LEVEREGE

A Primer on Cellular IoT

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Executive Summary

In June 2016, the 3rd Generation Partnership Project (3GPP) -- a consortium of telecommunications standards organizations -- finalized the specification for Narrow Band IoT (NB-IoT). NB-IoT completes the trilogy of major cellular IoT network releases (LTE-Cat M and EC-GSM being the other two) while we await the development and deployment of 5G networks. These three standards are muscling their way into an already crowded and fragmented LPWAN market; positioning themselves as strong contenders to SigFox, LoRa, RPMA, and Weightless.

For years, LTE networks simply did not meet the requirements for certain IoT applications as they consumed too much power and were too expensive for large-scale networks of sensors. This void was promptly filled by startups that rolled out their own LPWAN services. However, cellular IoT is no longer the technology of the future. While some of the standards discussed here are still not commercially available, their deployment is impending as we make our way through 2017.

This document examines the specifications for each of the major cellular options and also discusses the criticisms and shortcomings raised by other LPWAN players. Although cellular IoT and unlicensed LPWANs cover slightly different use cases, this document will draw comparisons of the two types of approaches.

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Introduction

From 2G to 4G LTE, cellular networks have been the de facto standard for mobile wireless broadband services in the last decade. With the rise of mobile apps and the need for ubiquitous internet connectivity, the focus of the market has been providing higher band- width and increased network capacity. Today we can stream videos and communicate via LTE networks faster than ever and are pushing for the next generation of 5G networks. As the IoT market starts to mature, cellular providers have be- gun to shift their focus on providing connectivity to billions of things for IoT applications. While the specifications for IoT connectivity differ greatly for each application, use cases involving smart cities are typically characterized by inexpensive electricity, gas, or water meters measuring consumption on an infrequent basis and alerting operators only when thresholds are exceed- ed. Unlike previous LTE networks where speed and bandwidth were paramount, smart meters send small amounts of data every so often and need to be battery-powered with battery life lasting at least 5 years. Connecting millions of these inexpensive sensors to the existing LTE network is not practical since LTE was not designed to support that number of simultaneous connections or optimized for short bursts of small amounts of data.

LPWANs such as LoRa and SigFox have been designed with use cases such as smart cities in mind. They typically utilize unlicensed frequency bands at 915MHz or 2.4GHz for communication. Cellular IoT is the cellular industry’s response to provide low-power, wide-area networks. In its most recent release, 3GPP outlined three main standards for cellular IoT: LTE-M, NB-IoT, and EC-GSM. While some of these standards aren’t commercially available across all carriers today, expect them to be ready for prime time by the end of 2017. Considering the strong market presence that cellular providers hold, these standards look to be competitive to existing LPWAN options.

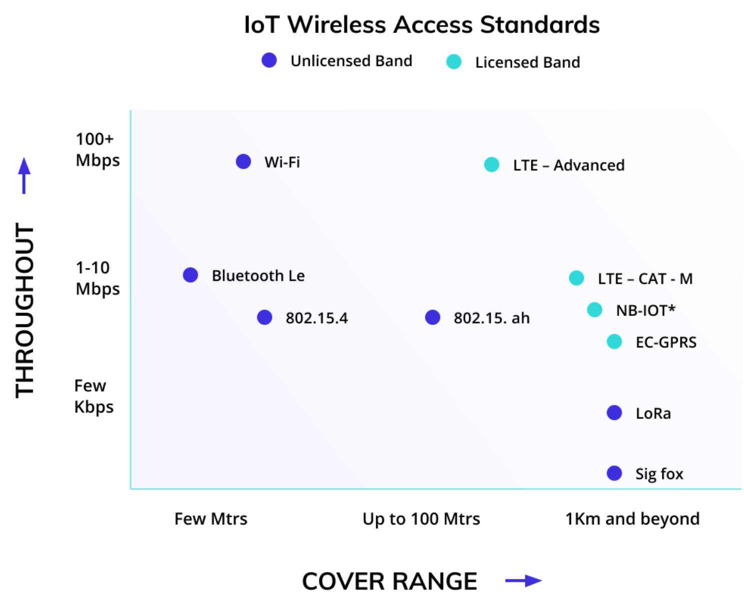

Figure 1, IoT Wireless Access Standards

Image Credit: Bluetooth, LTE Cat-M, NB-IoT, Wifi, Lora, Sigfox, 802.15.4: Helium; 802.11 ah: Sylvester Ajah; EC-GPRS: MWRF

Cellular IoT Requirements

Cellular IoT requirements bear similarities to LPWAN requirements, namely: Long battery life (~5 years minimum)

- Low device cost (≤ $5 per module)
- Low deployment cost
- Extended coverage (link budget enhancement of 15-20 dB)
- Network capacity (must handle a large number of connected devices)

Landscape Overview

In the licensed bands, 3GPP has defined three tracks for cellular IoT:

- LTE-M (Cat-M1) : LTE evolution track optimized for IoT. Previous edition (Cat-0) was released in Rel 12 in Q4 of 2014. Specifications were completed in Q1 of 2016 as part of Rel 13. LTE-M modules are coming to market now on major carrier networks like Verizon and AT&T.

- NB-IoT (Cat-M2) : Narrow-band LTE evolution track completed in Q2 of 2016 as part of Rel 13. Initial NB-IoT pilots are taking place now with commercial availability expected at the end of 2017 on some carriers.
- EC-GSM-IoT : GSM evolution track optimized for IoT, also completed in Q2 of 2016 as part of Rel 13. Similar release timeline to NB-IoT.

All of these standards will operate seamlessly on the existing LTE or GSM networks; supporting a broad array of IoT applications currently only available through non-cellular LPWAN options.

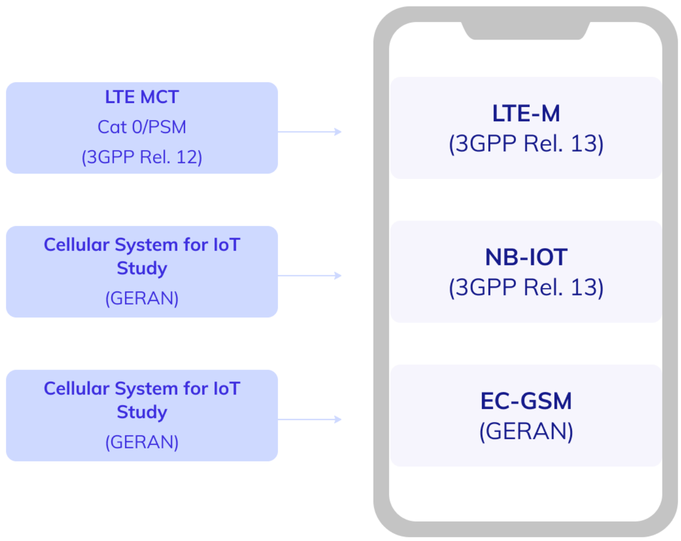

Figure 2, The Three Different Solutions for Specifying an Optimized Internet of Things Standard

Image Credit: Rhode & Schwarz

LTE Evolution Track

LTE was introduced by 3GPP in Rel 8 and was designed to provide better performance (See Appendix A for differences between LTE and GSM). The proliferation of smart phones and apps led to the standardization of Cat-4 devices with the ability to support 150 Mbps downlink peak rates and 50 Mbps uplink peak rates. Parallel to the development of smart- phones was the rise of IoT applications; initially for M2M use cases. Cat-1 devices, also defined in Rel 8, traded speed for lower cost. Cat-1 can only support 10 Mbps downlink and 5 Mbps uplink peak rate. However, for many M2M applications, only a small amount of data is transferred, so 10 Mbps is adequate.

As IoT infrastructure began to take shape, 3GPP realized that there are more applications where the sensors are stationary and only need to send data infrequently (and not necessarily in a time-sensitive fashion). Newer cellular IoT protocols respond to these needs. Cat-0, Cat-M, and NB-IoT avoid network overload on the current LTE technology infra- structure and support a massive number of simultaneously connected devices.

Key updates to meet IoT-specific requirements included device power saving mode (PSM) and enhanced discontinuous reception (eDRX) introduced in Rel 12 and 13 respectively - the details of each will be summarized in the following sections. Experts predict Cat-1 replacing 3G when it sunsets and Cat-0/ Cat-M replacing 2G in the future. The key thing to understand with the evolution of LTE is that these new categories are not necessarily replacing older versions, but rather complementing them by supporting new connected devices. The following graphic by Sequans does a great job showing what each protocol was designed for:

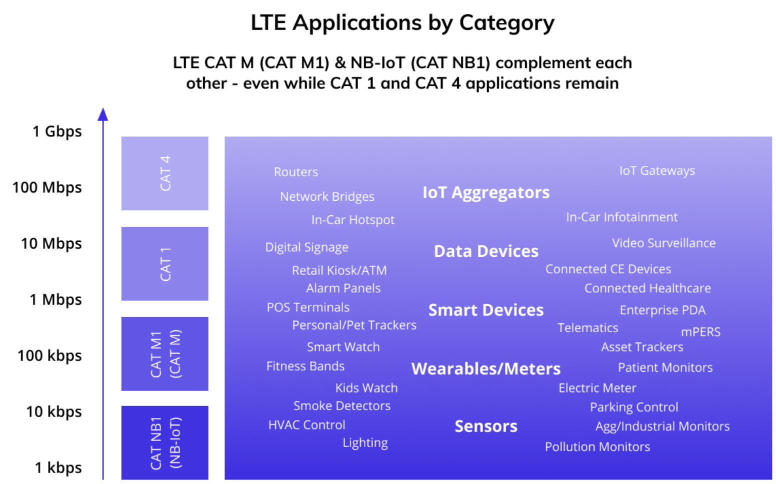

Figure 3, LTE Applications by Category

Image Credit: Sequans

LTE-M (Cat-M1)

Cat-M1 is also known as LTE-M and eMTC. The naming confusion comes from the fact that the spec- i cation was partially defined in Rel 12 and then finalized in Rel 13. While M initially stood for "ma- chines," Cat-M1 devices are not limited to M2M communication protocols. Rather Cat-M1 builds on the power reduction, lower complexity, and lower speeds established in Cat-1. Specifically, device bandwidth was capped at 1.4 MHz for both downlink and uplink (as opposed to 20 MHz for Cat-1 devices) and it reduced max transmit power to 20 dBm.

Long battery life to support smart metering applications are made possible with extended discontinuous repetition cycle (eDRX). eDRX is an improvement over power saving mode (PSM) introduced in Rel 12. PSM attaches a timer to the device, which sets the time the device is reachable as it moves from connected to idle mode.eDRX extends the 2.56s of PSM time to improve battery life.

In essence, by not constantly being connected to the network, the device can be idle and save power. Theoretically, for a device sending a daily update of 200 bytes, Nokia projects that the device can run on battery power for 10 years.

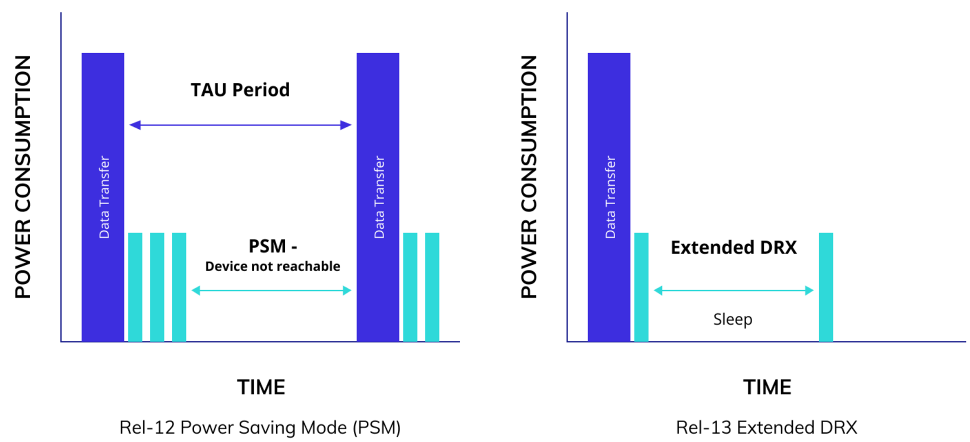

Figure 4, LTE-M Enhanced Battery Options
Image Credit: Qualcomm Technologies

On the cost reduction front, Cat-M1 devices utilize half-duplex FDD operation. Unlike full-duplex systems such as cell phones, half-duplex systems cannot transmit and receive signals at the same time. Since it must signify when the device is ready to receive, Cat-M1 devices reduce the complexity of a duplex filter (It's five times simpler than Cat-4 devices). Also the cost of the devices is significantly less owing to lower RF bandwidth support and a single receive chain. On the deployment front, cellular carriers claim low deployment cost since Cat-M1 devices share capacity with legacy LTE net- works. By the virtue of operating on a 1.4 MHz carrier, the IoT network will allocate a 1.4 MHz carrier within a legacy 20 MHz carrier. The data is multiplexed and controlled to ignored the legacy control information. In other words, a cellular carrier like AT&T only has to upload new base- band software onto its base stations to turn on LTE-M and won't have to spend any money on new antennas. In fact, in May of 2017, AT&T announced the completion of its nation- wide deployment of LTE-M network ahead of schedule and Verizon is in a similar position. Early cost structure analysis shows an almost 50% reduction as compared to Cat-1 modules.

LTE-M has a little higher data rate than NB-LTE-M and NB-IoT, meaning that it can transmit fairly large chunks of data. Thus, it can be used for applications such as tracking objects, wearables, energy management, utility metering, and city infrastructure.

However, if global coverage is a must, LTE-M will not work in areas primarily served by GSM or CDMA networks (2G/3G). Finally, critics of LTE-M will point to questionable battery life since eDRX has not been included on all LTE-M boards yet.

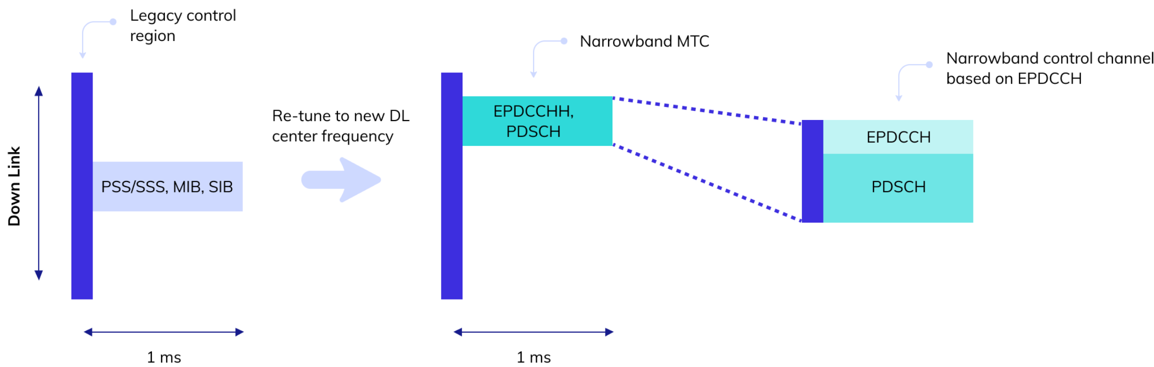

Figure 5, LTE-M Sharing Carrier Capacity in Legacy LTE Configuration
Image Credit: Nokia

NB-IoT

NB-IoT serves similar applications as Cat-M1 but is slightly different since it is not based on LTE. It is an independent radio interface, using DSSS modulation that is closer to old Neul versions of Weight- less-W than LTE. Due to this fact, a common argument against NB-IoT is high deployment costs. Opponents point to it not being LTE-based and claim that it needs to operate in a side band using different software or be deployed in deprecated GSM spectrum.

This is not necessarily true. NB-IoT operates on ultra narrow 180 kHz bandwidth, which is equivalent to one resource block in LTE transmission. This enables three different operation modes:

1. In-band operation: Utilizing resource blocks within an LTE carrier
2. Guard band operation: Utilizing unused resource blocks within an LTE carrier's guardband.
3. Stand-alone operation: Utilizing currently used GSM frequencies.

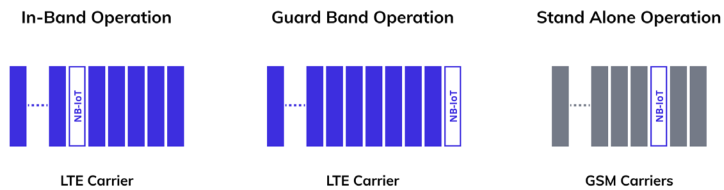

Figure 6, NB-IoT Operation Modes

Image Credit: Qualcomm

Some predict that NB-IoT will operate in a dedicated 200 kHz band reframed from GSM, which many think will be expensive. Others tend to think that NB-IoT will work with the operator's existing infra- structure since in-band and guard band operation is theoretically possible despite conflicts between resources used by the LTE systems.

Regardless, it's important to note that GSM technology already own 85% of the market share in the mobile communication space. With such strong market players, deployment cost issues may be mitigated if market domination continues. Plus, with 3GPP standardizing NB-IoT in Rel 13 that means that network interoperability and roaming support will be guaranteed.

Currently, NB-IoT is not commercially available. Vodafone had a press released in October of 2016 promising deployment in the first three months of 2017, but as of June 2017, commercial deployment in Ireland and Netherlands has been delayed. Still, the launch of NB-IoT globally is impending as of the time of this writing.

EC-GSM

EC-GSM (extended coverage GSM) is similar to NB-IoT in that is uses 180 kHz, but only utilizes existing GSM networks. It can reuse 2G chips by a simple rmware upgrade. This upgrade enables eDRX and PSM features to make it power-efficient. The biggest advantage and disadvantage of EC-GSM is it is tied to the existing GSM radio interface.

As of today, GSM technology still dominates cellular protocols. Thus, big carriers looking for cheap a deployment option may consider EC-GSM. However, in North America, GSM networks are already sunsetting for LTE-based networks. If 5G is the future, having a protocol more compatible with LTE may be more forward-facing than EC-GSM.

Figure 7, Coverage Comparison with Extended Coverage

Image Credit: Ericsson

Cellular IoT vs. Unlicensed LPWAN

There is speculation that there will only be one winner with either cellular IoT or unlicensed LPWAN (LoRa/SigFox/RPMA) dominating the IoT market. While this may very well be possible from a business standpoint, technology-wise, both can coexist. Provided that deterministic reliability and real-time response time are not critical drivers of a given application, unlicensed LPWAN may still be a cheaper option to deploy and operate as big carriers sunset older GSM networks.

The biggest advantage of cellular IoT is the support, maturity, and scale of the large mobile network operators (AT&T, Orange, Vodafone, etc.). Since the LTE infrastructure already exists, these operators can provide reliable services within a licensed band without duty cycle limitations. All of the cellular IoT options also support slightly higher data rates, meaning that they can cover a wider range of use cases. Lastly, if 5G is as revolutionary as advertised, cellular IoT provides a clearer path to the future of wireless communications.

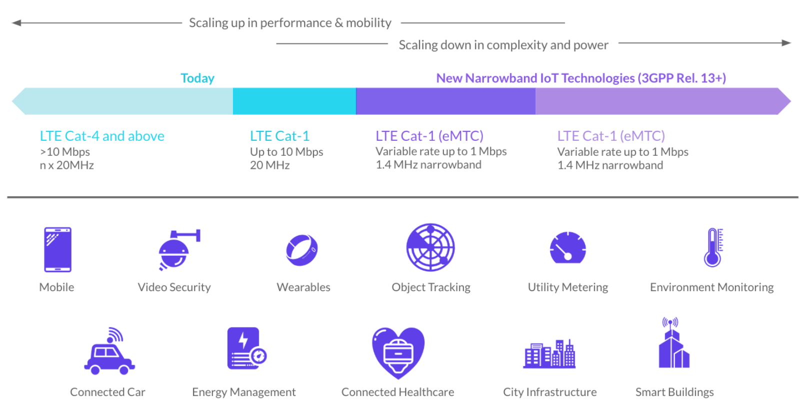

Figure 8, Cellular IoT 3GPP Roadmap and Use Cases

Image Credit: Qualcomm

This does not mean that unlicensed LPWANs are inferior or will be eliminated in a winner-take-all competition. Unlicensed LPWAN players believe that cellular approaches may be too expensive or inflexible to meet the requirements of certain IoT applications where a large number of sensors must operate within a private network. Since LoRa and SigFox also support public networks, they may be the preferred option for certain applications with alternative business models.

Ultimately, the two networks serve similar but different needs. If high throughput and two-way communication is critical, cellular IoT may be a better fit. If bandwidth and downlink capability is not required, then unlicensed LPWANs may be cheaper to deploy, maintain, and manage.

Appendix A: GSM vs. LTE

One cannot directly compare GSM and LTE as they serve different requirements. GSM is primarily a voice technology, rivaling CDMA. GSM is backed by AT&T and T-Mobile in the US and holds over 80% market share globally. CDMA or Code Division Multiple Access is another voice technology developed by Qualcomm. Both of these protocols are transitioning into LTE.

LTE is a wireless broadband technology that supports high speed data. GSM and CDMA can support both voice and data, while LTE can only support data thus far (Voice over LTE or VoLTE is under development). A comprehensive comparison of the two is available on RF Wireless World , also copied below for convenience:

Specifications	GSM	LTE
Full form	Global System for Mobile Communication	Long Term Evolution
Frequency Band (MHz)	There are four major frequency bands used across the globe GSM850, GSM900, DCS1800 and PCS 1900	LTE supports frequency Band 1 to 25, band 33 to band 43
Channel Bandwidth	200KHz is supported in GSM	Release 8 supports 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz and 20MHz
Access Scheme	It supports FDMA/TDMA	Supports OFDMA in the down-link and SC-FDMA in the uplink
Topology	FDD (Frequency Division Duplex)	TDD (Time Division Duplex) and FDD both
Modulation Method	GMSK	Long Term Evolution

Table 1

Specifications	GSM	LTE
Protocol Stack	Composed of PHY, LAPDm, R-RM, MM, CM layers at Mobile Subscriber(MS)	Composed of PHY, MAC, RLC, PDCP, RRC
Application	Used mainly for voice calls, GPRS/ EGPRS needed for data cells	Used mainly for data cells
Advanced Features	Supports gsm advanced features, such as MUROS, VAMOS, SAIC, MSRD	LTE Advanced release-10 is available which supports MIMO, beamforming, Carrier Aggregation etc.
Modulation Efficienty (b/s/ Hz) or spectral efficiency	1.35 b/s/Hz	Downlink cell: 1.69 bps/HZ/user for 2x2 MIMO and 2.67 for 4x4 MIMO (in case of LTE standard) 2.4 and 3.7 respectively for LTE-Advanced standard

Table 1, Continued

Glossary

EC-GSM	Extended Coverage GSM
eDRX	Enhanced discontinuous repetition cycle LPWAN Low-power, wide-area network
LTE	Long Term Evolution (4G wireless)
MCT	Machine Type Communication NB-IoT Narrow-band IoT
PSM	Power Saving Mode
TAU	Tracking Area Update
UE	User Equipment
3GPP	3rd Generation Partnership Project