Qualcomm

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Understanding the benefits of LTE Cat 1bis technology

Introduction

IoT applications call for diverse data rates.

On the low end, some applications require a few kilobits (kpbs) per second; others need data rates in the tens of Kbps, up to hundreds of kbps. In the middle tier, some applications require throughput in the 1-to-10 Mbps range. On the high end are IoT devices that require 100 to 150 Mbps of throughput. A mix of non-3GPP and 3GPP IoT air interface technologies have been deployed to enable these applications. Table 1 below summarizes different IoT standards, some unique attributes of each of them and the IoT applications that use the technologies.

On the 3GPP side, LTE-M and NB-IoT are two IoT-specific standards introduced in 3GPP release 13. They provide low power operation, extended coverage range and low data rate; they are aptly called low-power wide area networking, or LPWAN technologies. In Release 13, LTE Cat 1bis was also added to the standards. Cat 1bis requires one receive- (Rx) antenna, making it easier and cheaper to build devices in smaller form factors. Recently, IoT use cases involving drones and industrial automation have evolved, requiring either higher throughput, lower latency or both. 5G or higher-category LTE devices (LTE Cat 16) are suitable for such use cases.

Rel-17 introduces the RedCap (also known as NR-Light) – reduced capability – modem. RedCap is the 5G equivalent of the LTE Cat 4 modem, allowing data rates of approximately 200 Mbps using sub-6GHz spectrum. Rel-18 takes that a step further and brings in support for IoT-centric eRedCap (enhanced RedCap) modems offering data rates from 10 to 15 Mbps, the 5G equivalent of LTE Cat 1bis.

Cat 1bis and eRedCap are complementary technologies, with eRedCap providing an evolution path to Cat 1bis.

	LTE Cat 1	LTE Cat 1bis	LTE Cat 4	LTE Cat NB2 (NB-IoT)	LTE Cat-M1 (eMTC)	RedCap	eRedCap
3GPP release	Rel-8	Rel-13	Rel-8	Rel-14	Rel-13	Rel-17	Rel-18
Bandwidth	Up to 20 MHz	Up to 20 MHz	Up to 20 MHz	180 KHz	1.4 MHz	FR1:20 MHz	FR1: 5-20 MHz[1]
Duplex mode	FD, TDD	FD, TDD	FD, TDD	HD, FDD	FD[2], HD, TDD	FD, HD, TDD	FD, HD, TDD
Download (DL) peak data rate	10 Mbps	10 Mbps	150 Mbps	127 Kbps	300 kbps	FR1: 220 Mbps	10 Mbps
Upload (UL) peak data rate	5 Mbps	5 Mbps	50 Mbps	159 Kbps	375 kbps	FR1: 120 Mbps	10 Mbps
Max Tx/ Rx chain	1T/2R	1T/1R	1T/2R	1T/1R	1T/1R	1T/2R (1T/1R)	1T/1R
Tx power	23 dBm	23 dBm	23 dBm	14/20/23 dBm	20/23 dBm	20/23/26/ 29 dBm	23 dBm
Range (MCL)	144 dB	141 dB	144 dBm	164 dB	156 dB	140 dB	137 dB
Power save	eDRX, PSM	eDRX, PSM	eDRX, PSM	eDRX, PSM	eDRX, PSM	eDRX, MICO	eDRX, MICO
Voice	Supported	Supported	Supported	Supported	Supported	Supported	TBD

Table 1: Characteristics of IoT standards

LTE-M- and NB-IoT-based devices such as trackers, energy meters and other IoT devices are commonly found in commercial deployments. In this paper we compare and contrast capabilities of these LPWAN technologies with LTE Cat 1bis to develop a better understanding of the suitability of Cat 1bis in low-power, low-throughput use cases. To perform this comparison we consider the following factors:

- Network deployment considerations
- Global connectivity/Roaming
- Power consumption
- Data rates
- Coverage aspects
- Positioning/Location performance
- Cost structure
- Evolution in standards

[1] 5 MHz support with 30 KHz sub-carrier spacing will require changes to Physical Broadcast Channel (PBCH) as compared to conventional NR.
[2] The full-duplex flavor of Cat M is not available commercially, either on device or on networks.

Network deployment considerations

One of the impediments to adoption of NB-IoT and LTE-M is that these two technologies require operators to upgrade software on their networks.

That comes with extra capital expenditure (CapEx), along with greater operational expenditure (OpEx) to run the network. In addition, for LTE-M deployment, operators need to earmark six resource blocks; in many cases, that can constitute as much as 10 percent of the available bandwidth in lower parts of the spectrum.[3] If the LTE-M network does not carry enough load, the capacity dedicated to LTE-M usage will be underutilized and users on LTE networks will be deprived of these resources. This is not a standards limitation but could be a limitation resulting from specific network infrastructure implementations There are ways to minimize the losses by dynamically sharing spectrum between LTE and LTE-M, but that requires additional software licenses and network upgrades.

In contrast, Cat 1bis devices operate on the regular LTE network – the same LTE network on which our cell phones run. Unlike LTE-M and NB-IoT, operators do not need to perform any upgrade to their RAN or core network. The eNB functions such as admission control, congestion control, mobility management and scheduling are common between Cat 1bis and regular Cat 1. The LTE network treats a Cat 1bis device in the same way as a Cat 1 device, but with one Rx antenna. No dedicated bandwidth needs to be allocated for Cat 1bis devices; they coexist with regular LTE Cat 1, Cat 4 and smartphones on the same network and spectrum.

Global Connectivity/Roaming

Global data connectivity using LTE-M and NB-IoT is a distant dream.

Not all operators deploy LTE-M or NB-IoT and the deployment of these technologies remains fragmented. In the graphic below, Map 1 depicts the state of global LTE-M and NB-IoT deployment as tracked by GSMA. NB-IoT is deployed by 110 operators across approximately 60 countries. On the other hand, LTE-M is commercialized by 60 operators in 34 countries. As shown in the map, the two technologies are available in most parts of Europe, North America and Australia, plus parts of Asia.

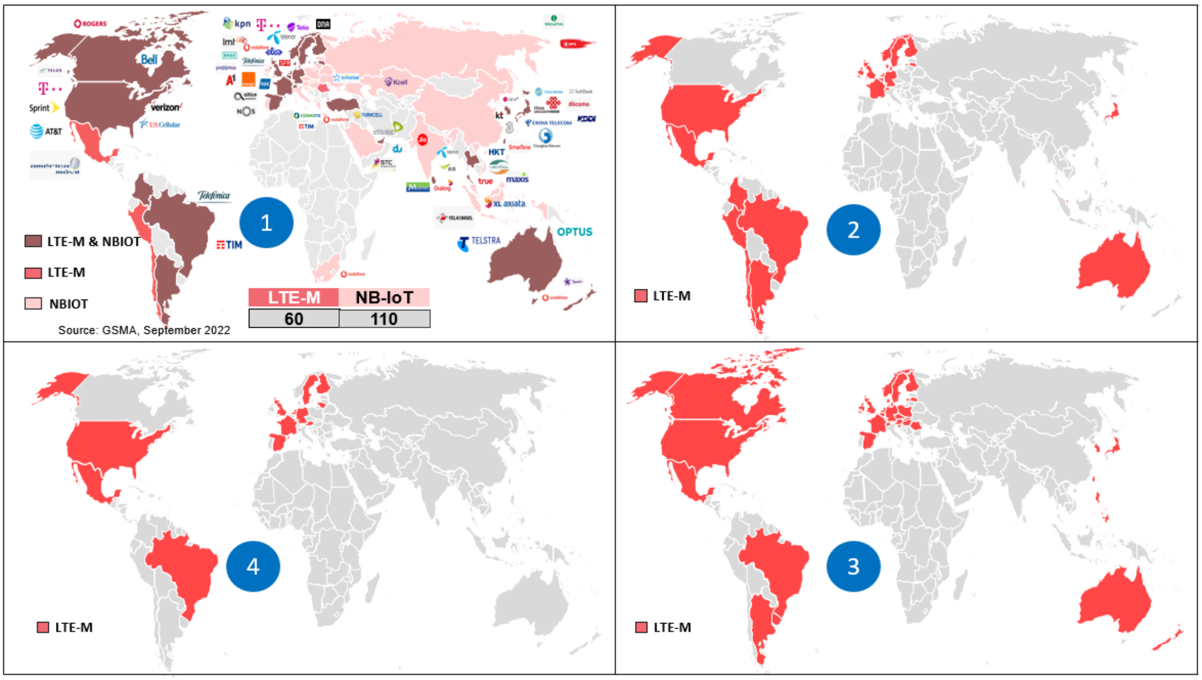
The state of international roaming over LPWAN is quite different. Map 2 shows the LTE-M connectivity footprint offered by a large wireless operator, including its roaming tie-ups. Maps 3 and 4 depict the connectivity footprint plus roaming tie-ups for two large mobile virtual network operators (MVNOs). The maps demonstrate the drastic reduction in the number of countries served and the area in which a device can use LTE-M services offered by a single service provider.

From the standpoint of an IoT service provider, it is difficult to rely on a device that can work everywhere over LTE-M. A similar story applies to NB-IoT data connectivity and roaming. Use cases such as globally deployed asset trackers require worldwide data connectivity, for which device manufacturers must resort to a multi-mode device.

As mobile phones have proliferated, cellular network operators have set up comprehensive, worldwide roaming tie-ups to support their traveling customer base. Operators today provide LTE data connectivity in nearly every country through an extensive network of roaming relationships, with local breakout options for IP data. IoT LTE Cat 1bis devices that run on the same networks as cell phones benefit from the roaming agreements set up for cell phones. Thus, they can get ubiquitous data connectivity from a single service provider – just as consumer devices do.

[3] Commonly used LTE channel bandwidths are 5, 10 and 20 MHz. For a 10 MHz spectrum allocation, if the operator dedicates 1 MHz for e-MTC, that would constitute 10 percent.

[4] Map 1 data from "Global Cellular IoT Module Market Analysis: Q2 2022," *Counterpoint Technology Market Research*, September 2022, https://report.counterpointresearch.com/posts/report_view/iot/3305



Power consumption

To allow devices to stay in sleep state longer and save power, 3GPP introduced features such as extended discontinuous reception (eDRX) and power-saving mode (PSM).

Applications like smart energy meters and trackers typically have a fixed, predictable pattern of sending and receiving data; they can use eDRX and PSM for longer DRX sleep cycles. The two features, commonly used in NB-IoT and LTE-M networks, also apply to Cat 1bis devices. A survey of operators revealed that a number of the major operators in the US, Europe and Asia have enabled eDRX and PSM for their Cat 1 and Cat 1bis devices. As a result, energy meters and trackers with Cat 1bis can enjoy the same extended sleep cycle as LTE-M-based devices.

Some use cases in asset tracking allow the device to operate in power-down mode, in which the device wakes up periodically to report data. The rest of the time, it is powered down and unreachable.

Similar to LTE-M and NB-IoT devices, a Cat 1bis device has only one receive RF chain—an architectural benefit over a traditional Cat 1 device. The single chain means lower cost, some savings in power consumption and design flexibility in form factor-constrained devices.

Another important metric tied to the battery life of a device is ON time: the time that a device must be in active mode to complete a data transaction. Exploring device ON time leads into a discussion of data rates.

The peak uplink data rates with NB-IoT NB2 and LTE Cat-M1 are 160 Kbps and 375 Kbps in half-duplex mode. However, the typical data rates achieved in the field are far lower. Publicly available statistics from ATT and Orange[5] indicate that the average LTE-M data rate in the field is about 100 Kbps and data rates in coverage extension scenarios are in the tens of Kbps. In a recent study, we discovered that the average NB2 data rate for a Latin American operator was only 3 Kbps. Typical data rates advertised for NB2 devices are about 10 Kbps. Figure 1 below shows device ON time for uploading 500 bytes of payload based on typical data rates for NB2, Cat-M1 and Cat 1 devices.

[5] "What is the Difference in Data Throughput between LTE-M/NB-IoT and 3G or 4G?" GSMA, October 2019, https://www.gsma.com/iot/resources/what-is-the-difference-in-data-throughput-between-lte-m-nb-iot-and-3g-or-4g/; "The Network Technology Roadmap," AT&T, https://iotdevices.att.com/att-iot/TechnologyRoadmap.aspx

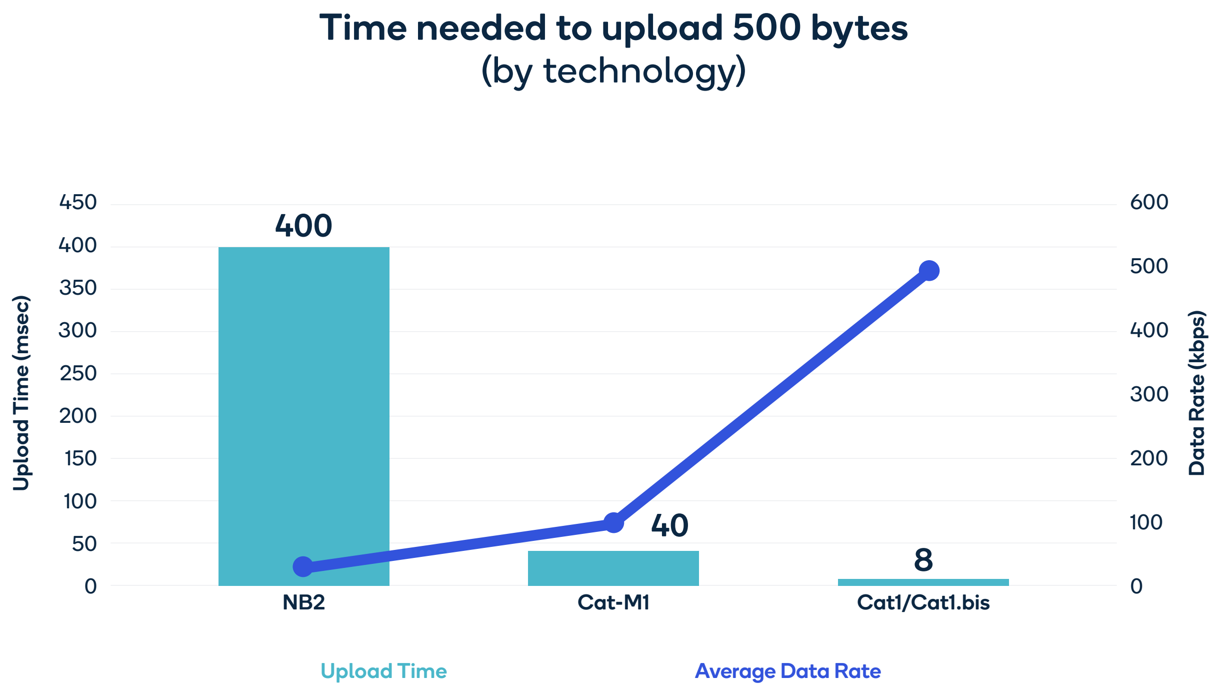


Figure 1: Device ON time for NB2, Cat-M1 and Cat 1 devices

As shown, to upload or receive 500 bytes of data on NB-IoT and LTE-M, device ON time is 400 milliseconds and 40 ms respectively; in contrast, a Cat 1bis device can complete the same data transaction in 8 ms (throughput = 500 Kbps).

Power consumption is largely dependent on the mode of operation of the device and how the device is implemented. For delay-tolerant and/or low duty-cycle applications, IoT devices rely on reduced power states like eDRX and PSM – which apply to both LPWAN and Cat 1bis – to greatly increase battery life. It is also worth noting that device power consumption is increasingly dominated by tasks unrelated to the cellular modem, such as tracking location and processing sensor data. Even then, power consumption of LTE Cat 1bis modems is now on par with or better than that of LTE-M modems (see Table 2).

	Cat 1bis[6]	LTE-M[7]
Power-Saving Mode (PSM)	1.7 µA	1.4 µA
e-DRX = 81.92 s, PTW = 2.56 s	< 50 µA	120 µA

Table 2: Power consumption, Cat 1bis and LTE-M modems

A related concern from device manufacturers is the inability to perform firmware over-the-air (FOTA) updates over NB-IoT and sometimes over LTE-M. Sending to the device a FOTA image a few megabytes in size takes a long time at LPWAN data rates. Delta FOTA sends only incremental changes to the device; it can reduce device ON time, but it requires device makers to implement the delta FOTA framework. Similarly, with increasing adoption of intelligent edge-connected applications, IoT devices will send and receive more data, but LPWAN data rates may not suffice to support such a transformation. For example, smart energy meters can do more than simply collect data on energy usage. They can (and will) monitor the actual load on the grid, changes in consumption patterns and fluctuations in metrics like voltage. They will then feed the parameters to the utility cloud for quick remedial response from the grid. Those innovations will require higher data rates.

[6] Current consumption for Qualcomm® 216 LTE IoT Modem.
[7] Current consumption for Quectel BG770A-GL module.

The need is particularly acute in asset tracking. As described above, non-ubiquitous LPWAN coverage results in a significant power consumption penalty for LPWAN devices compared to Cat 1bis devices. During the voyage of a typical shipping container, an asset tracker may have to perform public land mobile network (PLMN) search and registration in several countries. That takes longer when coverage is not ubiquitous, often requiring additional scanning to fall back to other radio access technologies (RAT). The result is sub-optimal power consumption.

Coverage aspects

The most vital benefit of LTE-M and NB technology is in the area of coverage.

Both techniques use Layer-1 packet repetition (control, data channel included) to provide extended coverage compared to traditional LTE. In theory, LTE-M or enhanced machine-type communication (eMTC) offers a 12 dB extra link margin over LTE, and NB offers a 20 dB margin. That extended RF coverage comes at the cost of reduced spectral efficiency (reduced data rates) because operators have to allocate more resources for packet repetition and increased latency. Due to the reduced number of antennas, LTE Cat 1bis carries an additional 2.5 to 3 dB of penalty compared to traditional LTE Cat 1.[8]

Extended coverage is suitable for devices in challenging RF environments such as basements, elevators and deep indoor locations. The extended link margin is not usually indicated for mobile devices like asset trackers, or for devices like parking meters or energy meters that act as a hub to aggregate data from surrounding meters.

Positioning/Location Performance

In general, cloud-based positioning techniques rely on user equipment (UE) to detect nearby LTE cells.

Positioning accuracy tends to improve as a function of the number of cells detected. As channel bandwidth increases, correlation gain also increases, allowing the device to detect synchronization channels and decode system information from more LTE cells.

The envelope supported by Cat 1bis is 20 MHz, compared to six resource blocks or 1.4 MHz in LTE Cat-M1. Even if operators deploy 5 or 10 MHz of channel bandwidth, the chances of detecting LTE cells for positioning are higher than in Cat-M1. That is another reason LTE Cat 1bis is more suitable for a tracker use case.

Figure 2 below shows the number of cell sites, or towers, detected by an LTE Cat 1 device operating on a 10 MHz channel (graph on left) vis-à-vis the cell sites detected by a Cat-M device (graph on right). With support for higher channel bandwidth, a Cat 1 device can detect between five and 10 cell sites fairly consistently, thereby improving location accuracy.

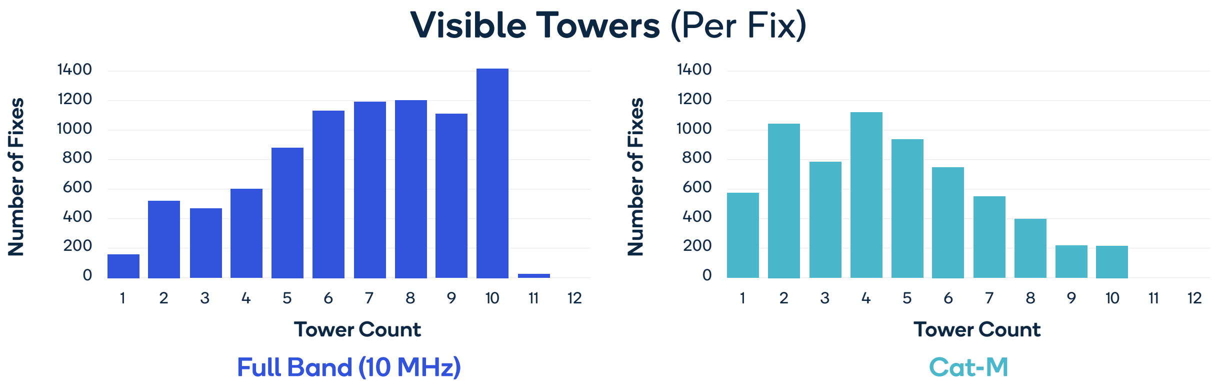


Figure 2: Towers detected, 10 MHz channel vs. Cat-M device

[8] Note that LTE Cat 1bis and Cat 1 devices can also make use of repetitions for extended coverage. For download, it is coverage enhancement (CE) mode A; for upload, it is transmission time interval (TTI)-bundling and physical uplink shared channel (PUSCH), physical uplink control channel (PUCCH) repetition. However, that capability is not currently deployed on networks or in devices.

Cost structure

LTE Cat 1bis modules and devices have a cost advantage over Cat 1 devices.

Similar to LPWAN modules, Cat 1bis modules and devices have a single antenna and a single receive RF chain, in contrast to the two antennae needed for Cat 1 devices. LTE-M and NB offer a small cost advantage: the RF front end needs no surface acoustic wave filter (i.e., it is SAW-less) due to the half-duplex nature of communication. As a result, the cost structure of Cat 1bis is comparable to that of LPWAN.

Figure 3 shows data on the average selling price (ASP) of modules sold worldwide. In 2020, the ASPs of Cat 1bis and LPWAN modules were on the order of USD10; since then, the price of Cat 1bis modules has fallen. (That is tied to sharp increases in Cat 1bis sales volumes in the Asian market.)

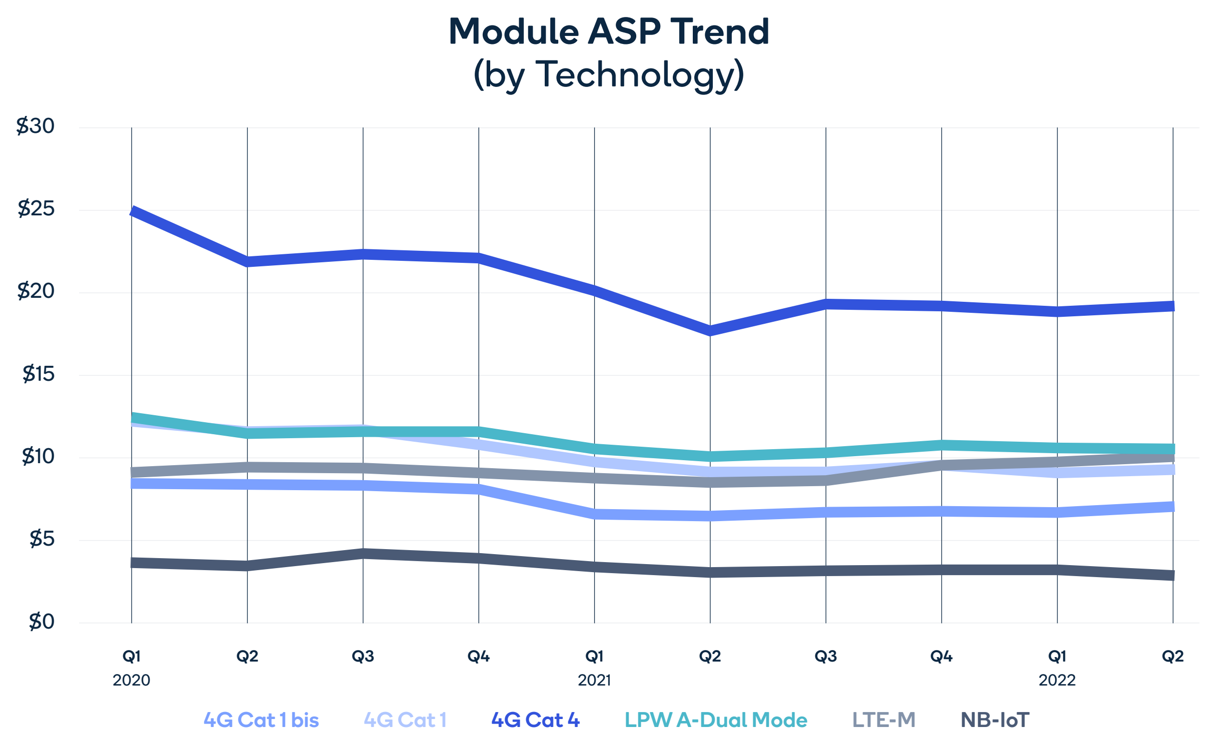


Figure 3: Average selling price (ASP) for wireless modules, USD
(Data source: Counterpoint Technology Market Research)

Evolution in standards

LTE Cat 1bis devices can be used on a 5G core (5GC) network.

In Rel-15, the 3GPP has defined an option 5 for network architecture, allowing upgraded LTE (eLTE) devices to connect to a 5GC network over upgraded eLTE NB (eNB). Allowing an LTE Cat 1bis device to register with 5GC will enable a low-power but ready state, such as radio resource control (RRC) inactive. It will also ensure service continuity for these devices in case operators should phase out 4G core networks. LTE Cat 1bis devices can also connect to a combined Evolved Packet Core-5GC core network. Cat 1bis UEs can time-share or frequency-share spectrum with 5G devices (5G NR UEs) using dynamic spread spectrum (DSS). That will ensure continued service for Cat 1bis devices when operators re-farm LTE spectrum for other advanced technologies.

3GPP has laid out a clear path for the evolution of Cat 1 technology (see Figure 4). In its initial specification, 3GPP defined UE category Cat 1, allowing for upload and download data rates of 5 and 10 Mbps respectively over a channel bandwidth of up to 20 MHz. With the introduction of Cat 1bis in 2016, the RF and throughput capabilities were maintained while power consumption was improved by reducing to one RF receive chain.

Before the end of 2023, 3GPP will freeze Rel-18 standards, among which is NR eRedCap. As described above, eRedCap is designed specifically for resource-constrained IoT devices. NR eRedCap will extend support for similar channel bandwidths of up to 20 MHz and provide data rates of around 10 Mbps using the same single-antenna architecture used by Cat 1bis. That sets out a clear continuity path for applications that require simple RF design and Cat 1-like data rates. When eRedCap devices roll out, LTE will become their fallback technology, enabling operation in Cat 1bis mode on LTE.

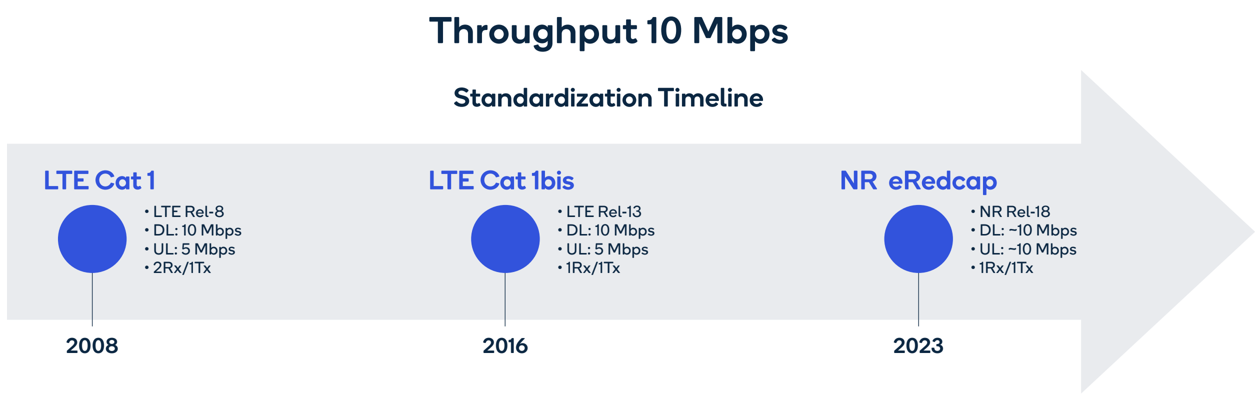


Figure 4: Evolution of Cat 1

Conclusion

Cat 1bis has benefits that ease the pain points of IoT adoption.

Its wider global roaming footprint, its support for power saving features and its low power consumption should allow manufacturers to build devices that are easy to deploy and have a long battery life.

LTE-M provides coverage benefits, but they may not apply in non-stationary use cases like globally deployed asset trackers, which stand to gain a lot with the proliferation of Cat 1bis. Compared to LPWAN modules, Cat 1bis modems and modules are price-competitive. They have a clearly defined evolution path in 3GPP standards in the form of eRedCap-based products in the future.

Cat 1bis-based devices have been widely adopted and certified globally in recent years. The trend will only accelerate as more operators follow the lead of AT&T, Verizon and Deutsche Telekom in certifying the Qualcomm® 216 LTE IoT Modem.

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