The Importance of LTE Cat 1

and its Position in the Cellular IoT 4G/5G Landscape

SEQUANS

Contents

1. Introduction

In the late 1980s, the city of London launched a project to manage its fleet of buses called the *Automatic Vehicle Location and Passenger Information at Bus Stops project* (AVL/PIBS)[1], which was designed to provide information about routes and timetables to passengers at bus stops. At that time, it was very difficult to embed and connect sensors and displays across the city, and even more difficult to track the real time location of moving vehicles, so the project was considered ahead of its time and was one of the first demonstrations of what we now know as the *Internet of Things*, or IoT. The project required a great deal of innovation, investment, and resources, especially regarding the proprietary radio communications technology needed to connect the buses and bus stops. Since that time, the wireless world has advanced significantly, and with the introduction of 2G and 3G cellular communications technology, complex projects like the London bus project became much easier to deploy and manage.

Today we see connected objects everywhere around us. We have come to expect the ability to instantly access information anytime and anywhere, in real time, where and when we need it. For example, we depend on remote access to information that makes our lives easier in our homes and businesses, or when faced with bigger challenges, such as the management of a natural disaster, a power grid failure, or trying to contain a pandemic like Covid-19. To overcome these wide area challenges, and to provide anytime/anywhere connectivity, ubiquitous cellular coverage is required, and to be effective, it must consume very little power and be available at a low cost. 2G and 3G cellular brought the ubiquitous coverage at a reasonable price, but not the low power.

Then, 4G LTE (long term evolution) appeared on the scene and while it was originally designed to serve the ever-increasing high throughput needs of smartphones, it also evolved to address the needs of connected objects through the introduction of UE (user equipment) categories LTE Cat M (or LTE-M), and NB-IoT, part of Release 13 introduced by 3GPP in 2016.[2] These new narrowband categories were defined for low power consumption for battery powered objects, and for low data rates to lower system cost and spur widespread adoption of IoT. LTE-M and NB-IoT fulfilled these promises, but required new networks to be built. LTE Cat 1, however, as defined in the original 4G Release 8[3], can operate on all legacy LTE infrastructure, giving it a unique place in the world of IoT connectivity.

Today, all leading operators have shut down or are in the process of shutting down their existing 2G and 3G networks and are re-farming the spectrum to use it for the more efficient 4G and 5G networks. While LTE-M and NB-IoT were defined specifically for low power, low data rate IoT use cases, legacy LTE Cat 1 can support a wider range of IoT use cases, including those with throughput requirements higher than what can be supported by LTE-M or NB-IoT. LTE Cat 1 therefore complements LTE-M and NB-IoT and has a valuable role to play in the coming decade and beyond, because it is cost-effective and will not be replaced by 5G until such time as 5G New Radio is able to meet the LTE Cat 1 price point, not expected until around 2030.

2. History

2.1 Broadband IoT

In early 2000, mobile operators made huge investments in new spectrum that was initially used for 3G. To improve their return on investment, they focused on how to increase the capacity of their networks while bringing differentiated, higher data rate services to their customers. These two objectives became the main drivers of 4G development.

When 3GPP standardization groups came together to create a specification for LTE, their principal goal was to achieve better spectral efficiency and provide users with higher throughput for a better internet experience.[4] The 3GPP Release 8 standard introduced UE categories 1-5 with downlink data rates defined for Cat 1 at 10 Mbps up to Cat 5 at 300 Mbps. In all subsequent standard releases, the main objective was to find ways to increase the peak data rates in both downlink and uplink by implementing various transmission schemes such as MIMO and carrier aggregation. These techniques have enabled today's smartphones to achieve up to 1.2 Gbps of throughput downlink and up to 220 Mbps uplink. Consequently, silicon vendors were racing to create chipsets to support higher and higher data rates, with little consideration given to price or power consumption.

The industry was at a turning point with new ecosystems developing rapidly. Mobile phone manufacturers began developing sophisticated smartphones, inspired by the availability of higher data rates; applications developers began building new ways of communicating and sharing information for the new more capable smartphones; and cloud and storage companies created a new paradigm for secure information storage whereby data, formerly stored locally, began migrating to the cloud.

With this explosion of innovation, all focus was on giving consumers faster and more capable smartphones, larger displays, and more applications which, when combined with larger bandwidth/higher throughput capabilities, enabled much better end user experiences. At this time, we saw the emergence of wireless DSL (digital subscriber line), which became cheaper than ADSL (asymmetric digital subscriber line) in some regions, and mobile routers, which allowed consumers to benefit from enhanced wireless connectivity to connect their smartphones, tablets, and laptops, anytime, anywhere. But beyond the large and highly visible consumer market, there was also a world of things just waiting to be connected.

2.2 Massive IoT

In 2010, the LTE-enabled IoT was born and began its rapid growth when a great interest built up around machine-to-machine (M2M) communications. As the market developed, it became clear that LTE solutions built to connect consumer applications were not ideal for the support of M2M or IoT applications. They were not only too expensive, but also way too power hungry. At first, M2M devices were connected using 2G and 3G chipsets---the same chips used to connect mobile phones, because they had reached a sufficiently low price level. This was acceptable because traditional M2M devices (mainly automotive devices, electric meters, streetlights, and medical equipment) were not running on small batteries and therefore did not require optimized power consumption.

The industry began to recognize the huge market that would emerge and boom if M2M devices could be connected with solutions that were optimized for low power consumption. Thus began the emergence of low power wide area (LPWA) networks. Most M2M/IoT devices operate in a dormant state, waking up only to send data to the cloud briefly before returning to a sleep state. Take, for example, a smart utility meter that transmits consumption data once a day to the utility company, or a water level sensor that communicates an alarm when a water tank's maximum level has been reached.

Enabling this market required the building of LPWA networks and the first to emerge in the mid-2010s were proprietary networks, including LoRa, Sigfox, Weightless, and others. At the same time, the cellular industry recognized that LTE Cat 1, which had been available since the introduction of the first LTE release, Release 8, if optimized, could be a powerful solution for use with M2M and IoT applications. The innovators began to move.

2.3 LTE Cat 1 for M2M and IoT

Sequans was the first[5] chipset company in the world to build, certify, and commercialize a dedicated LTE Cat 1 UE chipset optimized to support M2M and IoT devices. LTE Cat 1 is ideal for the support of applications in vertical markets such as telematics, utilities, and medical that can benefit from a cost optimized platform for large volumes.

Then, beginning with 3GPP Release 12[6] in 2015, new LTE features to improve power consumption were introduced. One of these, power saving mode (PSM), enables devices to stay dormant for long periods of time in what is commonly known as deep sleep, while remaining registered with the network, enabling it to wake up quickly to transmit data. Then in Release 13[7], the two new narrowband UE categories, LTE-M (Cat M1) and NB-IoT (Cat NB1) were introduced. These new categories became the cellular industry's answer to the demand for low-power, low-cost solutions for low data rate IoT applications and devices. One of the key factors contributing to the cost reduction in these Release 13 specifications was the removal of one of two antennas and its associated RF chain.

Sequans was the first chipset company[8] to adopt this standard and build, from the ground up, a dedicated LTE-M/NB-IoT platform called Monarch. Introduced in early 2016, Monarch, by design, enabled a very low module cost and took power consumption down to a new low---a mere 1 microamp in PSM---a level which is still unmatched in the cellular industry today. Sequans second generation Monarch 2 chip has brought further power optimization keeping Sequans as the leading edge provider of LTE-M/NB-IoT technology.

Following PSM, another low power mode was introduced called eDRX (extended discontinuous reception). Unlike PSM where devices are constantly dormant and typically wake up when solicited locally by the application, an eDRX device wakes up at pre-configured intervals to listen for possible incoming messages, before going back to its dormant state.

LTE-M and NB-IoT networks have been widely deployed and continue to spread around the world[9] and while these networks are proliferating in support of a growing number of IoT applications, it has become clear that some IoT applications that were operating on 3G networks with speeds up to 15 Mbps cannot be supported by the low data rates of LTE-M.[10] In answer to this, LTE-M and NB-IoT rates increased in Release 14, achieving rates up to 1.1

Mbps for LTE-M and 160 kbps for NB-IoT.[11] Still, this is not enough for devices required to carry real-time audio, video, or high-quality voice, so the industry turned to LTE Cat 1 with its higher data rate of up to 10 Mbps.

2.4 Evolution of LTE Cat 1 and Cat 1bis

3GPP then introduced a new Release 14 UE category called Cat 1bis that specified changes to Cat 1 definitions to optimize the technology for IoT applications. One change was the removal of one of the two RF chains of the original Cat 1 definition. This enabled a new lower cost structure that improved the viability of many Cat 1 IoT business models. This new low-cost design, combined with the new low power consumption capabilities of PSM and eDRX, enabled Cat 1bis chip and module solutions to achieve both low cost and low power, significantly widening its market applicability.

With the birth of each new cellular generation, coverage is achieved in phases while mobile operators invest in and build out their networks to cover wide areas. In these early deployment phases, it is quite common to have isolated cells or devices at the cell edge where signal strength is relatively weak. In these situations, a second RF chain on the UE can be helpful. This technique enhances the reception level (+3dB in theory). For devices designed with a single antenna, message repetitions at the physical layer can increase their reach. When the signal is weak, repeating the transmission several times allows the receiver to recombine the missing parts and rebuild the original message. This technique is in use with LTE-M and NB-IoT; however, this technique increases latency, and can severely impact real time data transmission as used in voice calls, for example, and it may cause the connection to fail.

In later phases of network deployment, the coverage issue is overcome by network density, but then in high density areas, the UE tends to receive signals from several cells at the same time, causing interference. In this situation, a second antenna or re-transmissions won't be helpful because there is no need to add more signals. In other words, the signal strength is high, but the quality is low. To improve quality, there are several mitigation techniques defined in the 3GPP standard. One of those techniques is called CRS-IM (Cell-specific Reference Signal Interference Mitigation)[12], which relies on cell interference mitigation using LTE signal properties to improve user signal quality.

CRS-IM functionality can significantly improve UE performance in many interference-limited scenarios. It can be achieved with network support (i.e., network provides aggressor cell information to UE), and can also be accomplished without any infrastructure support, if the UE hardware was designed to support this feature.

Release 15[13] focused on CRS-IM for single RX UEs, notably aiming at Cat 1bis.

In summary, in the massive IoT space, 3GPP offers three solutions: NB-IoT, LTE-M and Cat 1bis, all enabling low power consumption and low-priced module, and varying data rates for a variety of application types.

3. Evolution to 5G

Telecommunications standards are in constant evolution, reflecting advancing technology (see Figure 1).

The 4G era, which originally addressed throughput aspects, introduced enhancements beyond its 3G predecessor, addressing two major technology areas:

1. **Mobile Broadband** (MBB) for data and voice services using LTE Category 4 and beyond.
2. **Machine Type Communications** (MTC) for connectivity

for Internet of Things applications using LTE Cat 1, LTE-M, NB-IoT, and later, LTE Cat 1bis

The transition to 5G has begun, addressing three major technology areas, and a fourth added more recently:

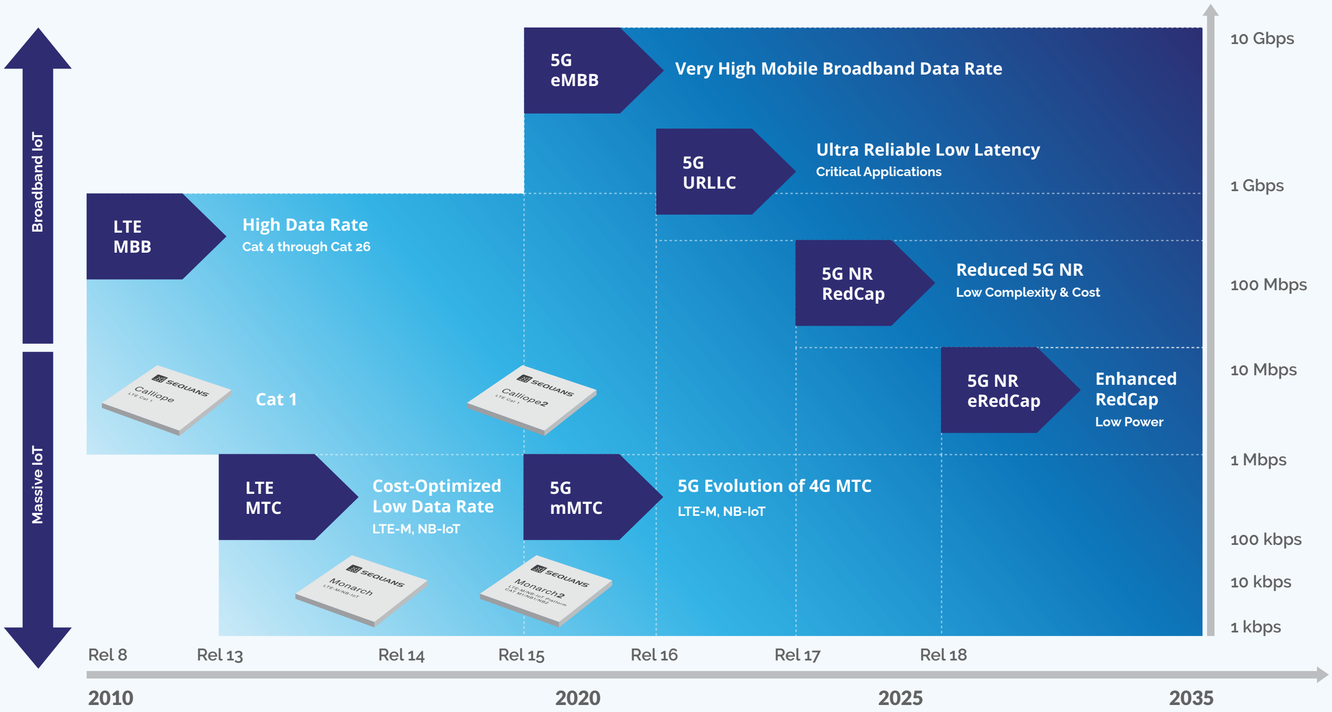
1. **enhanced Mobile Broadband** (eMBB) is the first of the 5G technologies adopted by operators. eMBB pushes data rates up to several gigabits per second using very large chunks of spectrum and the adoption of a new radio waveform called New Radio or NR.

2. **massive Machine Type Communications** (mMTC) is the evolution of the existing LTE-M and NB-IoT standards with feature enhancements, enabling lower power consumption and very high density of up to 1 million connected devices per square kilometer. mMTC uses the same LTE radio waveform so, by design, mMTC is supported by any 5G network, either non-standalone (NSA) or standalone (SA) with dynamic spectrum sharing (DSS), thereby permitting device sustainability over time.

3. **ultra Reliable Low Latency Communication** (uRLLC) addresses applications requiring extremely low latency (1ms) and the ongoing technological transformation necessary to support new types of communications segments, including industry 4.0, autonomous driving, medical remote surgeries, virtual and enhanced reality, and real time gaming.

4. **New Radio Reduced Capability.** In addition to the three major areas described above, another area of interest has been identified called New Radio Reduced Capability (NR RedCap). As the evolution from 4G to 5G has brought new features and a new radio waveform, the price point of 5G platforms has risen accordingly, begging the question of how to find a temporary solution or gap filler that allows for the transformation of 4G Cat 4/Cat 6 technologies using 5G NR, but at an affordable price. 3GPP addresses this question beginning in Release 17[14] but the wide adoption of platforms that can meet today's Cat 4 price point will likely not appear until after 2025.

Figure 1: 4G and 5G Use Cases Over Time



To accommodate the trend towards NR lower data rates and lower cost, 3GPP initiated a discussion around the *evolution* of RedCap (also referred to as eRedCap) as part of Release 18.[15] eRedCap, as envisioned, would complement RedCap by specifically targeting a data rate of 10 Mbps, along with lower power and lower cost. In the long term, eRedCap could then be positioned as a replacement for Cat 1 while utilizing a NR waveform. By 2030, if this standard evolution is confirmed, the industry will likely see dual mode support for NR eRedCap with LTE Cat 1 fallback, to ensure a smooth roll-out of eRedCap, while avoiding service disruption for existing IoT objects. 4G Cat 1, therefore, can be the gap filler between LTE-M and the future NR eRedCap for all applications requiring up to 10 Mbps along with low power consumption and low price.

The strategy of using 4G Cat 1 as a transitional gap filler does not prevent carriers from refarming their LTE legacy spectrum for future 5G usage since a Cat 1 device can operate on bandwidth as small as 3 MHz corresponding to 12 PRB (physical resource blocks), while delivering a data rate of ~10 Mbps in the downlink. Network operators therefore can keep 3 MHz dedicated for Cat 1 (12 PRB or 3 MHz), LTE-M (6 PRB or 1.4 MHz), and NB-IoT (1 PRB or 200 kHz), while refarming other parts of their spectrum.

The wide adoption of 5G around the world has pushed operators to accelerate the migration of their 2G and 3G spectrum to 4G and 5G technologies which has in turn accelerated 2G and 3G network shutdown[16] and the migration of 2G and 3G applications to newer technologies. Since 5G technology focuses primarily on broadband applications, the 4G waveform is recognized as the best technology to support these migrating narrowband applications, since it brings connectivity at low cost and low power with data rates from a few kbps (NB-IoT) up to a few Mbps (Cat 1) and will coexist with 5G NR to 2030 and beyond.

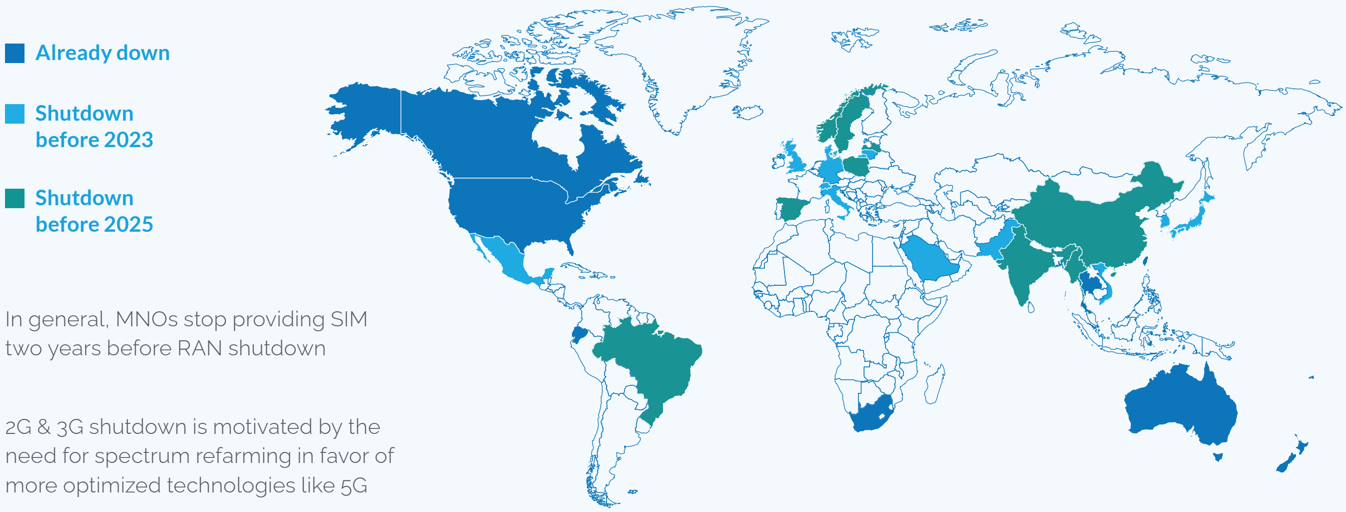
4. Massive IoT Market

4.1 4G Coverage

During any massive IoT product design cycle, choosing the right cellular connectivity technology can be stressful. One might go for the lowest cost if the technology can serve the application's throughput and latency needs. But, bearing in mind that published speeds are theoretical, achieved under ideal conditions in shielded rooms, and that real world deployments always show lower speeds, low cost alone is not sufficient to endorse this choice. Also, one must ensure that the chosen technology is covered by a network vendor, with data plans and SIMs available for the regions where the product is planned for deployment.

During the previous decade, considerations of price and coverage automatically led to selection of 2G/3G connectivity

Figure 2: Planned 2G and 3G Network Shutdowns



In general, MNOs stop providing SIM two years before RAN shutdown

2G & 3G shutdown is motivated by the need for spectrum refarming in favor of more optimized technologies like 5G for IoT. But in 2021 we know that these technologies are fading out, with many operators already having shut down their 2G/3G networks and many others preparing to. See Figure 2.[17]

An IoT company starting a project today would be well-advised to look beyond 2G and 3G and to find future-proof solutions.

LTE-M and NB-IoT are today's obvious choices for IoT projects, but there are some complexities to consider. For example: LTE-M and NB-IoT need specific operator investment and network support that is not needed with legacy LTE networks. Also, LTE-M and NB-IoT are not deployed equally around the world. Part of the world deployed LTE-M while the other part deployed NB-IoT, and still others adopted both (see Figure 3). Further complicating matters, LTE-M and NB-IoT roaming agreements are not uniformly available. For IoT products targeting a single region, LTE-M or NB-IoT will suffice. However, for devices targeting more than one region, using both technologies becomes mandatory and the price advantage of choosing NB-IoT only is lost since a dual mode solution must be dimensioned to support LTE-M in addition to NB-IoT. This adds complexity because of the wider bandwidth requirement of LTE-M (1.4 MHz) as compared to NB-IoT (200 kHz). See Figure 3.[18]

Although both technologies are defined in 3GPP, it is important to note that no fallback mechanism exists between the two technologies. The only way for a nomadic IoT object to detect which of these technologies is available at its location, is to scan for a signal, and if no signal is detected, switch to the other technology and restart the scanning process. This process is power hungry and therefore unfriendly to battery-powered devices. Moreover, objects might be moving through no-coverage zones, adding more inefficiency.

LTE Cat 1 on the other hand is already widely-adopted with worldwide roaming agreements in place. It works on any existing 4G LTE network and today's LTE coverage is available on a global scale. According to the GSA (Global mobile Suppliers Association), in November 2021, there were 797 operators running LTE networks providing mobile and/or fixed wireless access services in 240 countries/territories worldwide. See Figure 4.[19]

Figure 3: Global LTE-M and NB-IoT Coverage Map

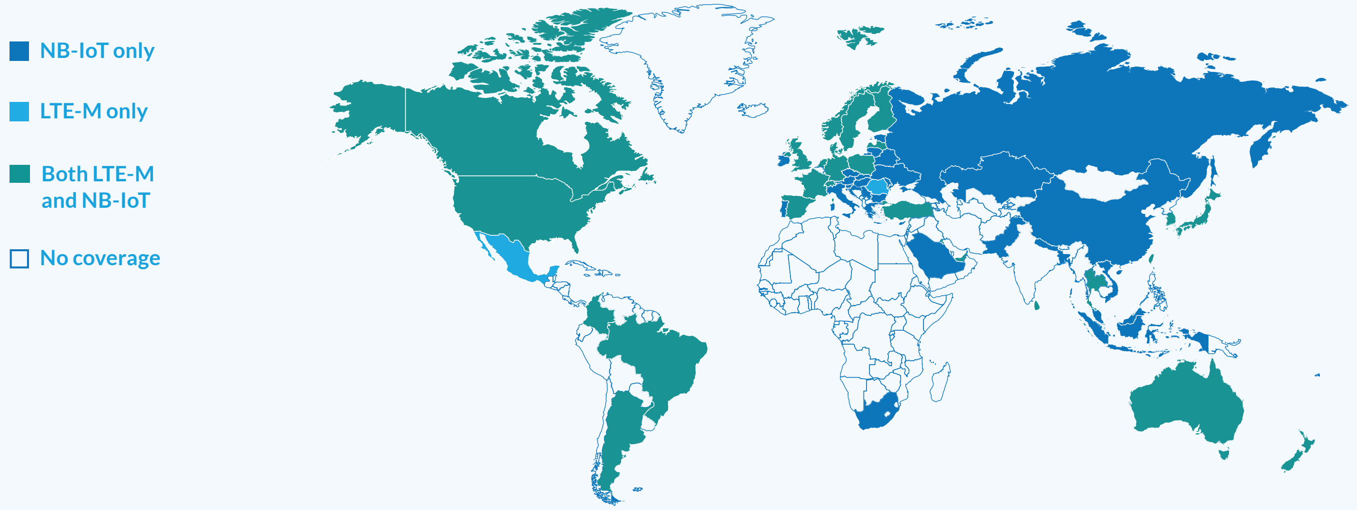
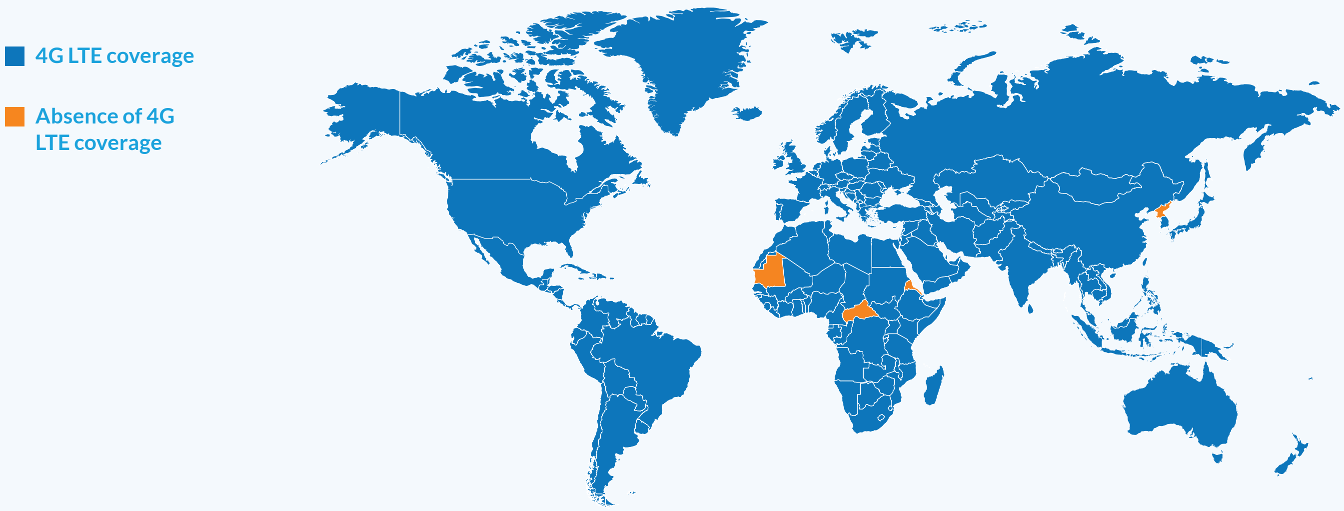


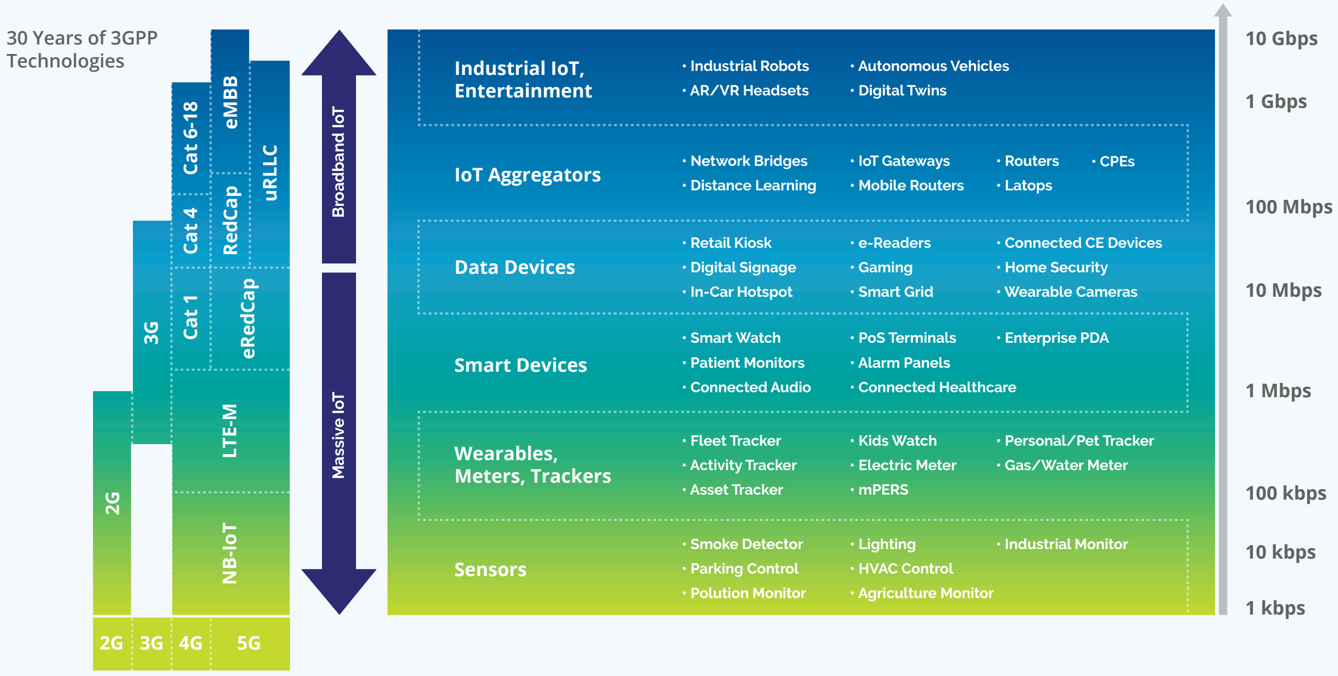
Figure 4: 4G LTE Coverage Map



4.2 LTE Categories Supporting Massive IoT

In choosing the LTE category to support a certain application, the main driver is usually the data rate. But, beyond the data rate,

Figure 5: Applications by 4G and 5G Category



one should consider other key performance requirements such as latency, cost, coverage, power consumption, and mobility. See Figure 5.

When considering power consumption, the race to sleep phenomenon must also be considered. While a well-optimized NB-IoT chipset may instantaneously transmit a small amount of data with very little power, when it comes to transmitting a larger amount of data, LTE-M may be the more efficient option since it allows for quicker transmission and therefore an overall lower battery drain. A comparison of several key performance indicators (KPI) for all three technologies is in Table 1.

Table 1: Key Performance Indicators for the Three Main LPWA 4G Technologies

	Cat 1	LTE-M	NB-IoT
Data Rate	😀	😐	☹
HW Price	☹	😐	😀
Data Plan Price	😐	😀	😀
Deployment	😀	😐	😐
Latency	😀	😀	☹
Power Consumption	😐	😀	😀
Mobility	😀	😀	☹
Voice / VoLTE	😀	😐	☹

Table 2: Examples of Applications Where LTE Cat 1 is a Good Fit

	Smart watches	• **Features similar to smartphones** • **Hybrid watch** • **Smart-Home enabled**
	Wearable Cameras	• **First-person activity recording**

Table 2 Continued: Examples of Applications Where LTE Cat 1 is a Good Fit

Connected Audio	• Mobile mini-speaker for music and VoLTE calls • Conference room audio for VoLTE calls • Headset, earbuds for music and VoLTE calls • Feature phone, mPERS, push-to-talk
e-Readers	• Tablet for reading, editing, highlighting digital publications • Usage of e-Ink • Smart-Home enabled
Home Security & Video	• Voice enabled speakers • Cameras • Sensor centralization
Gaming	• Online gaming • Game console monitoring and maintenance
Medical	• Wellness and activity trackers • Healthcare devices • Shipping container trackers with large amounts of sensor monitoring data
Aftermarket Telematics	• Pay-as-you-drive insurance • Sub-prime auto financing • Stolen vehicle recovery
Smart Grid & Aggregators	• Metering data aggregators or hubs • Management in the electricity production & distribution system

4.3 Cat 1 Application Types

A very wide range of applications can be served with LTE Category 1 technology as can be seen from Table 2 below.

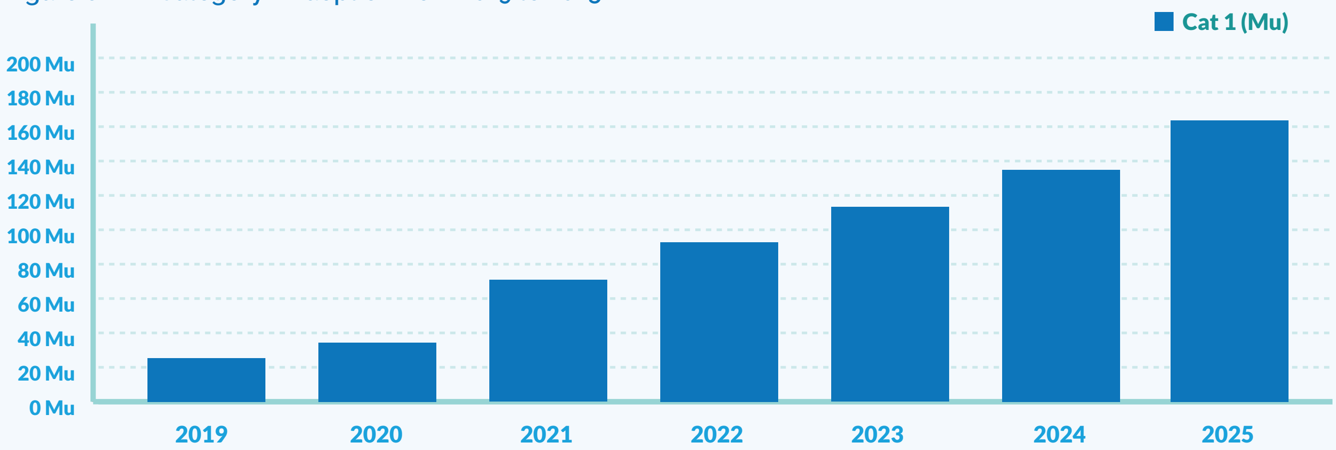
Some of these applications, such as telematics and smart grid, are typically already connected by cellular, and others, such as medical or connected audio apps, typically have another kind of connectivity such as Bluetooth or WiFi, and some, such as water meters, typically don't have any connectivity at all.

Cat 1 may also be used as a connectivity solution based on regional factors, or by deployment limitations. In some countries, China for example, LTE-M is not deployed today and the limited throughput and capability of NB-IoT cannot be used for applications needing higher throughput, low latency, or mobility, such as smart electricity meters, people or pet trackers, or mPERS devices. Cat 1 is a universal technology and can be used across multiple regions (see Figure 4).

4.4 Single-Mode Cat 1 Total Addressable Market

Total addressable market (TAM) for single-mode LTE Cat 1 applications for the next few years is shown in Figure 6.

Figure 6: LTE Category 1 Adoption from 2019 to 2025[20]



By single-mode, we mean a module that supports LTE only, with no 2G or 3G fallback. The following figures (7 and 8) provide a view split by region and by application.

Figure 7: LTE Category 1 Adoption in 2021 and 2024 Split by Region (in millions of units)[21]

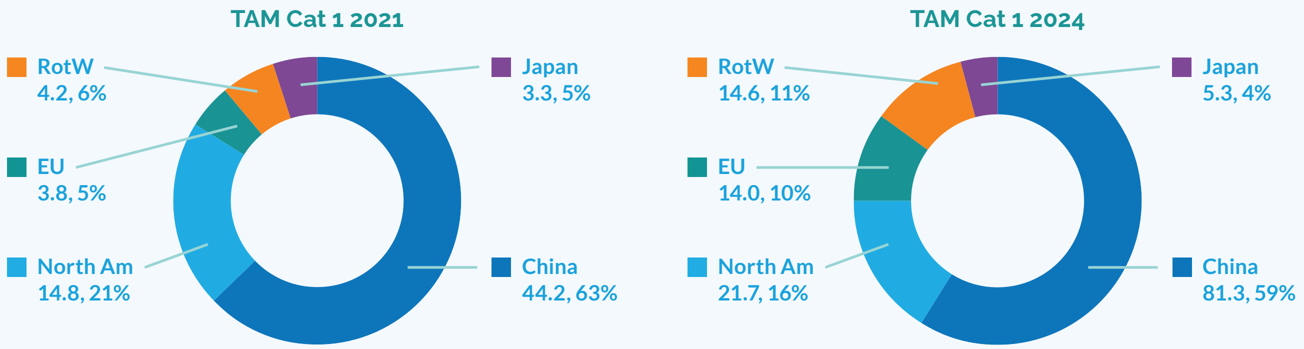
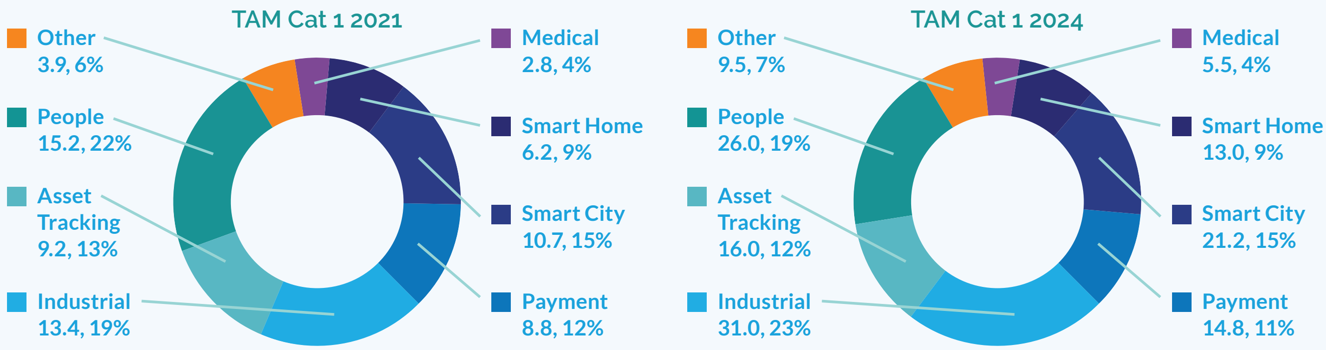


Figure 8: LTE Category 1 Adoption in 2021 and 2024 Split by Application (in millions of units)[22]



5. Sequans Cat 1 Product Portfolio and Roadmap

Sequans has a portfolio of Cat 1 chipsets and modules optimized for IoT and designed to serve the requirements of a wide range of application types and regions.

Sequans Cat 1 Chips

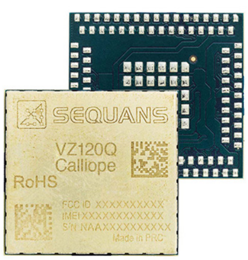
Calliope

Sequans Calliope LTE Cat 1 platform is designed specifically for wearables and other Cat 1 M2M and IoT devices. Calliope comprises baseband and RF chips, an integrated IoT applications processor running Sequans' carrier-proven LTE protocol stack, an IMS client, and a comprehensive software package for over-the-air device management and packet routing.

Calliope 2

Calliope 2 is Sequans' second-generation, 5G-ready, single-chip Cat 1 solution compliant with the 3GPP Release 15 massive IoT standard. Calliope 2 is built on five years of Sequans' exclusive and field proven experience with first generation Calliope, which is and has been the industry's leading LTE Cat 1 chip for IoT since its introduction in 2015. Calliope 2 is designed for the cost-effective support of IoT applications such as wearables and hearables and smart city/smart home IoT devices that require VoLTE and a data rate higher than a few 100 kbps. Calliope 2 brings several significant advancements over Calliope 1, including higher integration, significantly improved power consumption in both active and low power modes, a comprehensive VoLTE voice engine and EAL5+ security for iSIM. Calliope 2 user application software and interfaces are compatible with Sequans' Monarch 2 LTE-M/NB-IoT platform, allowing easy migration among Cat 1, LTE-M, and NB-IoT massive IoT technologies.

Sequans Cat 1 Modules



Calliope 1 Modules

The Calliope Cat 1 modules, VZ120Q, US130Q and EU140Q are the first, all-in-one, single-mode LTE category 1 (Cat 1) modules certified compliant with MNO open network specifications. Other bands can be supported to cover additional bands and regions, including Japan. The modules can be easily paired with a GNSS solution for asset and IoT tracking. Calliope modules comprise Sequans' Calliope Cat 1 Platform and all other elements necessary for a complete LTE modem system. These include an LTE-optimized transceiver, a complete dual-band RF front-end for the dedicated bands, key interfaces, all in a single compact package. Calliope modules also include Sequans' carrier-proven LTE protocol stack, an IMS client, and a comprehensive software package for over-the-air device management and packet routing. Calliope modules support VoLTE and are compatible with Linux, Android, Windows and a wide range of embedded and real-time operating systems.

Calliope 2 GC02S1 Module

The Calliope 2 GC02S1 module is Sequans' first single-mode LTE Cat 1 module based on its second generation Calliope 2 chip platform. The Calliope 2 GC02S1 module comprises Sequans' Calliope 2 chip platform and all other elements necessary for a complete LTE modem system. These include an LTE-optimized transceiver, an RF front-end, and key interfaces, all in a single compact package. The Calliope 2 GC02S1 module also includes Sequans' carrier-proven LTE protocol stack, an IMS client, and a comprehensive software package for over-the-air device management and packet routing. The Calliope 2 GC02S1 module supports VoLTE and is compatible with Linux, Android, Windows and a wide range of embedded and real-time operating systems. For cost optimization, it is being offered in one worldwide SKU with several regional SKUs to serve North America, Europe, Japan, and the rest of Asia.

Sequans-Powered Modules of Partners

Sequans has several industry-leading module partners, all of whom are making IoT modules for global markets based on Sequans' LTE chip technology. Some are building Sequans-based modules according to their own specifications while others are making Sequans-based modules according to the specifications of other companies who market and sell them under their own brands.

Among Sequans' Calliope Cat 1 module partners is Thales who offers the Cinterion® ELS31 module that is tailored for M2M and industrial IoT applications.

Another partner is Renesas who has licensed access to Sequans Calliope 2 Cat 1 technology to provide cost and power-efficient solutions for those IoT applications needing higher than LTE-M speed and support for VoLTE as needed to connect speakers or alarm devices.[23]

Additional modules based on Sequans Calliope Cat 1 technology are in the works and this trend is accelerating as the need for replacing existing 2G and 3G based solutions is becoming more urgent.

6. Conclusion

Over the coming decade, LTE Cat 1 technology will become the de facto replacement for fading 3G and many existing 3G applications will have to migrate to a modern technology, while waiting for an NR-based replacement (NR eRedCap or others) with global availability at reasonable cost. Sequans offers best-in-class chip and module solutions to serve this Cat 1 growing market. Sequans is a fabless designer, developer, and supplier of cellular connectivity solutions for massive and broadband IoT. Sequans' product portfolio is a comprehensive set of 5G/4G chips and modules that are fully optimized for non-smartphone devices. Sequans owns the majority of the technology used in its chipsets and can therefore serve long lifecycle project needs, create product derivations when necessary, and combine technologies to help ease the market transition to dual mode 4G/5G solutions.

About the Authors

Imad MIKAIEL has a product marketing management role at Sequans Communications. In his early years at Sequans, he occupied the role of technical account manager for Sequans' strategic accounts, including infrastructure vendors and carriers, and he represented Sequans locally and internationally, establishing customer support offices in various countries, including USA, Russia, India, China, Japan, Korea, and Brazil. Imad also manages Sequans partnership programs with major MCU vendors. Imad has more than 30 years of experience in the telecommunication industry. Prior to joining Sequans, Imad held the position of embedded software manager at VLSI Technology / Philips Semiconductors, and filled customer support roles at Mentor Graphics and later at Texas Instruments. Imad holds a master's degree in electrical engineering from "Université de Nice Sophia Antipolis". Imad is an enthusiastic technologist and is particularly interested in the role of ubiquitous connectivity for all kinds of objects, for the betterment of life everywhere.

Jeremy GOSTEAU has a product marketing management role at Sequans Communications where he has held various positions, including product manager where he helped Sequans define the company's first 4G LTE modem in 2009, and the company's first IoT dedicated semiconductors: Calliope for Cat 1 and Monarch for LTE-M and NB-IoT in 2014 and 2016, respectively. He launched

major features with key partner operators, for example, with China Mobile at the Shanghai expo in 2010, and with Verizon at the Super Bowl in 2014, and with Deutsche Telekom and its tech incubator, hubraum, in 2019. As a product marketer, Jeremy, identified the main market segments that Sequans' product portfolio should target in the IoT space, and he contributed to the company's long term product strategy. Jeremy has represented Sequans in France, the UK and the USA, He holds a master's degree in electrical engineering from the Imperial College in London, and from Supelec in Paris. He is passionate about enabling a better- connected world, through the convergence – in the semiconductor space – of cellular communications, satellite connectivity, enhanced security, and AI-empowered networks towards 6G.

7. Footnotes

- [1] Towards an intelligent transport system: 1st World Congress on applications of transport telematics and intelligent vehicle-highway systems : Papers. (1994). Artech House.
- [2] 3GPP.org; About Release 13, https://www.3gpp.org/release-13
- [3] 3GPP.org; About Release 8, https://www.3gpp.org/specifications/releases/72-release-8
- [4] Nohrborg, Madgalena, for 3GPP, LTE, December 2008, https://www.3gpp.org/technologies/keywords-acronyms/98-lte
- [5] Light Reading, Verizon Tests LTE Cat-1 Devices with Ericsson and Sequans, March 2, 2015, https://www.lightreading.com/components/mobile-wireless-components/verizon-tests-lte-cat-1-devices-with-ericsson-sequans-/d/d-id/714123
- [6] 3GPP, About Release 12, https://www.3gpp.org/release-12, 2015
- [7] 3GPP, About Release 13, https://www.3gpp.org/release-13, 2016
- [8] Sequans Communications, Sequans introduces Monarch, Industry's First LTE Cat M Chip for the Internet of Things, February 2016, https://www.sequans.com/press-release/sequans-introduces-monarch-industrys-first-lte-cat-m-chip-for-the-internet-of-things/
- [9] GSMA, Mobile IoT Deployment Map, https://www.gsma.com/iot/deployment-map/
- [10] GSMA, Ronan Le Bras, What is the Difference in Data Throughput between LTE-M/NB-IoT and 3G or 4G?, October 2019, https://www.gsma.com/iot/resources/what-is-the-difference-in-data-throughput-between-lte-m-nb-iot-and-3g-or-4g/
- [11] 3GPP, About Release 14, https://www.3gpp.org/release-14, 2017
- [12] W. Li, Y. Zhang, L. Huang, J. Cosmas and Q. Ni, "A cell specific reference signal interference cancellation scheme for LTE cellular access systems," 2015 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, 2015, pp. 1-6, doi: 10.1109/BMSB.2015.7177212.
- [13] 3GPP, About Release 15, https://www.3gpp.org/release-15, 2015
- [14] 3GPP; About Release 17, https://www.3gpp.org/release-17, 2020
- [15] 3GPP; About Release 18, https://www.3gpp.org/release18, 2021
- [16] GSMA, 2G-3G Sunset Guidelines, Version 1.0, June 3, 2021 https://www.gsma.com/newsroom/wp-content/uploads/NG.121-v1.0-2.pdf
- [17] Sequans data collected through carrier discussions and using Internet resource such as https://1ot.mobi/resources/blog/a-complete-overview-of-2g-3g-sunsets.
- [18] https://www.gsma.com/iot/deployment-map/
- [19] GSA NTS Snapshot November 2021 (available on https://gsacom.com/technology/lte/)
- [20] Source: Sequans, leveraging ABI Research and TSR market data
- [21] Source: Sequans, leveraging ABI Research and TSR market data
- [22] Source: Sequans leveraging ABI Research and TSR market data
- [23] Source: Sequans Communications, January 7, 2021, https://www.sequans.com/press-release/renesas-and-sequans-expand-their-5g-collaboration/

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