WHITE PAPER

Cellular technology evolution for IoT applications in the 5G era

The importance of NR RedCap for 5G IoT

Abstract

This paper touches upon the progression from 4G LTE to 5G New Radio (NR), current and coming standards, and the importance of 5G NR RedCap for IoT applications.
The cellular industry is in a transition period spanning two generations of cellular technology: 4G LTE and 5G New Radio (NR). Although much effort has been made to develop the next generation of cellular standards, the deployment process is happening relatively slowly. For this reason, and much like prior transitions (3G to 4G for instance), it is expected that for some years, the two technologies will coexist.

When 3GPP established the first specifications for 5G NR technology in Release 15, the industry's attention was focused on enhanced mobile broadband (eMBB), which primarily addressed consumer demand for high-speed mobile and fixed wireless connections. eMBB, however, was never designed to fulfil the needs of IoT applications. As a result, 4G LTE designers who target the IoT market have found themselves without the possibility to connect to 5G NR networks. Acting upon this situation, 3GPP has been expanding the scope of 5G New Radio in subsequent releases to address these shortcomings.

White paper: Cellular technology evolution for IoT applications in the 5G Era
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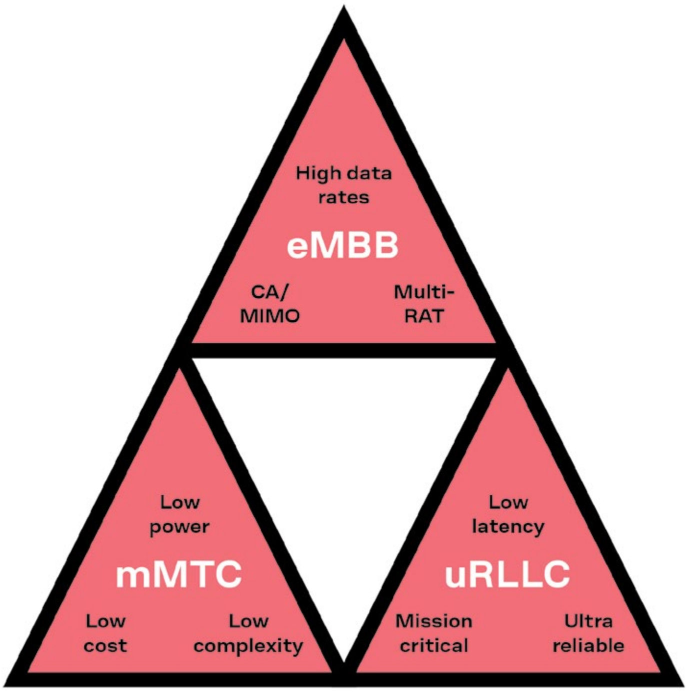
The cornerstones of 5G New Radio: eMBB, uRLLC, and mMTC

In June 2018, the 3GPP standards body launched a set of specifications for 5G NR (New Radio) communications, defining three use case umbrellas with unique characteristics for different contexts:



eMBB (enhanced Mobile Broadband) provides higher data rates and better latency. This specification, powered by technologies like wide channel bandwidths, Carrier Aggregation, and MIMO (Multiple Input Multiple Output), is a Multi-Radio Access Technology (Multi-RAT) that enables high data rates and advanced features. At present, eMBB is the main deployment driver for 5G. Many investments and activities are focusing on this pathway, the most common implementation being consumer smartphones.

uRLLC (ultra-Reliable Low Latency Communication) is the solution that provides the lowest possible latency, highest network reliability, for latency sensitive and mission critical applications. In the near future, this specification will be highly relevant to robotics, autonomous vehicles, and industrial automation.

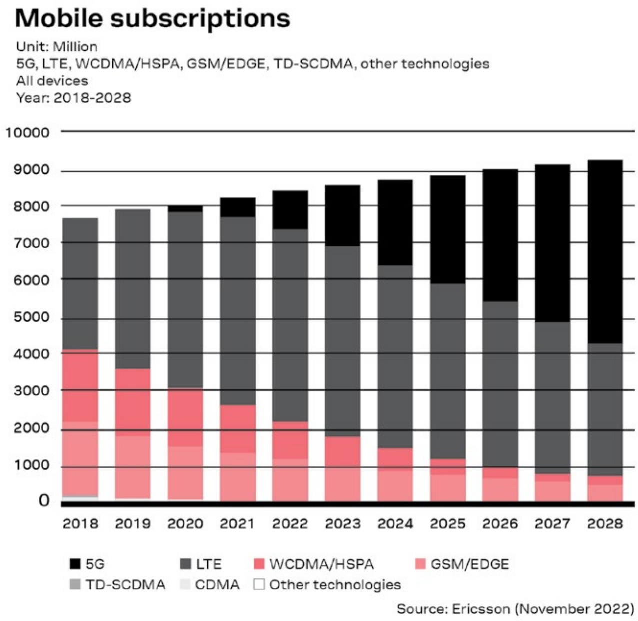
mMTC (massive Machine Type Communication) offers ultra-low power consumption and enhanced in-building coverage when compared with legacy cellular technologies – both which are critical requirements for many IoT applications. LTE-M and NB-IoT, although technically under the 4G LTE umbrella, are considered forward-compatible with 5G mMTC and are officially part of the 5G mMTC family.

5G NR (New Radio) is the new radio standard developed specifically for 5G. It utilizes two frequency ranges, FR1 for bands up to 7.125 GHz and FR2 for bands between 24.25 and 71.0 GHz. The frequency range above 24 GHz is also commonly referred to as millimeter wave (mmWave).

4G LTE and 5G will coexist for at least the next 10 years

Technology adoption is a complicated process that requires extended transition periods. During these periods, older technologies phase out while new ones gain ground. Cellular technology evolution has occurred slowly but at a steady pace. 2G was introduced in1991 and although the main aim of 3G and 4G was to obsolete the prior generation, at present, 15% of global mobile subscriptions remain on 2G (Fig. 4).

The transition from 4G to 5G is occurring along similar lines. Introduced in 2010, 4G currently encompasses more than 50% of global subscriptions with no shutdowns announced to date. As the mobile subscriptions graph points out, the number of 5G subscribers increases yearly while 4G network users decrease, although rather slowly. According to Ericsson's Mobility Report, 4G will be the leading mobile technology by subscription count at least until 2027.



The transition from 4G to 5G has been much more complex than the transition from 2G and 3G to 4G. Based on user equipment (UE) categories, 4G LTE prioritized higher data rates. But considering how the universe of cellular applications has broadened, data speed is no longer the only factor at stake. Unlike prior cellular technology generations, 5G was not specifically designed to replace 4G. The market demanded a multi-dimensional rather than a one-dimensional upgrade, not only focusing on data rates. Thus, 5G came to offer a broader spectrum of possibilities and new core network implementation options, to name a few of these dimensions. Indeed, with the introduction of ultra-low latency and low power, users now have the chance to explore other potential applications.

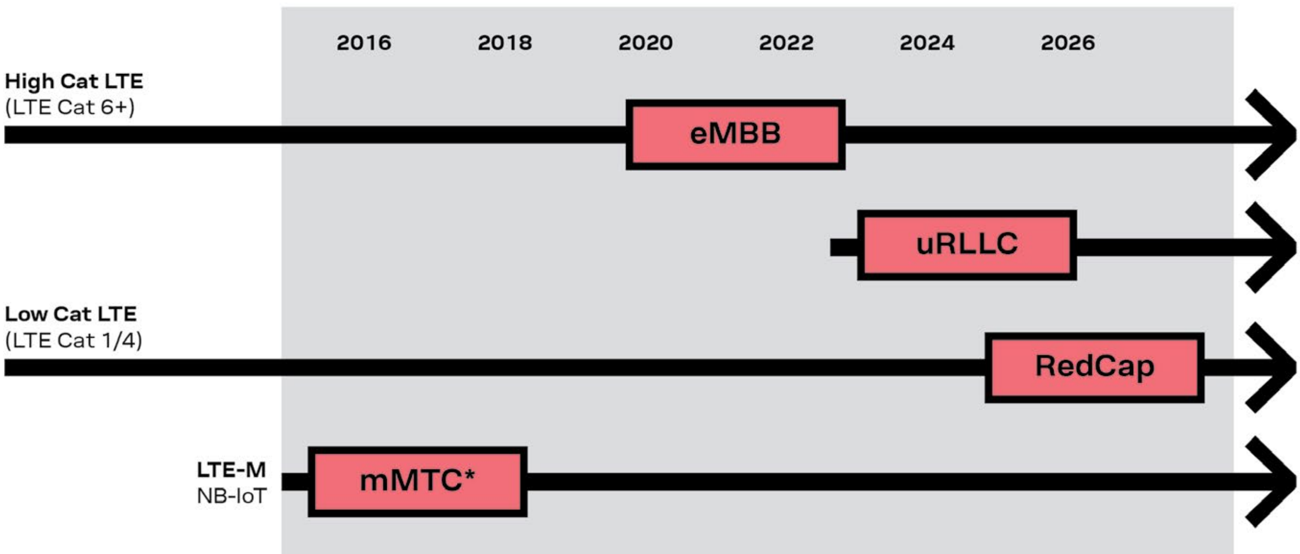
The slow consumer migration and multi-dimensional approach brought by 5G are crucial factors to consider when thinking of the migration from 4G IoT applications to 5G. LTE-M and NB-IoT are available today and part of the 5G mMTC family, providing a path for power sensitive and low data rate applications. For medium data rate IoT applications, RedCap closes an important gap in the 5G specification, enabling LTE Cat 4 and Cat 1 applications to migrate to 5G NR. In the meantime, LTE will be functional and available on operator networks into the 2030s.

A new 5G specification for IoT and its scope

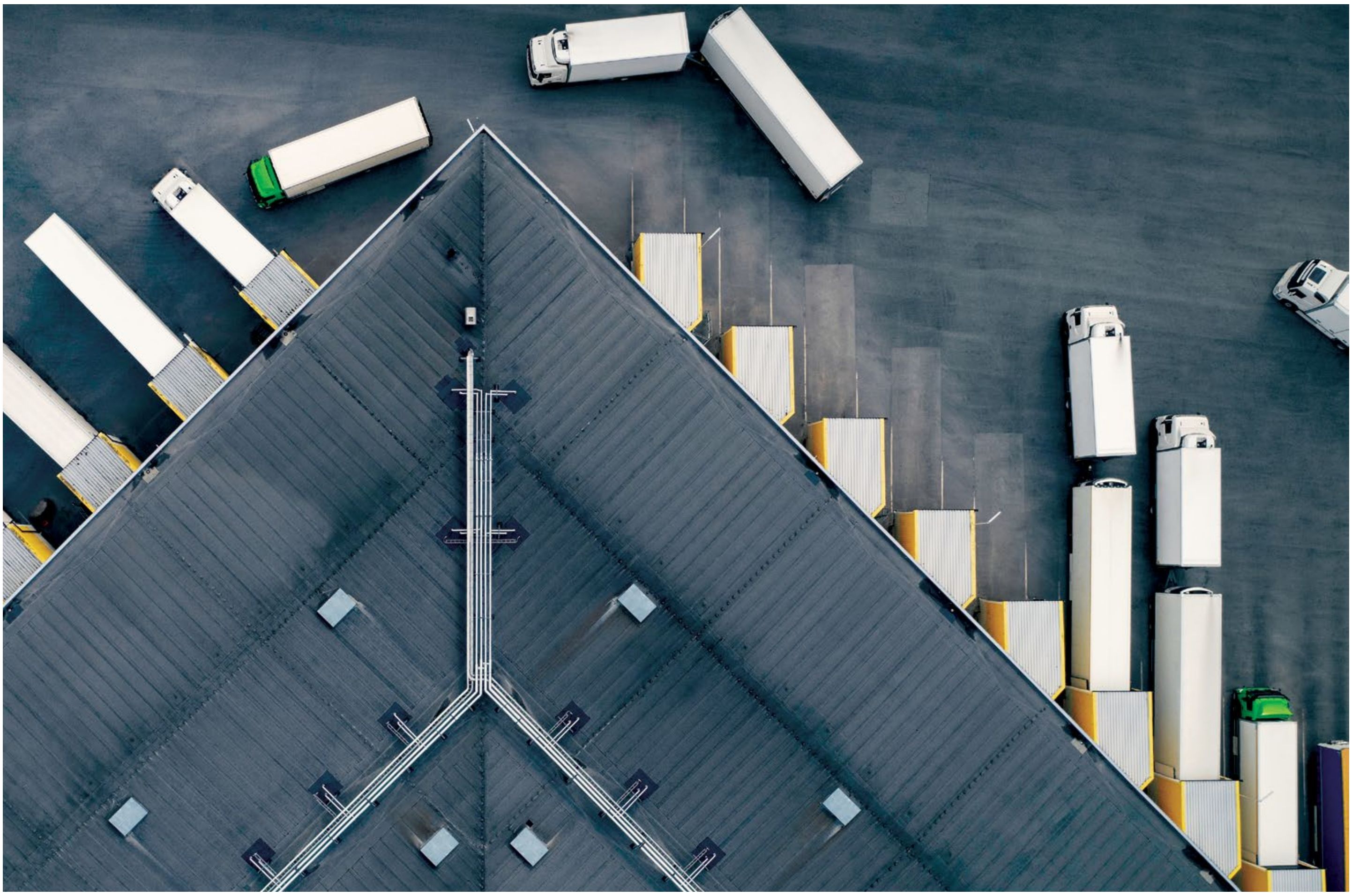
eMBB, uRLLC, and mMTC provide extensive possibilities to their users. Still, a series of mid-range IoT applications in areas such as industrial monitoring and control, sensor networks, telematics, video surveillance, and wearables were not well served by these specifications; typically, because they require data rates higher than LTE-M or NB-IoT, yet lower than eMBB.

As a response to these demands, in December 2020, 3GPP introduced a new work item to study the requirements for these mid-range IoT applications. In June 2022, 3GPP Release 17 was published, including a new 5G NR spec: 5G NR Reduced Capability (RedCap). In terms of performance and complexity, RedCap is positioned above LTE-M and NB-IoT, but below eMBB and uRLLC. It is especially suitable for applications currently connecting via LTE Cat 1 or Cat 4. Following typical development timelines for new chipsets and necessary upgrades to operator networks, it is expected that the earliest commercial RedCap devices could reach the market in 2024.

Earliest 5G deployment timeline



*mMTC (Le., LTE-M and NB-IoT) retain an LTE air interface through at least R17. These technologies are already considered “5G” by 3GPP and ITU, and 5G Radio Access Networks can provide direct, in-band support for and compability with devices using these technologies.



Considering the main use cases, RedCap was designed to encompass various requirements:

Data rate: RedCap will support data rates up to the LTE Cat 4 range when deployed at 20 MHz bandwidth. Data rates may vary depending on the actual network configuration and the type of duplex operation, including FD-FDD (full-duplex frequency division duplexing), HD-FDD (half-duplex frequency division duplexing) or TDD (time division duplexing). For example, operation in FD-FDD at a bandwidth of 20 MHz (considering receive diversity) with 256-QAM, could reach a maximum of 227 Mb/s (downlink) and 91 Mb/s (uplink). Operation in TDD could reach a maximum of 181 Mb/s (downlink) and 18 Mb/s (uplink) with a DL/UL pattern of 4:1 – which is still higher than what is achievable with LTE Cat 1.

Device complexity: The RedCap specification reduces bandwidth, number of antennas, and MIMO layers. It also introduces complexity reduction features when compared with eMBB and uRLLC implementations, resulting in lower cost. Lower complexity can enable smaller device sizes – within acceptable ranges for wearable form factors.

Band support: Both FDD and TDD support 5G New Radio FR1 and FR2 bands. In theory, RedCap devices could support the same FR1 and FR2 band ranges as eMBB devices, thus creating efficient rollout options for mobile operators worldwide. This will simplify the eventual migration to 5G NR stand-alone networks. However, mobile operators may elect to deploy RedCap on a more limited set of bands than eMBB devices.

Power consumption: For many IoT and wearable applications, device energy efficiency is critical. By adding eDRX (extended discontinuous reception) cycles in idle and inactive modes and relaxing neighbor-cell measurements for stationary devices, RedCap helps further reduce device power consumption as compared with eMBB.

RedCap vs eMBB

Reducing capabilities equals reducing complexity. When comparing the capabilities of Release 17 RedCap devices with the capabilities of Release 15 eMBB devices, one can pinpoint at least five relevant reductions in the specification that, in turn, may lower device complexity and cost.

1. Maximum Bandwidth. A 5G eMBB device must support a maximum bandwidth of 100 MHz in FR1 and 400 MHz in FR2. For a RedCap device, these correspond up to 20 MHz (FR1) and 100 MHz (FR2) in Release 17. Due to cost considerations, most RedCap devices will likely be deployed in the FR1 spectrum, therefore supporting a maximum bandwidth of 20 MHz.

2. Receiver antennas. eMBB devices require a minimum of two receiver antennas, and in certain bands may require four. According to the 3GPP specification, one to two receiver antennas may suffice for a RedCap device. However, since receive diversity maximizes data throughput, it is plausible that mobile operators will demand two antennas for a variety of use cases.

3. The maximum number of downlink (DL) MIMO layers. RedCap devices have a reduced number of DL MIMO layers, so RedCap devices with two receiver antennas have a maximum of two DL MIMO Layers. The device needs to inform the network how many layers it supports before the network grants access.

4. Maximum downlink modulation order. For FR1, eMBB devices can support up to 256-QAM (quadrature amplitude modulation). RedCap mandates 64-QAM support in FR1 and FR2, with 256-QAM optional in DL in FR1. Although 256-QAM is more bandwidth-efficient for mobile operators, it also adds complexity to the device. Mobile operators may elect the 64-QAM requirement to achieve the targeted complexity reductions, although they could also opt for 256-QAM to maximize bandwidth efficiency.

5. Duplex operation. For FR1, in FDD bands, eMBB devices must support full-duplex operation (FD-FDD), enabling simultaneous transmit and receive on the downlink and the uplink frequency bands. This requires multiple duplex filters, which, of course, increases the device cost. RedCap devices, on the contrary, do not mandate full duplex FDD; it is not necessary that the device transmits on the uplink and downlink frequencies at the same time (HD-FDD or half-duplex FDD). HD-FDD is less bandwidth-efficient and therefore not all operators may support it, at least initially.

Several of these functionalities are optional or include value ranges. This aspect is relevant to mobile operators, who will have a considerable range of implementation requirements, some stricter than others, depending on the service-level agreement.

5G NR RedCap instead of LTE for IoT applications

Comparing RedCap to eMBB helps to understand the selections made in the 3GPP standard to reduce complexity. Most IoT companies, however, do not choose between eMBB or RedCap, as eMBB will always be too feature-rich and expensive for the vast majority of IoT use cases. But what about LTE Cat 1 or Cat 4? Where does RedCap stand in comparison to these?

RedCap introduces features that may be appealing to IoT designers currently working with LTE Cat 1 and Cat 4, especially for those targeting mid-range IoT applications. For certain configurations, RedCap peak data rate can be higher and latency lower than LTE Cat 4. RedCap also provides an intrinsic connection to the 5G Core in the private network, which benefits the end-users if network longevity is of prime concern.

IoT designers also need to consider timing, from go-to-market timing to the life span of the planned IoT device. Although LTE networks will be available for many years, a transition toward 5G stand-alone networks is inevitable. In some regions, the first 5G NR RedCap devices are expected to hit the market sometime in 2024. Subsequently, other regions will follow, depending on operator schedules and priorities. RedCap transition timing thus will also depend on the geographical location. Finally, device designers should bear in mind that some IoT applications have a very long lifespan, often ten years or even longer. Hence, devices should be designed to connect to networks into the late 2030s.

How does 5G NR RedCap fit in with other 5G use cases for the IoT?

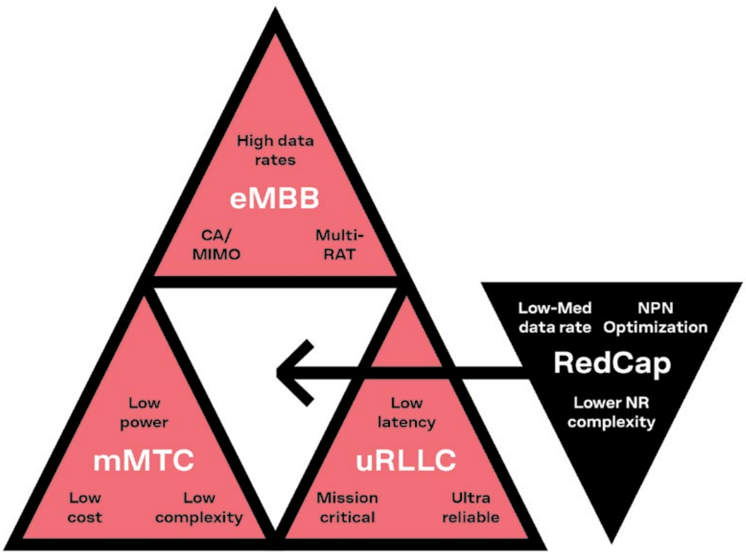
RedCap fills a gap for many IoT applications not well-served by Release 15/16 5G NR standards. For instance, eMBB solutions are significantly over-dimensioned and too costly for the majority of IoT use cases. uRLLC aims at demanding use cases in very specific IoT verticals that require ultra-low latency, while being complex and costly to implement. On the contrary, mMTC solutions (LTE-M and NB-IoT) are well-suited for many IoT applications, but they do not meet the performance requirements of mid-range IoT use cases.
Let's look at some of the applications that may rely on RedCap at an early stage:

Wearables: Consumer-focused applications like smart watches and other wearables must support relatively high data rates in small form factors. This is not achievable with either eMBB or mMTC. At the same time, mobile operators who sell wearables are eager to add 5G subscribers to their networks, giving them an incentive to expand their 5G offering with additional devices.

Heavy equipment: Construction, mining and agricultural equipment is often outfitted with cellular connectivity for telematics, remote diagnostics, and fleet management capabilities. For these applications, medium data rates in the LTE Cat 1 range are typically sufficient. The lifespan of such equipment extends for many years, thus requiring support for the 5G transition. Guaranteeing uninterrupted equipment connection to mobile networks well into the future should be paramount for many manufacturers.

Smart factory: Smart factories must also guarantee the longevity of the equipment on the factory floor, especially for those deploying 5G non-public networks (NPNs). Smart factory applications are varied, including use cases such as ethernet replacement or robotics, ideally suited for eMBB or uRLLC. But what about sensor networks, video surveillance, autonomous guided vehicles (AGVs) and industrial wearables like smart glasses? For non-public network owners to operate within a single 5G infrastructure, it is critical to have a medium data rate technology that can operate in a 5G New Radio network.

Over time, many other applications will migrate to RedCap. Essentially, any use case currently utilizing LTE Cat 1 or Cat 4 air interfaces will tend towards 5G NR RedCap. These encompass a broad range of applications, including alarm systems, video surveillance, point-of-sale terminals, telematics, first responder video, and smart grid applications.



What do we know about Rel-18 5G NR RedCap?

By Q1 2024, 3GPP is aiming to release the next set of specifications, Release 18. Release 17 has laid the foundation for RedCap to cater mid-tier IoT applications in the 5G era. Release 18 is intended to keep expanding RedCap's support for a new range of use cases and reach markets such as industrial wireless sensor networks and smart grids, where further complexity reductions should be considered.

Some of the main features directly related to RedCap within the frame of Release 18 are the following: Support for low-tier IoT devices with capabilities between the existing LPWA UE (user equipment) and Release 17 RedCap UE. The targeted peak data rate for Release 18 RedCap is about 10 Mb/s, which can be achieved by potentially reducing the UE baseband bandwidth to 5 MHz for data channels in FR1, while maintaining the UE's RF bandwidth at 20 MHz. In this way, one may avoid device ecosystem fragmentation. It is also clearly stated that Release 18 RedCap should not overlap with existing LPWA solutions, which will retain better power consumption and in-building coverage.

Conclusion

This white paper has focused on the importance of 5G NR RedCap for IoT applications by explaining why the current cornerstones of 5G, eMBB, uRLLC and mMTC, are insufficient to address all use cases, specifically those of consumer wearables and mid-tier IoT applications.

Considering requirements such as data rate, device complexity, band support and power consumption, RedCap is especially suitable for applications currently connecting via LTE Cat 1 or Cat 4. Furthermore, looking into maximum bandwidth, receiver antennas, number of downlink MIMO layers, maximum downlink modulation order, and duplex operation, RedCap clearly reduces device complexity and cost as compared with its eMBB and uRLLC cousins. Given these attributes, RedCap will likely find resonance with adopters coming from varied industries, including the wearables space, makers of heavy equipment, and smart factory deployments. RedCap will eventually become the default migration path for applications that currently connect to LTE Cat 1 or Cat 4 networks.

Industries relying on cellular IoT solutions for the success of their businesses also need to think about the timing and life span of their applications. This will allow them to make informed decisions about which technologies can fulfil their current and near-future requirements in the best possible way.

The evolution of the 3GPP specification is another puzzle piece that needs consideration. Release 18 is around the corner and will expand the scope of 5G NR RedCap in the coming years. Thus, keeping an eye on 3GPP developments and the potential implications for specific IoT use cases is of paramount relevance. As cellular technology has evolved over recent decades, 3GPP has increasingly incorporated the needs of IoT markets in its specifications. The 5G era will be no exception.

To find out which cellular technology best suits your use case and when a transition for your application to 5G is appropriate, contact your nearest u-blox sales representative or fill out a project information form.

About the authors

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Sabrina Bochen has 15+ years' experience in marketing, product strategy, and portfolio planning in the telecommunications and technology sectors. With responsibility for developing winning marketing strategies, she has established new customers and sales channels for handsets, modules and other cellular products. She has successfully planned and created cellular product roadmaps, bringing to market 40+ products and services.

She joined u-blox in 2016, initially focusing on go-to-market strategies for u-blox's cellular IoT and automotive portfolio. More recently, she has taken on responsibility for u-blox's long-term roadmap strategy, including the adoption of 5G NR technologies in the IoT space.

She currently serves as Program Advisor to the Women In Leadership program at the University of California Riverside, which focused on developing aspiring female business leaders.
Sabrina is bilingual in English and German and holds a degree in Communication from the University of California at San Diego, where she graduated Magna Cum Laude.

Sylvia Lu, Head of Technology Strategy, Product Center Cellular, u-blox

Sylvia Lu is an award-winning Chartered Engineer and a Non-Executive Director. Sylvia has 15+ years of experience in the Telecom industry for four mobile generations with chipset vendors and provides guidance on the impact of emerging technologies on products and strategy. Sylvia is Head of Cellular Technology Strategy at u-blox, where she leads cellular technology strategy, global standards, and industry alliances.

Sylvia serves on several national and global industry Boards: she is an elected board director of CW (Cambridge Wireless), and serves on the Advisory Board of UK5G, which provides independent advice to the UK government and national 5G networks on future plans for 5G deployment. She serves on the Board of 5G-ACIA (5G Alliance for Connected Industries and Automation), joins forces with global industry stakeholders to influence 5G development and deployment in line with industrial imperatives to accelerate Industry 4.0.

She holds a first degree in Electronic Engineering from Birmingham University and a Master of Science degree in Communications, and Signal Processing from the University of Bristol. She graduated with a Distinction from the University of Oxford in PGDip Strategy & Innovation, and is completing an Executive MBA degree at the University of Cambridge.

About u-blox

u-blox (SIX:UBXN) is a global provider of leading positioning and wireless communication technologies and services for the automotive, industrial, and consumer markets. Their solutions let people, vehicles, and machines determine their precise position and communicate wirelessly over cellular and short range networks. With a broad portfolio of chips, modules, and a growing ecosystem of product supporting data services, u-blox is uniquely positioned to empower its customers to develop innovative solutions for the Internet of Things, quickly and cost effectively. With headquarters in Thalwil, Switzerland, the company is globally present with offices in Europe, Asia, and the USA.

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