 4.14. User Plane Radio Protocol Stack for Layer 2 Evolved UE-to-Network Relay (PC5).⁵⁵

As can be seen in Figures 4.13 and 4.14, in Layer 3 relaying architecture, there is no direct connection between the network (and an eNB in particular) and the remote UE. UE-NW Relay operates as an IP router, which inspects each packet up to IP layer and then either “keeps” it for itself or forwards it to the remote UE. On the other hand, in Layer 2 architecture there is a direct, end-to-end connection on the PDCP protocol layer between the remote UE and an eNB. On the Core Network side, a connection from the remote UE terminates either in the Serving Gateway (S-GW) on IP protocol layer as shown in Figure 4.13 or in the Mobility Management Entity (MME) for the Control Plane on NAS protocol layer. This brings several important benefits as compared to Layer 3 framework:

- End to end connectivity on NAS level allows remote UE identification and reachability by the Core Network to virtually the same extent as for non-relayed communications, giving a possibility to for example apply service or subscription based QoS or charging policy enforcement etcetera.
- Direct connection between the UE and the eNB allows to use RRC protocol’s functionality to apply proper RRM policy and access control or ensure service continuity using the mechanisms similar to those used for direct communication like, for example handover
- LTE built-in security mechanisms provided by PDCP layer can be used for integrity protection and ciphering

In addition, the Layer-2 relay protocol stack includes a so-called adaptation layer (AL) above Radio Link Control (RLC) protocol with a purpose to:

- Allow the traffic belonging to different remote UEs to be multiplexed and served over a single Data Radio Bearer (DRB) established on Uu interface between relay UE and eNB
- Allow remote UE and relay UE to differentiate the traffic belonging to several e2e radio bearers of the same remote UE when carried over the short-range D2D interface (which can be either based on PC5 or non-3GPP technology such as Bluetooth or WiFi)

All these mechanisms were not available in the Layer-3 relaying framework and could only be addressed by having some special treatment on application layer (for example packet encryption in higher layers). Even with Layer-2 relaying, additional enhancements are needed to take full advantage of the benefits. Apart from specifying a modified protocol stack, additional required modifications were studied to allow for enhanced power efficiency of remote UE (which is of very high significance for use cases such as IoT and wearables) by allowing for paging and system information relaying or limitation of measurements by applying group mobility. On sidelink interface, although the baseline of sidelink discovery and communications was kept, modifications to allow for higher power efficiency and for the support of UE’s

⁵⁵ Figure 5.1.1-1 from 3GPP TR 36.746.

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with limited bandwidth capabilities were also addressed, for example sidelink DRX and Transmit Power Control, semi-persistent transmission over sidelink or eNB assisted UE discovery or association of discovery transmission and reception resources. The full list and the details of the studied functionalities can be found in 3GPP TR 36.746⁵⁶ for RAN aspects and in 3GPP TR 23.733⁵⁷ for Core Network aspects. One should keep in mind that while this paper is being prepared, 3GPP has not yet finalized its study. Furthermore, the list of studied features is relatively long and it is very unlikely that all of them will make their way into the potential normative phase in Release 15 of LTE.

4.3.2 3GPP REL-14 SUPPORT FOR V2V SERVICES BASED ON LTE SIDELINK WI

Stimulated by the increasing interest in connected vehicles, 3GPP specified several enhancements as part of LTE Release 14, targeting both cellular and direct (sidelink) communication, and enabling both safety and commercial automotive services. The supported functionalities focus on services where one communication end point is a vehicle and the other end point may be another vehicle (V2V), an application associated to road infrastructure (V2I), a pedestrian using a smartphone (V2P) or a server in the network infrastructure (V2N). While vehicle to network (V2N) typically relies on cellular connectivity, vehicle to vehicle/infrastructure/pedestrian (V2V/I/P) may be enabled by a cellular connection, a direct communication, or a combination of the two. The most appropriate connectivity technology for a certain service can be chosen taking into account factors such as radio, regulatory and business requirements. Different regions in the world are indeed likely to adopt different technology choices for similar V2X services, at least initially.

3GPP spent a large effort to ensure that LTE-based vehicle to everything (V2X) provides superior performance compared to other technologies targeting similar services, such as 802.11p-based Dedicated Short-Range Communications (DSRC). Indeed, LTE-V2X benefits from the capability to complement direct communication using the 5.9GHz Intelligent Transport Systems (ITS) band (similarly as DSRC) with cellular capabilities using licensed bands. The LTE PC5 direct interface has also been optimized by 3GPP for V2X safety services and it is expected to provide a significant performance advantage compared to DSRC under comparable propagation conditions.

The Release 14 PC5 interface is derived from the evolution of the Rel-12/13 PC5 interface, which was initially developed targeting Proximity Services (ProSe) in the Public Safety context. Release 14 improves PC5 in different aspects, such as:

- The physical layer is enhanced to support relative speeds up to 250km/h by densifying the Demodulation Reference Signal (DMRS) pattern in time domain;
- Accurate synchronization and standalone operation in ITS bands is enabled by taking advantage of Global Navigation Satellite System (GNSS);
- Low-latency scheduling protocol where control information and data may be transmitted in the same subframe;

⁵⁶ 3GPP TR 36.746, *Technical Specification Group Radio Access Network; Study on further enhancements to LTE Device to Device (D2D), User Equipment (UE) to network relays for Internet of Things (IoT) and wearables.*

⁵⁷ 3GPP TR 23.733, *Technical Specification Group Services and System Aspects; Study on Architecture Enhancements to ProSe UE-to-Network Relay.*

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- Distributed efficient resource allocation is enabled by resource sensing and future resource reservation in the distributed scheduling protocol (Mode 4). Alternatively, the eNB may dynamically assign radio resources to the devices (Mode 3).

Additional enhancements enable cost- and power-efficient PC5 implementations for handheld devices. It should be noted that the PC5 interface was optimized for the traffic properties of IP-less V2X safety traffic and may not be efficiently reused, as it is, for MBB-type of applications.

The cellular (Uu) interface was also enhanced in Release 14, including scheduling optimizations for periodic V2X traffic and update of Quality of Service (QoS) Class Identifier (QCI) parameters.

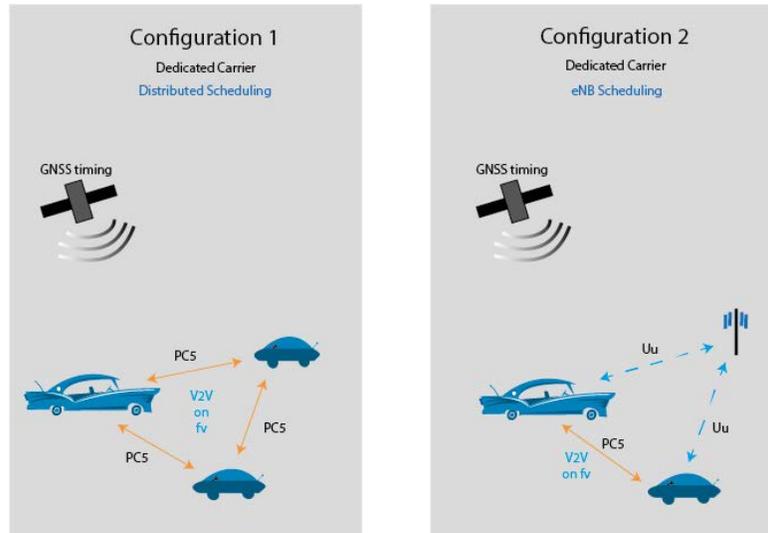


Figure 4.15. Distributed Scheduling (Mode 4) and eNB-scheduling (Mode 3) of V2X Resources on a Dedicated Carrier.

4.3.3. CHARGING

Short Message Service is also one of the capabilities used for Machine Type communications per TS 23.282:

- Trigger Delivery using T4 introduced from Rel-11, allowing a Service Capability Server (SCS) to send information to the UE via SMS, to trigger the UE to perform application specific actions that include initiating communication with the SCS for the indirect model or an AS in the network for the hybrid model
- In Rel-14, UE SMS originating using T4 path allowing to MSISDN-less UE to reach an SCS/AS recipient of this short message

In 3GPP Rel-14 existing offline and online charging from the SMS-SC have been enhanced to include specific behavior and information related to these SMS MT and SMS MO.

4.3.4 DEVICE MANAGEMENT AND SERVICE ENABLEMENT

The Open Mobile Alliance (OMA) Light Weight Machine-to-Machine (LwM2M) protocol provides the capability for applications to communicate and manage IoT devices. LwM2M is based on the Internet

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Engineering Task Force (IETF) Constrained Application Protocol (CoAP) providing communication between a LwM2M Server and a LwM2M Client (where Client is located in a constrained IoT device).

Some of the abilities which are helpful from 5G developments include:

- Low data byte transmission with allowance for client to sleep (i.e., non-continuous communication)
- Suitable for constrained devices (hence reduced footprint for reduced CAPEX for car manufacturers)
- Several objects can be reported in one message using simple content types like TLV, JSON and single objects with simple text content type
- Ability to support a range of solutions through pre-defined objects (connected car objects/resources)
- Client (Things) could send notifications to server based on defined trigger events for example periodic reporting, reporting upon change of value, reporting based on thresholds reached
- LwM2M by default works with 3GPP technologies hence easier integration with telecommunication operators
- LwM2M also works with technologies like WiFi and default can traverse any IP network
- Ideally LwM2M can also easily cater to the normal device management scenarios
- LwM2M also works with LPWAN technologies 3GPP has defined like CAT-M1/NB-IoT with its frugal foot print of communication.

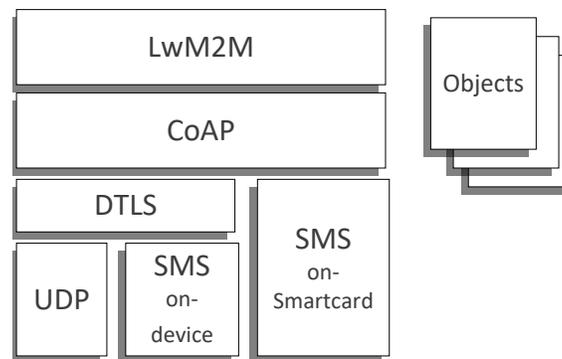


Figure 4.16. Light Weight M2M.⁵⁸

The core interfaces between the server and the client are categorized into:

- Bootstrap
- Client Registration
- Device Management and Service Enablement
- Information Reporting

⁵⁸ Open Mobile Alliance™, *LightweightM2M (LWM2M) v1_0*, OMA-TS-LightweightM2M-V1. URL: <http://www.openmobilealliance.org/>

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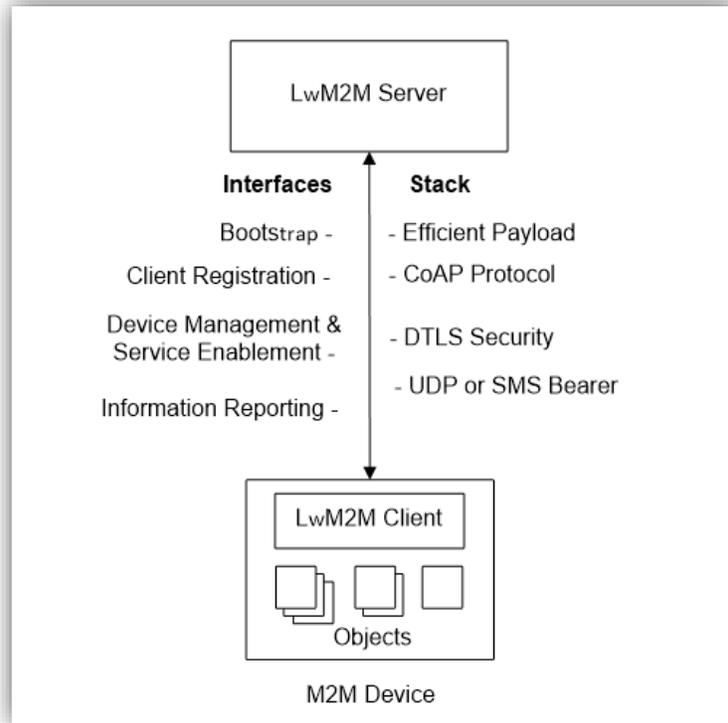


Figure 4.17. The Overall Architecture of the LwM2M Enabler.⁵⁹

OMA LwM2M is unique in the aspect that it converges both management and application control functionality within one communication session allowing for efficient handling of IoT devices. Since OMA LwM2M protocol is based on IETF CoAP, the OMA LwM2M protocol allows different transport bindings (for example, User Datagram Protocol (UDP), Short Message Service (SMS)) and is secured using IETF Datagram Transport Layer Security (DTLS) protocol.

The device management features defined by OMA for release 1.0 of LwM2M are:

- Access control on the specific contents that could be handled remotely by different entities
- Software / firmware Management for applications inside the Client
- Lock & Wipe of the device from misuse
- Connection management for choosing various radio methods by the Client
- Device Capability Management to identify the capabilities existing in the device
- Location of the device
- Connection Statistics in terms of communication characteristics over the air

The object registry provides a unique way of identifying the necessary and relevant objects. The object registry is maintained by OMNA (Open Mobile Naming Authority). It includes categories for interleaving 3rd

⁵⁹ Open Mobile Alliance™, *LightweightM2M (LWM2M) v1_0*, (OMA-TS-LightweightM2M-V1. URL: <http://www.openmobilealliance.org/>)

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party management objects and application objects into the OMNA registry from vendors and other standards organizations (for example, GSMA, oneM2M and IPSO Alliance).

6. DISCUSSION OF 3GPP IOT SOLUTIONS VS NON-3GPP SOLUTIONS

While a lot of IoT applications can be supported over the wide-area cellular networks deployed by MNOs, there are certain entities that prefer their own private networks for reasons such as data security or controllability of network. Since these entities generally do not own any spectrum, they will often have to operate their private networks using unlicensed or shared spectrum. In such cases, they need to use non-3GPP air interface technologies. In some other cases, they may partner with MNOs to use the latter's licensed spectrum to run their private networks, thus allowing the use of regular cellular technologies.

6.1 MULTEFIRE

Even though existing 3GPP cellular technologies cannot be directly deployed in unlicensed spectrum without the aid of licensed spectrum, owners of private networks would still want a technology that can offer performance and reliability similar to today's cellular technologies. For example, some of the machinery being connected in a private IoT network may be mobile. It is important to ensure that the connections to those machines are maintained without interruption during mobility. This is something that is inherently supported in a cellular network but is not always guaranteed in a network based on alternate technologies.

MulteFire is an LTE-based cellular technology that can operate exclusively in unlicensed or shared spectrum. The first MulteFire standard (Release 1.0) was completed in January 2017 by the MulteFire Alliance⁶⁰. It leverages elements of License Assisted Access (LAA) and eLAA from 3GPP for DL and UL respectively. This allows the deployment of private networks for commercial or industrial IoT to be deployed by entities without licensed spectrum. MulteFire 1.0 defines wideband operation with minimum carrier bandwidth of 10 MHz in the US-specific CBRS band and the global 5 GHz unlicensed band. As an LTE-based technology, interworking between MulteFire and LTE networks can be easily supported if needed.

The next release of MulteFire (1.1) will include enhancements targeted for IoT. These include coverage extension and support of narrowband operation (Cat-M1) in other bands such as the ISM bands in 900 MHz and 2.4 GHz. Many of the features described in Section 4 will be incorporated in MulteFire 1.1.

6.2 OTHER UNLICENSED IOT CONSIDERATIONS

While this paper focuses on the extensions to 3GPP standards that address IoT, it should also be noted that much of the current IoT traffic is carried by unlicensed spectrum today. At a high level, the unlicensed IoT traffic has some of the same benefits of cellular IoT including:

- Coverage range: from a few kilometers in dense urban areas up to 15-30 kilometers in rural areas
- Power consumption: 10+ years of battery life (the device's power produced cannot exceed 10-25 mW, to comply with usage of ISM frequencies, and to limit data consumption and preserve battery life)
- Low cost: competitive radio chipset cost

⁶⁰ www.multefire.org.

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Interestingly, this IoT traffic may be carried by traditional 802.11⁶¹. This being the case, and given that 5G's tenets include heterogeneity and wider methods for authenticating devices onto a 5G network, then the handling and management of IoT from a wider set of IoT access types can be handled through concepts such as network slicing. This raises the positive prospect of additional IoT access technologies being integrated with and into a 5G system via such functions as N3 Interworking Functions (N3IWF). Such approaches have the opportunity of unifying the management IoT and enhancing the business opportunities that IoT may provide.

7. CONCLUSION

3GPP standards have kept pace with the growing demands as evidenced by the Release 14 enhancements. This paper details the technology advances that will support the growing markets for wearables, health care, connected vehicles, and more:

- Both eMTC and NB-IoT have been enhanced to better support IoT devices requiring more accurate positioning, higher data rates, longer battery life, multicast communications, direct communication between devices, and more efficient support for low mobility devices.
- The core network has been enhanced to provide more efficient handling of large numbers of IoT devices communicating in short data bursts, group based communications, non-typical mobility patterns (for example, stationary, geographic limits), and optimized quality of service.
- Specific system enhancements aim at supporting connected vehicles and wearables, with improved efficiency, safety, and quality of user experience. Device management enhancements improve battery life while also providing safety features such as data protection for lost or stolen devices.

U.S. operators have already deployed initial IoT services in their networks, many with LTE-M, which are being used by individuals and IoT application providers. As these deployments are upgraded with Release 14 enhancements, the market is primed to take advantage of the new capabilities with new devices in new industries. IoT applications will make use of the additional data generated by IoT devices to continuously improve the user experience, which at the same time drives a need for privacy and data security enhancements. Factory automation will drive more enhancements in the 5G time frame with even more stringent requirements on latency and reliability. Increased use of sensors and inventory management will continue to drive battery life optimizations, mobility management efficiencies and expanded coverage.

CIoT provides many benefits for the IoT and will encompass a significant share of the market. These benefits include:

- High data rates: CIoT supports a full range of IoT devices, from sensors which send occasional short bursts of data to devices which send streaming video to multiple endpoints.
- Mobility: CIoT provides the mobility management to track and maintain communications with IoT devices wherever they are and however they are traveling.
- Energy efficiency: CIoT offers resource efficiencies in the core and access networks that also translate to longer battery life in the IoT devices.
- Proximity services: CIoT's relay functionality allows devices outside of network coverage to communicate with devices inside network coverage.

⁶¹ *The Internet of Things- Transforming the World We Live In*, Presentation by Bob Gessel, Ericsson. Slide 12: <http://www.cvt-dallas.org/IOT-Nov15.pdf>

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- Device density: CIoT's group management functionality includes resource efficient multicast communications as well as increased coverage to support more devices in a local configuration.
- New markets: CIoT supports new services for fast growing markets such as connected vehicles and wearables. Future enhancements will support additional vertical industries such as factory automation.

A majority 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. Whereas 4G has been driven by device proliferation, bandwidth hungry mobile services, and dynamic information access, 5G will also be driven by IoT applications. There will be a wide range of IoT use cases in the future, and the market is now expanding toward both Massive IoT (MlIoT) deployment as well as more advanced solutions that may be categorized as Critical IoT.

To reach massive scale, which is defined by 3GPP as at least 1 million devices per kilometer,⁶² mobile networks must more efficiently support the simplest devices that communicate infrequently, and are ultra-energy efficient so they can deliver an extremely long ten-year battery life. The requirement would be for low-cost devices with low energy consumption and good coverage.

Alternatively, Critical IoT applications will have very high demands for reliability, availability, and low latency which could be enabled by LTE or 5G capabilities. The volumes would be much smaller, but the business value is significantly higher. There are also many other use cases between the two extremes, which today rely on 2G, 3G or 4G connectivity.

Declining modem costs, evolving LTE functionality and 5G capabilities are all expected to extend the range of applications for critical IoT deployments. However, many use cases exist between these two extremes, which today rely on 2G, 3G or 4G connectivity.

Network connectivity is essential for the Internet of Things (IoT) and there are many wireless access technologies currently in use but given the wide variety of use cases, environments and requirements, no single connectivity technology and standard can adequately serve all use cases.

Looking ahead, 3GPP Release 15 introduces 5G Phase 1. While the requirements included in 3GPP TS 22.261 address MlIoT along with URLLC, eMBB, and other new cellular capabilities, 5G Phase 1 will focus on eMBB as an early deployment option of the 5G New Radio and evolved core network. 3GPP SA2 has initiated a study on the architectural impacts of MlIoT in the Release 15 timeframe, which will enable the architecture and protocol enhancements for MlIoT to be realized in Release 16. These enhancements will further expand the IoT capabilities to take advantage of increased coverage with wide area cells and small cells, improved resource efficiency for IoT devices with limited or no mobility, and support for multiple access technologies, from LTE and 5G New Radio to WLAN and even fixed access. As the market for IoT continues to expand, 3GPP will continue to support the growing demands for new and improved communications for IoT devices.

Future white papers from 5G Americas will address the advancements for CIoT in Releases 15 and 16 as the market continues to grow and expand through many different use cases and services.

⁶² *Leading the LTE IoT evolution to connect the massive Internet of Things*, Qualcomm white paper, June 2017.

APPENDIX

ACRONYM LIST

3GPP	Third Generation Partnership Project
2G	Second Generation
4G	Fourth Generation
5G	Fifth Generation
ACP	Access Control Policy
AE	Application Entity
AESE	Architecture Enhancements for Services Capability Exposure
AGCH	Access Grant Channel
ALLJoyn	collaborative open source software framework that allows devices to communicate
API	Application Programming Interface
ARC	Automatic Retransmission Request
AS	Application Server
BBF	Broadband Forum
BCCH	Broadcast Control CHannel
BPSK	Binary Phase Shift Keying
BSS	Business Support Systems
BW	Bandwidth
CA	Carrier Aggregation
CAGR	Compound Annual Growth Rate
CAPIF	Common API Framework
CAPEX	Capital Expenditure
Cat -	Category
CAT-M1	Category – Machine 1
CDMA	Code Division Multiple Access
C-DRX	enhanced Connected Mode Discontinuous Reception
CE	Coverage Enhancement
CID	Cell ID
C-IoT	Cellular Internet of Things
CoAP	Constrained Application Protocol
CoRE	Constrained RESTful Environments
CP	Control Plane
CS	Circuit Switched

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CSE	Common Services Entity
C-SGN	CloT Serving Gateway Node
CSI	Channel State Information
CSP	Communication Service Providers
D2D	Device-to-Device
DA	Data Analytics
DAV	Data Acquisition and Verification
dB	Decibel
dBm	Decibel-milliwatts
DCN	Dedicated Core Network
DECOR	Dedicated Core Network
DL	DownLink
DMRS	Demodulation Reference Signal
DSC	Data Service Cloud
DSM	Device and Service Management
DSRC	Dedicated Short Range Communications
DTLS	Datagram Transport Layer Security
EC	Extended Coverage (Channels)
EC-GSM	EC- Global System for Mobile Communication
EC-GSM-IoT	Extended Coverage GSM IoT
ECHONET	Communication protocol designed to create the “smart houses” of the future
E-CID	Enhanced-UTRAN Cell Identifier/ Enhanced Cell ID
EC-SCH	EC-Shared CHannel
eDECOR	Enhanced Dedicated Core Networks
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
E-RAB	E-UTRAN Radio Access Bearer
E-UTRAN	Evolved Universal Mobile Telecommunications System Networks
FDD	Frequency Division Duplex

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FD-LTE	Frequency Division LTE
FeMTC	Further enhanced Machine-Type Communications
GERAN	GSM/EDGE Radio Access Network
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GROUPE	Group Based Enhancements
GSM	Global System for Mobile Communications
GSM IoT	Global System for Mobile Communications- Internet of Things
GSMA	GSM Association
GW	Gateway
HARQ	Hybrid Automatic Retransmission reQuest
HARQ-ACK	Hybrid Automatic Retransmission reQuest Acknowledgement
HD	High Definition
HD-FDD	Half-Duplex Frequency Division Duplex
HGi	Home Gateway Initiative
HLCOM	High Latency Communication
HSS	Home Subscriber Server
HTTP	HyperText Transfer Protocol
I-DRX	Idle mode Discontinuous Reception
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMEI	International Mobile Station Equipment Identity
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IIoT	Industrial Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
IPSO	IP Smart Object Alliance
ISD	Inter-Site Distance
ITU	International Telecommunication Union
IWF	Interworking Function
kHz	Kilohertz
Km	Kilometer
KPI	Key Performance Index
LAA	License Assisted Access

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LBT	Listen-Before-Talk
LPP	LTE Positioning Protocol
LPWA	Low-Power Wide-Area
LPWAN	Low-Power Wide-Area Networks
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LTE-M	LTE- Machine
LTE-MTC	LTE- Machine Type Communication
LwM2M	Light Weight Machine-to-Machine
m	meters
M2M	Machine-to-Machine
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Service
MCA	OneM2M defined reference point to interface an AE and CSE
MCC	OneM2M defined reference point to interface CSEs
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
MIoT	Massive Internet of Things
MME	Mobility Management Entity
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
MONTE	Monitoring Enhancements
M-PDCCH	Physical Downlink Control CHannel for MTC
MQTT	Message Queuing Telemetry Transport
ms	Millisecond
MSISON	Mobile Subscriber Identity Self Organizer Network
MTC	Machine-Type Communications
MTC_SIB	MTC Traffic Channel System Information Block
MVNO	Mobile Virtual Network Operator
N3IWF	N3 Interworking Functions
NAPS	Northbound APIs for SCEF – SCS/AS Interworking
NAS	Non-Access Stratum

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NB	Narrowband
NB-CIoT	Narrowband Cellular IoT
NB-IoT	Narrowband-IoT
NB-LTE	Narrowband-LTE
NB-PBCH	Narrowband Physical Broadcast CHannel
NB-PDCCH	Narrowband Physical Downlink Control CHannel
NB-PDSCH	Narrowband Physical Uplink Shared CHannel
NB-PRACH	Narrowband Physical Random-Access CHannel
NB-PRS	Narrowband Positioning Reference Signal
NB-RSRP	Narrowband Reference Signal Received Power
NB-RSRQ	Narrowband Reference Signal Received Quality
NB-PSS	Narrowband Primary Synchronization Signal
NB-PUSCH	Narrowband Physical Uplink Shared CHannel
NB-SSS	Narrowband Secondary Synchronization Signal
NIDD	Non-IP Data Delivery
NIP	Network Interworking Proxy
NLoS	Non-Line of Sight
Non-BL	Non-Bandwidth Limited
NPI	National Provider Identifier
OCF	Open Connectivity Foundation
OFDMA	Orthogonal Frequency Division Multiple Access
OIC	Open Interconnect Consortium
OMA	Open Mobile Alliance
OMNA	Open Mobile Naming Authority
oneM2M	oneM2M - Organization for standards for M2M and the IoT
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
PCH	Paging Channel
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network

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PDSCH	Physical Downlink Shared CHannel
PDTCH	Packet Data Traffic CHannel
PGCH	Packet Grant CHannel
PGW	Packet Data Network Gateway
PHICH	Physical Hybrid Automatic Retransmission Request Indicator Channel
PLMN	Public Land Mobile Network
PMCH	Physical Multicast Channel
PRACH	Physical Random-Access Channel
PRB	Physical Resource Block
PRMA	Packet Reservation Multiple Access
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
QAM	Quadrature Amplitude Modulation
QCI	Quality of Service Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Blocks
RBAC	Role-Based Access Control
RDS	Reliable Data Service
RF	Radio Frequency
RI	Rank Indicator
RNTI	Radio Network Temporary Identifier
RRC	Radio Resource Control
RRC_IDLE	Radio Resource Control Idle
RRM	Radio Resource Management
RSRP	Reference Signal Received Power

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RSRQ	Reference Signal Received Quality
RSTD	Reference Signal Time Difference
SA	Service and Architecture
S4-SGSN	Serving GPRS Support Nodes
SCEF	Services Capability Exposure Function
SCFDMA	Single-Carrier Frequency Division Multiple Access
SCH	Shared CHannel
SC-MCCH	Single Cell - Multicast Control Channel
SC-MTCH	Single Cell - Multicast Transport Channel
SC-PTM	Single Cell - Point-to-Multipoint
SCS/AS	Service Capability Server/Application Server
SDN	Software-Defined Networking
SDT	Smart Home Device Template
SGSN	Serving GPRS Support Nodes
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
SMS	Short Message Service
SRD	Short Range Devices
SRTTP	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
TCO	Total Cost of Ownership
TDD LTE	Time Division Duplex LTE
TM	Transmission Mode
ToA	Time of Arrival
TPV	Total Payment Volume
TR #	Technical Report #

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TTI	Transmission Time Interval
UD	New User Equipment
UDP	User Datagram Protocol
UE	User Equipment/ User Entity
UE-to-NW	User Equipment to Network
UL	UpLink
UP	User Plane
URLLC	Ultra-Reliable Low Latency Communications
USIM	Universal Subscriber Identity Module
UTDOA	Uplink Time Difference of Arrival
UTRAN	Universal Terrestrial Radio Access Network
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2N	Vehicle-to-Network
V2X	Vehicle-to-Everything
VoLTE	Voice-over-LTE
VPLMN	Visited Public Land Mobile Network
Wi-Fi	Local Area Wireless Computer Networking
WWAN	Wireless Wide Area Network

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