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Cellular IoT Evolution for Industry Digitalization

This Ericsson white paper describes the evolution of Cellular IoT from the more basic use cases and less demanding characteristics of Massive IoT, through the more demanding use cases expected to be addressed by Broadband IoT and onward to the extremely demanding use cases that are expected to be addressed by Critical IoT and Industrial Automation IoT. These will be enabled following the deployment of enhanced LTE networks and 5G NR technology.

Introduction

Cellular IoT has been widely adopted across the globe, with 2G and 3G connectivity enabling many early IoT applications. Greater bandwidth, lower latency and increased support for large volumes of devices per cell are coming to the market with 4G offerings. These will be enhanced further with the arrival of 5G networks, initially enabled by the 5G New Radio (NR) standard, which will enable Ultra-Reliable Low Latency Communications (URLLC) that support increasingly critical applications.

Cellular IoT therefore has the capability to address both the relatively simpler requirements of the Massive IoT market as well as the highly specific, sensitive demands of complex environments and applications. The number of Cellular IoT connections enabled by Narrowband IoT (NB-IoT) and Long Term Evolution for Machines (LTE-M) continues to grow. The number of devices connected by Massive IoT and other emerging cellular technologies is forecast to reach 4.1 billion by 2024.

Cellular IoT itself is a rapidly growing ecosystem based on 3GPP global standards, supported by an increasing number of mobile network providers as well as device, chipset, module and network infrastructure vendors. It offers better performance than other Low Power Wide Area (LPWA) network technologies in terms of unmatched global coverage, Quality of Service, scalability, security and the flexibility to handle the different requirements for a comprehensive range of use cases.

This growth in IoT connectivity is expected to accelerate, driven by two main factors:

- A push to digitalize industries such as manufacturing, automotive and utilities
- A growing interest from MNOs to expand their existing business beyond mobile broadband

This paper will describe the expected evolution of Radio Access Networks (RAN) for Cellular IoT and define connectivity requirements into clear market segments that are aligned with the many use cases spanning different industry verticals as they pursue full digitalization.

In addition to Massive IoT, which provides cellular connectivity to low complexity IoT devices based on NB-IoT and Category M (CAT-M) technologies, Ericsson now defines three further IoT segments — Broadband IoT, Critical IoT and Industrial Automation IoT. See **Figure 1**.

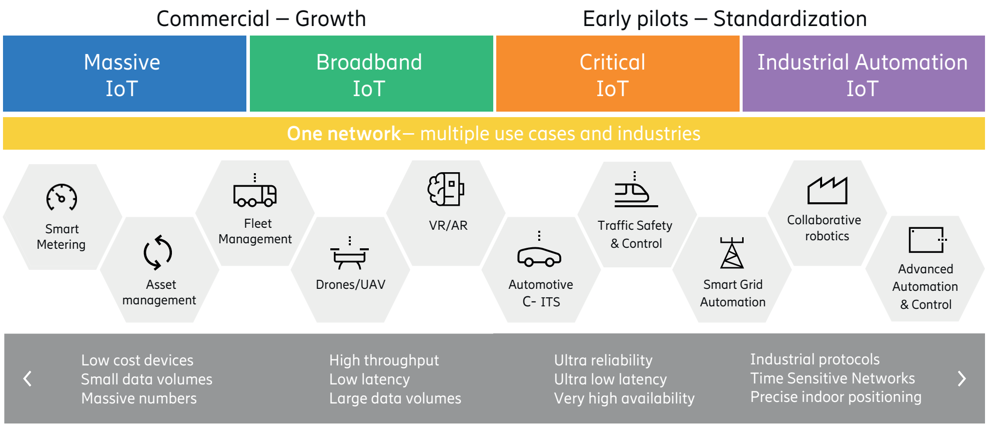


Figure 1: Cellular IoT segments

Broadband IoT adopts the capabilities of Mobile Broadband connectivity for IoT by providing much higher data rates and lower latencies than Massive IoT, while utilizing functionalities that are specific to Machine Type Communications (MTC) for coverage extension and extended device battery life. This segment targets a wide range of use cases in automotive, drones, Augmented Reality/Virtual Reality (AR/VR), utilities, manufacturing and wearables, based on 4G and 5G NR radio access technologies.

Critical IoT pushes the boundaries of Cellular IoT even further by enabling extremely low latencies and ultra-high reliability at a variety of data rates. This segment addresses extreme connectivity requirements of many advanced wide area and local area applications in intelligent transportation systems, smart utilities, remote healthcare, smart manufacturing and fully immersive AR/VR. Powered by the most innovative capabilities of 5G NR, Critical IoT is expected to enable many new use cases within the IoT arena.

Finally, the **Industrial Automation IoT** segment provides advanced Cellular IoT functionalities tailored for advanced industrial automation in conjunction with the other cellular IoT segments. It includes Radio Access Network (RAN) capabilities to facilitate the support of deterministic networks which, together with ethernet-based protocols and other industrial protocols, will enable many advanced industrial automation applications. These applications have extremely demanding connectivity requirements and require very accurate indoor positioning and distinct architecture and security attributes. Industrial Automation IoT reinforced by Critical IoT connectivity is the key enabler for the full digitalization of Industry 4.0 for the world's manufacturers, the Oil and Gas sectors as well as smart grid components for energy distribution companies.

With effective use of techniques such as network slicing and radio resource partitioning [1], all Cellular IoT segments can be supported in a single RAN allowing MNOs to optimize their assets and provide the best service to their customers.

Massive IoT

Massive IoT connectivity targets huge volumes of low-complexity devices that infrequently send or receive messages. The traffic is often tolerant of delay and typical use cases include low-cost sensors, meters, wearables and trackers. Such devices are often deployed in challenging radio conditions such as in basement of a building. Therefore, they require extended coverage and may rely solely on a battery power supply which puts extreme requirements on the device's battery life.

3GPP standardized three new technologies for massive MTC in Release 13: EC-GSM-IoT, LTE-M and NB-IoT. LTE-M extends LTE with new features for improved battery life, extended coverage and support for low-complexity device category series, named CAT-M. NB-IoT is a standalone radio access technology based on the fundamentals of LTE that enables extreme coverage and extended battery lives for ultra-low complexity devices.

The radio coverage per base station is extended by means of repeating the transmissions, exploiting relaxed requirements on data rate and latency. A device can be allowed to sleep for extended periods of time with extended Discontinuous Reception (eDRX) and Power Saving Mode (PSM) functionalities, which significantly enhances its battery life. The complexity of CAT-M and NB-IoT devices is kept low by the utilization of narrow bandwidths, half-duplex operation and the incorporation of a single transmit-and-receive antenna on the device.

CAT-M devices have relatively greater capability and are more complex than NB-IoT devices. NB-IoT supports 200 kHz bandwidth, whereas CAT-M supports 1.4 MHz bandwidth with CAT-M1 and 5 MHz bandwidth with CAT-M2. Although CAT-M can operate in full-duplex mode, today's CAT-M ecosystem supports only half-duplex operation to limit device complexity and power consumption.

CAT-M and NB-IoT should target complimentary use cases. CAT-M is better suited for applications that require relatively higher throughput, lower latency, connected mode mobility, better positioning and voice connections. Typical CAT-M use cases include wearables, sensors, trackers, alarm panels and customer support buttons, all with support for data and voice connections. On the other hand, NB-IoT is the technology of choice for very low throughput applications that are tolerant of delay but require extreme coverage, such as simple utility meters and sensors deployed in challenging radio conditions. An additional advantage for service providers is that NB-IoT can be deployed in the guard-band of an LTE carrier making use of the spectrum that is otherwise unused.

CAT-M and NB-IoT are considered future-proof and seen as 5G technologies [2, 3]. They can efficiently co-exist with 5G NR in the same spectrum and already fulfill all 5G massive MTC requirements, as set out in the IMT-2020 and 3GPP standards, in terms of coverage, latency, data rate, battery life and connection density [4,5]. CAT-M and NB-IoT are being further enhanced in 3GPP Rel-16.

Broadband IoT

Broadband IoT connectivity provides superior performance in terms of lower latency and higher throughput than the Massive IoT segment. Typical applications are advanced wearables, aerial and ground vehicles, AR/VR enabled devices and sensors that require greater capabilities than CAT-M or NB-IoT can provide. LTE has a range of device categories well-suited for such applications. For example, LTE is already providing cellular connectivity to millions of modern cars. There are LTE capable smart watches in the market and LTE-connected drones are coming next [6].

LTE offers high spectral efficiency and data rates, low latencies and has been enhanced with extended device battery life and improved coverage. With advanced multi-antenna solutions and carrier aggregation, LTE enables peak rates in the multi-Gbps range. Added to this, there are mechanisms for fast connection establishment and data delivery. With instant transmission schemes, the radio interface latency can be as low as about 10ms. The vendor specific LTE scheduler has advanced priority handling mechanisms to provide superior performance to a selected group of users.

LTE devices can operate in an extended coverage mode while supporting low throughput IoT applications. An optimized switching mechanism between normal coverage and extended coverage modes allows a user to experience superior data rates when in areas of good coverage and to access low data rates in challenging radio conditions. For example, a connected car can support high data rate applications, such as for infotainment, in a location that has normal coverage but, when it is parked underground in challenging radio conditions, it can utilize the coverage extension mode to enable low data rate applications. The features for enhanced battery life (eDRX and PSM) are also supported and can be useful for some applications, for example, for smart wearables and tracking of vehicles.

The introduction of NR is going to expand the capability of Broadband IoT. NR-based Broadband IoT would operate in both old and new spectrum with much wider bandwidths and new functionalities to support even greater throughputs, extending into the tens of Gbps, and reducing latency to about 5ms.

Critical IoT

Critical IoT connectivity enables extremely low radio interface latency, down to about 1ms, or high reliability of up to 99.9999%, with strict latency bounds at a variety of data rates. The reliability is defined as the probability of successful data delivery within a bounded latency.

There are use cases in smart grids, smart manufacturing, intelligent transportation systems, healthcare and fully immersive AR/VR that may require 5-20ms end-to-end latency and reliability as high as 99.9999%. Many use cases require real-time control and coordination between machines [7]. Examples include: automation of energy distribution, detection and restoration of faults in a smart power grid, real-time control of manufacturing robots, and real-time coordination between autonomous vehicles and the transportation infrastructure. There are also applications with human interaction, such as teleoperated driving and remote surgery that demand high reliability. However, since the stimuli perception and reaction times for humans are slower than for advanced machines, the latency requirements may not be as demanding for these applications.

5G NR is a clear technology of choice for enabling Critical IoT. Even in its first 3GPP release in 2018, Rel-15, NR has greater functionality than LTE for enabling URLLC. NR operates in a broader range of frequencies with much larger bandwidths than LTE to provide much higher throughputs to a larger number of devices with extremely low latency and ultra-high reliability. There is a clear future evolution path for NR. The standardization of NR-based, enhanced URLLC is already in progress in 3GPP Rel-16 [8].

NR can support Critical IoT in all its frequency bands to enable wide area and local area use cases, as illustrated in **Figure 2**. In the low frequency bands with paired spectrum allocations, NR Frequency Division Duplex (FDD) achieves extremely low latencies and ultra-high reliabilities with large coverage areas per base station because of favorable radio wave propagation. However, the channel bandwidths are limited in the low bands and therefore these bands should primarily target wide area users.

In the mid bands, NR offers a good balance of capacity and coverage and is well-suited for diverse local area and wide area use cases. For unpaired spectrum allocations in the mid bands, NR Time Division Duplex (TDD) achieves ultra-high reliability with advanced antenna solutions. However, it may not be possible to achieve extremely low latencies with a downlink-heavy static TDD transmission pattern typically optimized for downlink-heavy enhanced Mobile broadband (eMBB) traffic. For certain localized deployments such as factories with sufficient isolation, a low-latency favorable transmission pattern can be a viable option. In the high frequency mmWave bands, NR TDD achieves extremely low latencies with its ultra-short transmission capability [9]. The mmWave bands offer much wider channel bandwidths that allows NR to support a large number of Critical IoT users at high data rates. Preliminary evaluations have shown that ultra-high reliability levels can be achieved in the high bands with advanced antenna techniques.

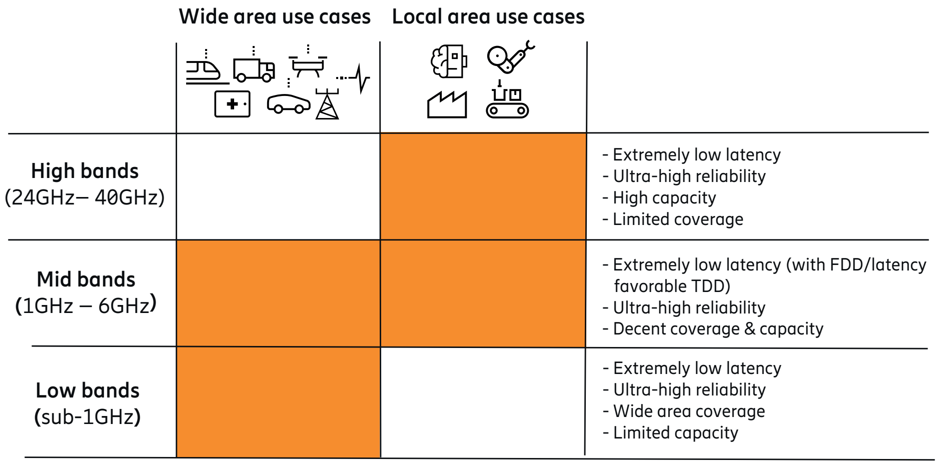


Figure 2: 5G NR provides Critical IoT connectivity in all its frequency bands targeting wide and local area use cases.

NR has a large set of functionalities for enabling URLLC. Its extreme low latency features include ultra-short duration transmissions, instant transmission mechanisms to minimize delays for data awaiting transmission, rapid retransmission protocols that minimize feedback delays from a receiver to the transmitter, instant pre-emption and prioritization mechanisms, interruption-free handovers between base stations and fast processing capabilities of devices and base stations. The ultra-high reliability features include a range of signal transmission formats that are adaptable in harsh radio conditions. There are methods for duplicate transmissions to provide reliability through diversity, for example, via carrier aggregation or multi-site connectivity. With advanced antenna solutions, there is tremendous potential to improve the link budget. The vendor specific scheduling algorithms and link adaptation algorithms are at the heart of NR to ensure an optimized utilization of available resources.

For a given deployment, there are fundamental trade-offs between latency, reliability, coverage and spectral efficiency. For instance, ultra-short transmissions that target extremely low latencies can reduce signal coverage per base station and robust signal transmissions require more radio resources which reduces throughput per base station. NR provides a great degree of freedom to optimize these trade-offs. 3GPP Rel-15 evaluations have already confirmed that the NR radio-interface can deliver a small sized message with 99.999% reliability within a 1ms latency bound in both uplink and downlink [10,11]. 3GPP Rel-16 is further evaluating 99.9% to 99.9999% reliabilities within 1ms to 7ms latency bounds at various data rates from Kbps to Mbps [8].

Industrial Automation IoT

Industrial Automation IoT as a segment, covers solutions primarily for a manufacturing setup but also others that share common requirements from an industrial network perspective such as control systems for railways as well as power generation and distribution.

As we move to Industry 4.0, the legacy of Industry 3.0 reflects an infrastructure framework within a factory of hierarchical communication that is isolated from physical hardware because of technology limitations and security needs. Here different networking technologies are used, customized to hyper-localized use cases, leading to inflexible configurations and a high cost of maintenance and integration of these dedicated and proprietary technologies.

Industry 4.0 envisions a factory where all devices and elements, including the very product as its output, are fully connected, utilizing flexible and open standard connectivity solutions as well as incorporating internet and cloud technologies. An industrial network is focused on enabling manufacturing with connectivity across all levels ranging from specific areas on the shop floor to systems and processes that are beyond the manufacturing site itself. Ethernet and IP connections are commonly used between these extremes but the connection of specific shop floor activities is usually handled by proprietary Fieldbus or industrial ethernet products which are integrated with the rest of the facility via gateways.

Cellular networks are the key enabler for Industry 4.0 using a non-public network at factory premises. This allows us to address the range of connectivity requirements, some yet unfulfilled, while replacing the multitude of different currently deployed technologies.

These varying use case requirements range from environmental sensors and trackers for inventory and supply management to more demanding connectivity for Automated Guided Vehicles (AGV), to the most demanding real-time sensors and robotics on the assembly line which are typically wired.

This means that an Industrial Network is built using a combination of Massive, Broadband and Critical IoT, with Industrial Automation IoT, based on 5G NR, addressing the gaps in capability. There is however a gap represented by cyber-physical control applications in process automation, catered for today by Fieldbus or industrial ethernet components, that 3GPP is now looking to address.

This gap in capabilities is characterized by requirements for a deterministic network, which places specific requirements on both latency and reliability that are supplementary to those that URLLC delivers alone. This means not just ultra-low latency and reliability, but guaranteed delivery is required and this must come with low delay variation, and extremely low loss, potentially all at the same time even though URLLC and Time Sensitive Networking (TSN) are at potentially different layers. Deterministic networks today are defined at both Layer 2 and 3 by IEEE and IEFT, while, in a cellular 5G network context, TSN may be considered as a control layer over end-to-end URLLC. (See **Figure 3**).

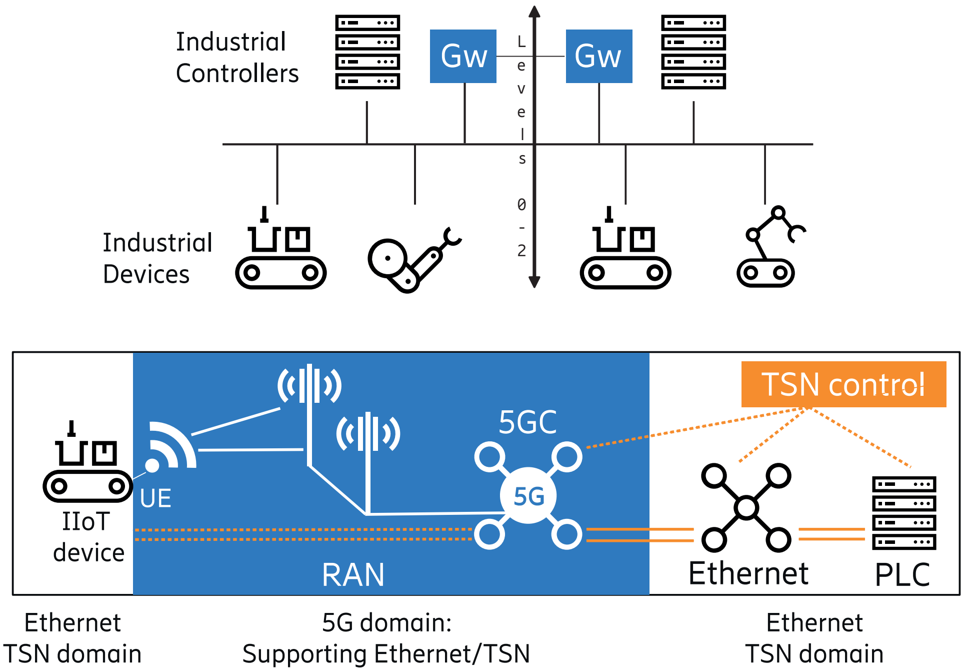


Figure 3: 5G NR will need to support Ethernet-based transport for TSN and industrial controllers

TSN and Industrial Control Systems typically use Ethernet-based transport. Merging the 5G and industrial domains therefore requires that NR natively supports ethernet rather than relying on encapsulation and gateway protocol translation methods to overcome any deterioration in performance. 3GPP is currently studying native support for Ethernet over NR which will then be an underlying baseline upon which TSN functions would be transparently supported.

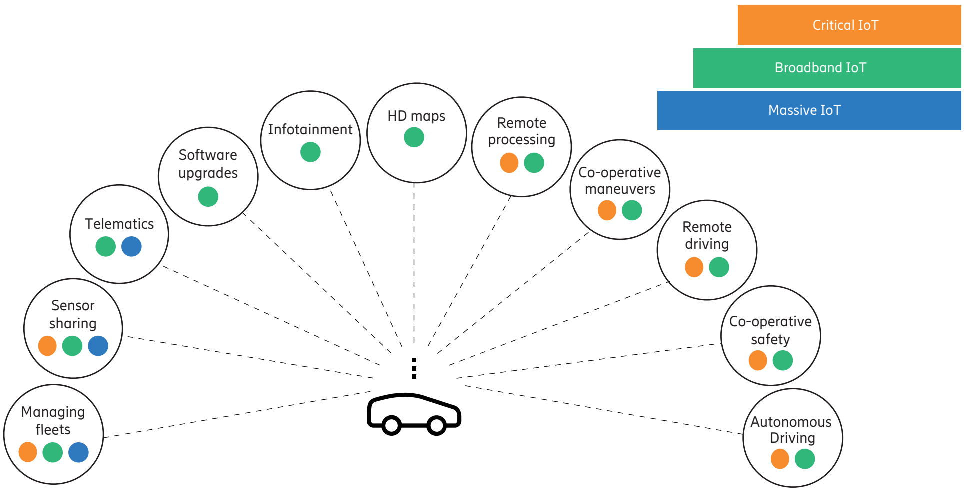
A 5G NR industrial network enables more advanced automation, easing flexibility and enabling greater efficiencies, thereby allowing a greater level of insight in real-time into the state of production and operation. In addition, a 5G/NR network facilitates incorporation of technologies such as cloud computing, machine learning and big data processing.

Industrial Automation IoT is the bridge between 5G Critical IoT networks and industrial systems. It comprises the set of functions that enables precise indoor positioning, native support for Ethernet over NR, scheduling and QoS adaptations that enable transparent TSN support and allow reuse of existing industrial devices and control systems.

Ericsson Cellular IoT segments and industry verticals

As various industry verticals adopt cellular as the unified connectivity solution, we are seeing different requirements across the breadth of each vertical. A combination of Ericsson Cellular IoT segments allows application of solutions in a flexible manner, often in a step wise approach.

Here we explore two representative verticals, Automotive and Smart Manufacturing, to detail how multiple Ericsson Cellular IoT segments are applicable.



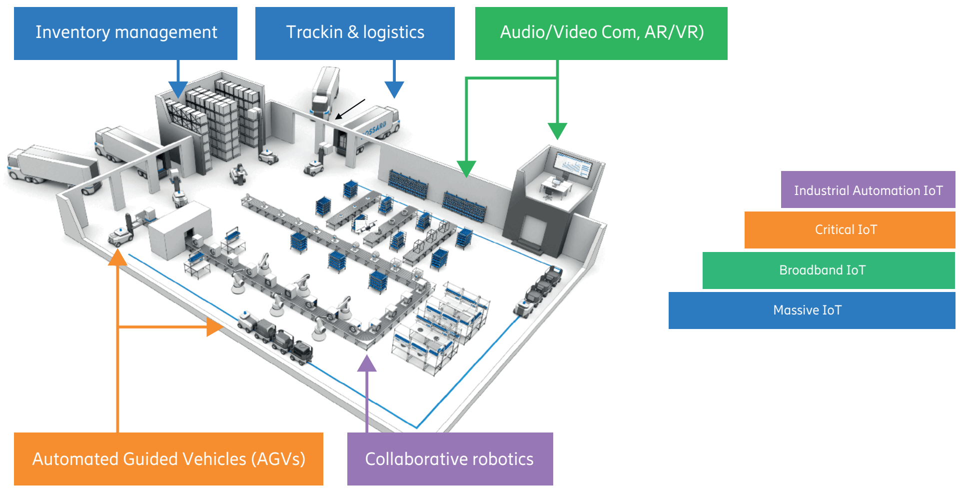


Figure 4: Cellular IoT segments combine to address industrial segments: Automotive (above), Smart Manufacturing (below)

Automotive

The automotive industry is in revolution with megatrends such as automation, sensor technologies and cellular connectivity enabling new functionalities for safety, efficiency and infotainment. Millions of cars are already connected via cellular networks and the various Cellular IoT segments have their own relevance for the emerging connected vehicle use cases.

- Fleet management, tracking and telematics are some of the applications that greatly benefit from extended device battery life, enhanced signal coverage and support for low-cost devices. These applications tend to have low data rates and relaxed latency requirements, that makes Massive IoT an appropriate connectivity choice.

- On-board infotainment, software upgrades for maintenance, real-time high definition maps for navigation and massive sensor sharing are use cases that demand Broadband IoT connectivity for providing high data rates, large volumes of data transfers and low latencies. Modern cars are supporting some of these applications with LTE. With enhanced automation levels and new software-defined capabilities in future smart vehicles, the data rate and capacity demands can be extreme. Connecting large numbers of smart vehicles would then require 5G NR in conjunction with LTE.

- There are numerous connected vehicle use cases that demand Critical IoT connectivity. For example, applications related to remote driving, autonomous driving, platooning, co-operative vehicle maneuvers, vehicle and pedestrian safety, and cloud-based real-time processing. These applications ask for combinations of low latencies, high reliabilities and data rates in a wide area deployment. Although some of these use cases can be supported partially with Broadband IoT in their early phases, the ongoing advancements in automation of vehicles and transportation systems mandate Critical IoT connectivity.

Smart Manufacturing

There is a range of connectivity requirements across various objects in a smart manufacturing factory, as depicted in Figure 4 above.

- Massive IoT (NB-IoT and Cat-M) can be used for tracking supply and inventory.

- Augmented Reality and other data communications greatly increase efficiency on the factory premises and are enabled using the Broadband IoT capabilities of an LTE/NR network.

- Automated Guided Vehicles (AGVs) and other factory tools typically require much lower latencies and some level of connectivity assurance that Critical IoT fulfils.

- Industrial Automation IoT enables connectivity of components on the assembly line. Enabling robot control and Programmable Logic Controller (PLC) interconnection as part of process automation. Using cellular 5G connections rather than cabling reduces cost since these types of equipment are typically very expensive to install, re-arrange or replace, leading to much more flexible factory floor designs and enabling the mobility of robotic elements.

Conclusion

Since the introduction of Cellular IoT to the global market, better performance in comparison to other LPWA technologies has been offered in terms of unmatched global coverage, Quality of Service (QoS), scalability and flexibility to handle a comprehensive range of use cases in one network.

More than 80 commercial Massive IoT networks had been launched by the end of 2018. Now, as 4G LTE networks continue to be enhanced and the initial rollout of 5G NR begins, the next steps in the evolution of Cellular IoT are already underway. In this paper, Ericsson has clearly defined the segments to facilitate digitalization of different industry verticals, utilizing the capabilities of both 4G and 5G networks.

All four segments of Cellular IoT will be supported within the same Radio Access Network, enabling ease of management and optimized use of MNO assets.

Glossary

AR	Augmented Reality
AGV	Automated Guided Vehicle
CAT-M	Category M
EC-GSM-IoT	Extended Coverage GSM IoT
eDRX	Extended Discontinuous Reception
eMBB	Enhanced MBB
GPRS	General Packet Radio Service
IoT	Internet Of Things
IMT	International Mobile Telecommunication
LTE	Long Term Evolution
LTE-M	LTE for Machines
MBB	Mobile Broadband
mmW	Millimeter Wave
MNO	Mobile Network Operator
MTC	Machine Type Communication
NB-IoT	Narrowband IoT
NR	New Radio
PSM	Power Saving Mode
QoS	Quality of Service
RAN	Radio Access Network
TSN	Time Sensitive Networking
URLLC	Ultra-Reliable and Low Latency Communications
VR	Virtual Reality
3GPP	Third Generation Partnership Project
5G	5th Generation (mobile communication technology)

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Further reading

- Network Slicing
  https://www.ericsson.com/en/digital-services/trending/network-slicing

- Cellular networks for Massive IoT — enabling low power wide area applications
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- Drones and networks: Ensuring safe and secure operations
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Marie Hogan is in charge of strategic product management of the Mobile Broadband and IoT areas of 4G and 5G Radio Access Networks at Ericsson. Her main responsibilities include driving the evolution of 4G radio access solutions to meet the growing demands on existing LTE networks and the early deployments and optimization of 5G radio access solutions, including new use cases supported by Cellular IoT. She has worked in many areas within Ericsson from product development to product management spanning 3G, 4G and 5G technologies. Marie has worked with both radio and core network solutions as well as transport, synchronization and security solutions. She holds an M.Sc. in Technology Management and a degree in Electronic Engineering.

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Christian Kuhlins is Strategic Product Manager for NB-IoT. After his education in Microelectronics at the Fachhochschule Nürnberg he joined Ericsson in 1998. He has worked on various technologies over the past 20 years and has been heavily involved in the early development of Bluetooth, WCDMA and LTE in various positions within R&D. He chaired the IoT Activity Group at LTE SAE Trial Initiative (LSTI). As Product Manager Christian worked with a variety of products for WCDMA and NB-IoT within Ericsson and is now a passionate evangelist of cellular IoT.
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