Ericsson White Paper
Uen 284 23-3278
January 2020

Cellular networks for Massive IoT

Enabling low power wide area applications
New radio access technologies are available specifically targeting the connectivity requirements of Massive Internet of Things (IoT) applications.

According to the current GSMA Mobile IoT rollout report,[1] the number of launched commercial networks is 35 for LTE-M (supporting Cat-M1 devices) and 92 for NB-IoT, and the numbers are constantly increasing.

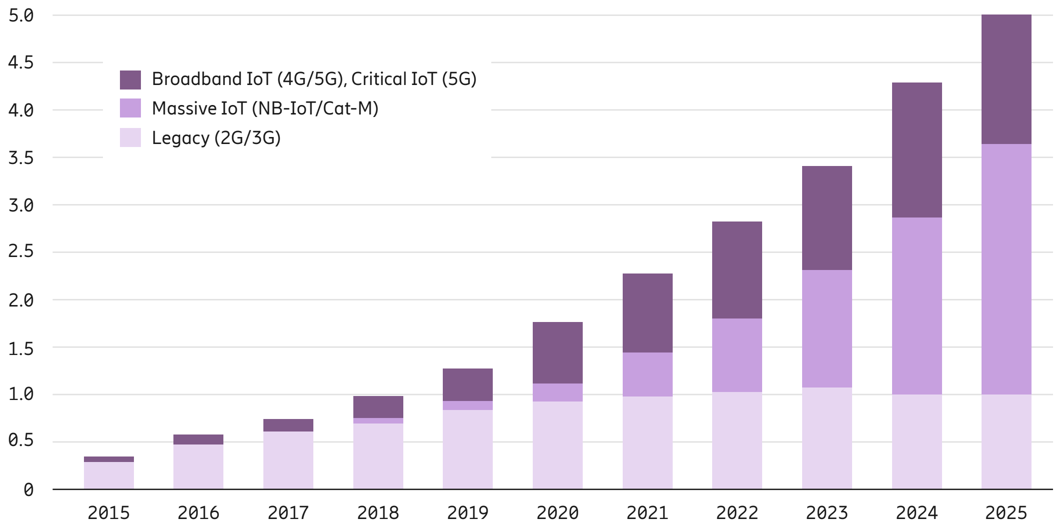
Commercial devices span various types of meters, sensors, trackers and wearables in many different industries, including utilities, automotive, transport, logistics, agriculture, manufacturing, healthcare, warehousing and mining.

Delivering new value with industry digitalization

New business opportunities enabled by cellular IoT
Digitalization of industries is set to take IoT to the next level. Cellular IoT is the key enabler of this digital transformation by delivering a wide range of machine-to-machine (M2M) and machine-to-person communications on a massive scale. Connected, intelligent software-defined products enable new opportunities for both consumers and industries by boosting connectivity.

As shown in Figure 1, Ericsson predicts there will be 5 billion IoT devices by 2025 connected via cellular 3GPP access technologies.[2]

Figure 1: Expected growth of Massive IoT connections (billion)[2]



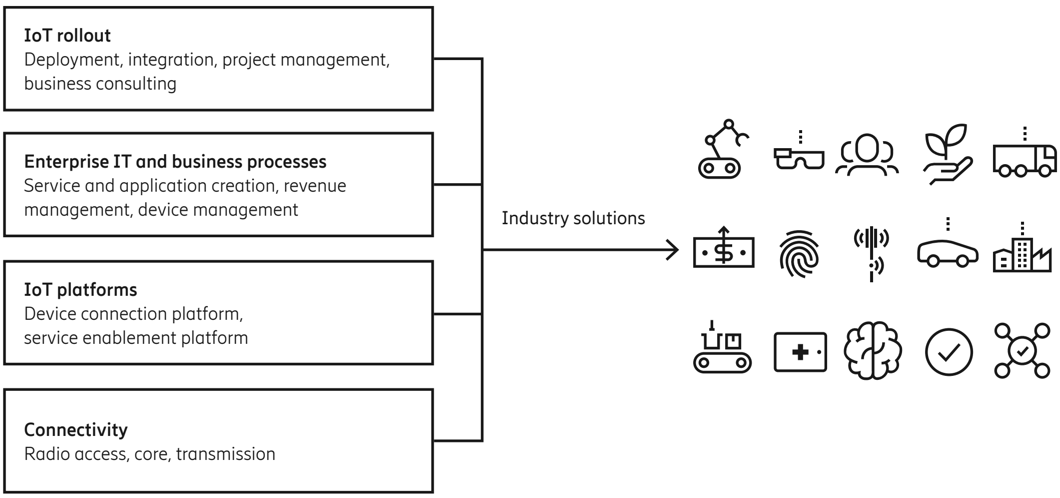
The new IoT landscape

The IoT revolution offers huge potential value in terms of improved efficiency, sustainability and safety for industry and society. Eighty-seven percent of global enterprises (of those deploying IoT now) are interested in adding more IoT applications or use cases in the future, indicating a positive experience so far.[3] Analysts predict that communications service provider IoT revenue globally will increase at a combined annual growth rate (CAGR) of 24.9 percent through 2023[4] with a variety of applications and solutions designed for individuals, businesses and industries. IoT is playing a major role across a variety of vertical sectors by generating cost savings and new revenue streams, as well as other benefits, such as improved quality.

Each IoT application needs a clear value proposition and business logic in line with the prevailing ecosystem, business models and value chains of the various stakeholders. For all applications, solutions need to be integrated on platforms that can scale and handle millions of devices efficiently.

To secure the successful deployment of an end-to-end use case, all stakeholders and parts of the setup need to be aligned. For example, a water metering use case needs a thorough analysis of how often data is transmitted to secure the battery lifetime of the devices involved. This means early battery changes can be avoided, which would otherwise have had a significant impact on the business case. Furthermore, the bundling of transmissions from several data packages into one occurrence (i.e. consumption data over a certain time slot) can optimize network performance.

Figure 2: The new IoT landscape



Service providers are in an excellent position to capture a share of the added value generated by the emerging cellular IoT market, as they are largely responsible for wireless connectivity on a global scale. The size of this share depends on the role that service providers adopt in the value chain. This could range from being a straightforward connectivity provider (monetizing connectivity in new ways), through to being an end-to-end solution provider of turnkey solutions to vertical markets.[5]

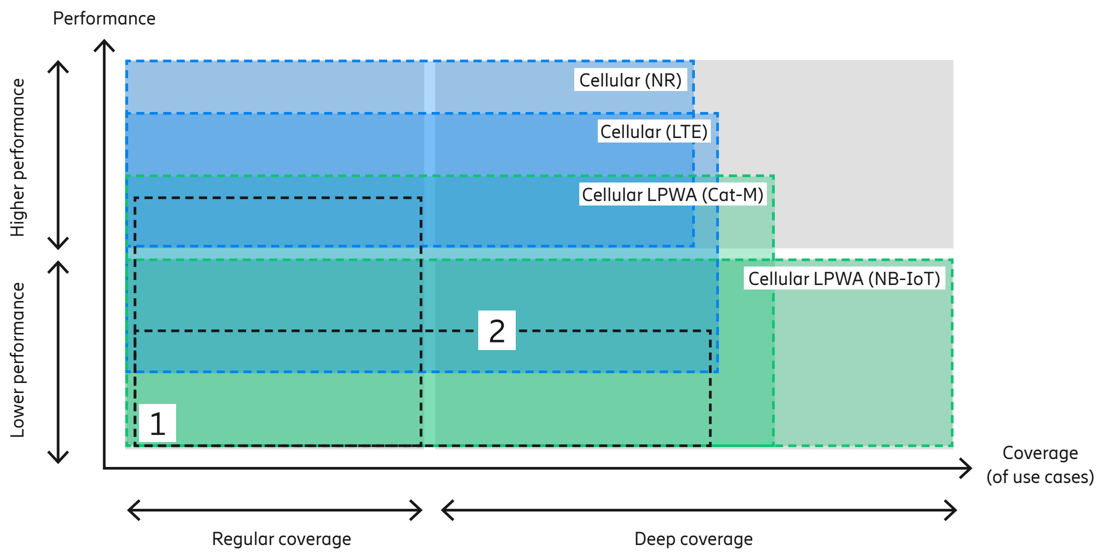
Different IoT connectivity alternatives
Connectivity is the foundation for IoT, and the type of access required depends upon the nature of the application. Many IoT devices are being served by radio technologies that operate on unlicensed spectrum and are designed for short-range connectivity with limited Quality of Service (QoS) and security requirements typically applicable to a home or indoor environment. Currently, there are two alternative connectivity tracks for IoT applications that depend on wide-area coverage:

Cellular technologies: 3GPP technologies like GSM, WCDMA, LTE and 5G NR operate primarily on licensed spectrum and historically have pre-eminently targeted high-quality mobile voice and data services. Narrowband IoT (NB-IoT) and LTE for machine-type communication (LTE-M) are optimized access technologies for low power wide area (LPWA) applications.

LTE-M extends LTE with features for extended device battery life, enhanced 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.

Unlicensed LPWA: Proprietary radio technologies, provided by, for example, Sigfox and LoRa, have been developed and designed solely for MTC applications addressing the ultra-low-end device segment, with very limited demands on throughput and QoS. However, the deployment of these technologies requires end-to-end establishment of a dedicated access network and core infrastructure.

Figure 3: Access technologies addressing different IoT areas



1 Unlicensed spectrum (Wi-Fi, Bluetooth, Zigbee, etc.)
2 Unlicensed spectrum (Sigfox, LoRa, etc.)

One way to segment IoT applications is to categorize them according to coverage needs and performance requirements, such as data, speed or latency demands.

The coverage needs of a particular use case may be highly localized (such as a stationary installation within a building), while other use cases require global service coverage (such as container tracking). 3GPP technologies already dominate use cases with large geographic coverage needs and medium- to high-performance requirements. In addition, all supporting functionality and related frameworks are provided, i.e. for roaming.

With new feature sets specifically tailored for LPWA IoT applications, 3GPP technologies have taken a large leap forward to cover segments with low-cost, low-performance requirements too.

Capillary networks combining cellular and unlicensed strengths

Even if existing 3GPP end-to-end connectivity is not feasible, cellular technology can still provide key benefits when used as a bridging option, i.e. as an aggregation and routing solution. This capillary network approach allows end devices to utilize varying access solutions from either the short range or LPWA domain and to access the cellular networks via a gateway device. Capillary networks enable the reuse of cellular functions and assets, such as security, device management, billing and QoS, without requiring each end device to be cellular-enabled. As an example, utility devices like meters and sensors in a building may communicate over Bluetooth to one main gateway which then connects with a server application over Cat-M/NB-IoT.

A wide range of cellular IoT requirements

A wide range of IoT use cases are being deployed and explored as 5G NR provides additional advanced capabilities. The market is now expanding towards both Massive IoT deployment and more advanced solutions that may be categorized into three additional segments of cellular IoT.[12]

Figure 4: Cellular IoT segments

Massive IoT	Broadband IoT	Critical IoT	Industrial Automation IoT
Low-cost devices Small data volumes Extreme coverage	High data rates Large data volumes Low latency (best effort)	Bounded latencies Ultra-reliable data delivery Ultra-low latency	Ethernet protocol integration Time-Sensitive Networking Clock synchronization service
Network slicing, network exposure, network data analytics, device positioning, device battery life			

Broadband IoT adopts the capabilities of enhanced mobile broadband for IoT to provide large volumes of data transfer, as well as much higher data rates and lower latencies than Massive IoT, while enabling additional capabilities for IoT such as extended device battery life, extended coverage and uplink-heavy data rates. Typical applications are wearables, aerial and ground vehicles, online gaming, cameras and sensors.

Critical IoT is for time-critical communications. It enables ultra-high reliability and/or ultra-low latency at a variety of data rates. In contrast to Broadband IoT, which achieves low latency on best effort, Critical IoT can deliver data within strict latency bounds with required guarantee levels, even in heavily loaded networks. This segment addresses the 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.

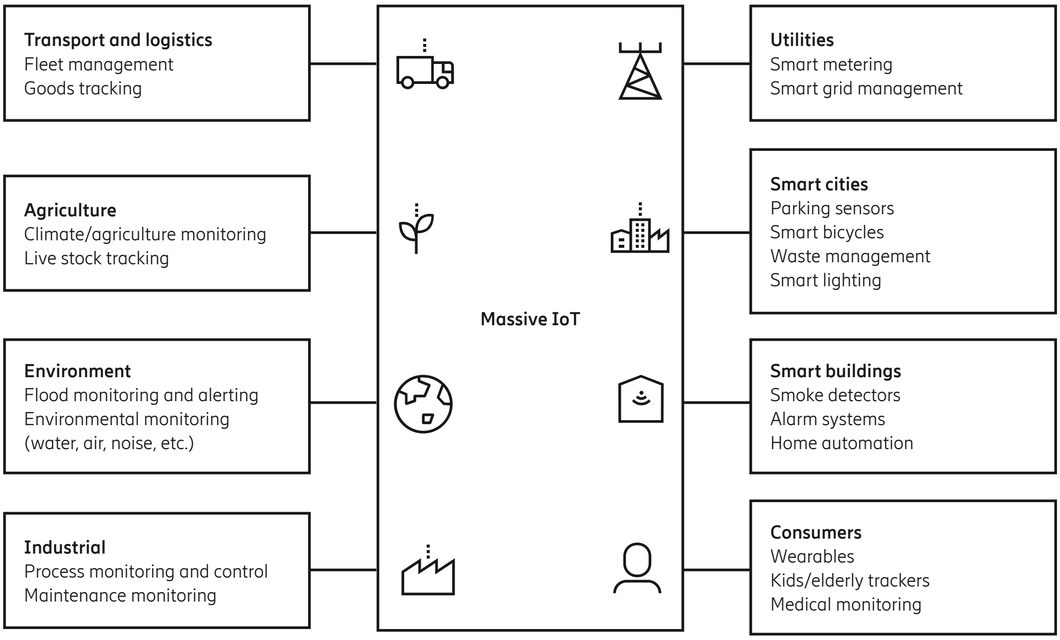
Industrial Automation IoT aims to enable seamless integration of cellular connectivity into the wired industrial infrastructure used for real-time advanced automation. It includes capabilities for integrating the 5G system with Ethernet-based industrial protocols and Time-Sensitive Networking.

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

Massive IoT use case diversity

The Massive IoT market segment includes several applications which are widely used in industries and societies, as shown in Figure 5.

Figure 5: Industry and society applications enabled by LPWA



The potential applications for IoT run into the millions, with a huge variety of requirements regarding cost, battery life, coverage, connectivity performance (throughput and capacity), security and reliability. Figure 5 illustrates some examples of applications and their requirements regarding devices and connectivity.

Some devices only send a few messages per day — such as status indicators for temperature — while others may require voice capabilities to guide a remote repair technician. If operators or service providers handle several applications, it may be of great benefit to be able to harmonize communication modules, so they all use the same underlying radio solution to reduce operational and fault management effort and complexity.

Thorough analysis of capability requirements is important to secure a sustainable business case, especially in low-complexity use cases with high volumes of devices, that only require a very low data transmission rate in cumbersome radio environments, but no mobility or voice.

For battery-driven devices, addressing energy consumption is essential when supporting mechanisms such as extended discontinuous reception (eDRX), power saving mode (PSM) and additional network functionality.

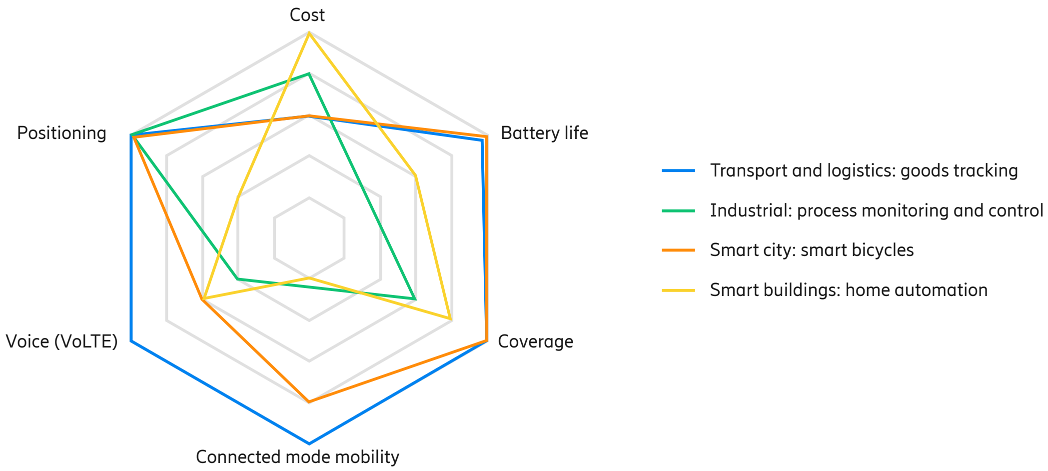
Positioning can be used to locate the point at which the sensor failed and to simplify operations. For tracking applications, location information is essential, but accuracy needs can vary and may be balanced with power consumption requirements.

In applications like building security, sensitive information could be reported over the air, which would require strict security. Furthermore, in the case of a break-in, it is crucial that the alarm information reaches the control center in time, making voice over Cat-M capabilities desirable. In addition, 3GPP cellular access technologies are providing a standardized and consistent framework of functionality to secure use cases from any network vulnerability.

Massive IoT and smart utility meters
Smart utility meters for electricity, gas and water are among the first set of popular applications being deployed around the world within the Massive IoT segment. These devices typically gather the end-user consumption during a time period, e.g. one day, and report this in one larger uplink report to a server. These devices can also be reached on-demand in the downlink to order status information and can be programmed to raise alarms in scenarios such as outage.

In some countries, utility meters are currently read manually, while in other countries, old proprietary radio communication systems, which are often costly in terms of operation and maintenance, are used. Automatic reporting of consumption over a cellular network infrastructure deploying Massive IoT technologies may significantly reduce overall costs for utility companies. At the same time, the collected consumption statistics will enable better control and forecast of utility distribution, which may then further reduce costs.

Figure 6: Device connectivity requirements for sample cellular Massive IoT use cases



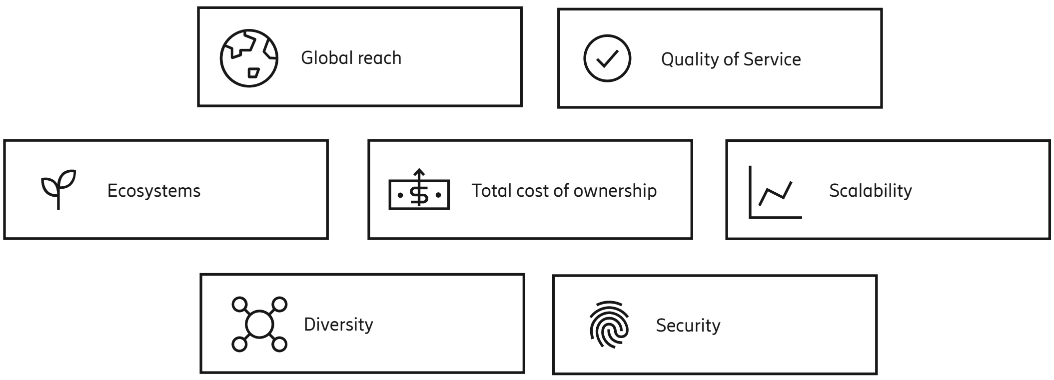
Key challenges for Massive IoT
The key challenges when it comes to enabling large-scale uptake of Massive IoT include:
- **Device cost** – a key enabler for high-volume, mass-market applications, enabling many of the use cases.
- **Battery life** – many IoT devices will be battery-powered, and often the cost of replacing batteries in the field is not viable.
- **Coverage** – deep indoor connectivity is a requirement for many applications in the utility area. Furthermore, regional (or even national or global) coverage is a prerequisite for many use cases, especially within the transport area.
- **Scalability** – in order to enable a Massive IoT market, networks need to scale efficiently. The initial investment required for supporting a limited number of devices must be manageable, while on the other hand, the network capacity must be easy to scale to handle thousands – or millions – of devices.
- **Diversity** – connectivity should be able to support diverse requirements from different use cases. One network supporting everything from simple static sensors to tracking services, to applications requiring higher throughput and lower latency, is essential in terms of total cost of ownership (TCO).

Depending on use case requirements and service level agreements (SLAs) between the operator and customer, different scenarios of network slicing may be applied. Network slicing provides the opportunity to set up multiple sub-networks using common existing network infrastructure, which can secure certain key performance indicators (KPI) for use cases or different customers.

The advantages of cellular technologies

Each of the technologies available for cellular IoT connectivity has its own advantages and disadvantages. However, the range of IoT connectivity requirements — both technical and commercial — means cellular technologies can provide clear benefits across a wide variety of applications, as summarized in Figure 7.

Figure 7: Advantage of cellular access technologies



In terms of global reach, cellular networks already cover 90 percent of the world's population. Cellular networks have been developed and deployed over three decades, and will be around for the foreseeable future. The cellular mobile industry represents a huge and mature ecosystem, incorporating chipsets, devices and network equipment vendors, operators, application providers and many others. The global cellular ecosystem is governed by the 3GPP standardization forum, which guarantees broad industry support for future development.

When it comes to scalability, cellular networks are built to handle massive volumes of mobile broadband traffic; the traffic from Massive IoT applications will be relatively small and easily absorbed. Operators can offer connectivity for IoT applications from the start-up phase and grow this business with low TCO and only limited additional investment and effort. Operation in licensed spectrum also provides predictable and controlled interference, which enables efficient use of the spectrum to support massive volumes of devices.

Cellular connectivity offers the diversity needed to serve a wide range of applications with varying requirements within one network, providing several access technologies such as LTE, NB-IoT, Cat-M and NR. While competing unlicensed LPWA technologies are designed solely for very low-end MTC with lower security demands, cellular networks can address everything from Massive IoT to Broadband IoT use cases up to Critical IoT and Industrial IoT.

QoS mechanisms will be essential for many IoT applications. Cellular systems have mature QoS functionality, and this enables critical MTC applications to be handled together with traffic from sensors, voice and mobile broadband traffic on the same carrier. QoS, along with licensed spectrum as described above, provides a foundation for long-term SLAs with a specific grade of service.

Traditionally, the security mechanisms of cellular networks have been based on a physical SIM attached to the device, referred to as a Universal Integrated Circuit Card (UICC). This has also enabled roaming between operators, which has been one of the main factors behind the huge success of mobile networks. The SIM will also be essential in future IoT applications, with SIM functionality embedded into the chipset (eUICC) or handled as a soft-SIM solution running in a trusted run-time environment of the module.

With a straightforward rollout of new software, cellular networks will be able to support the full breadth of applications, ranging from low-end use cases in the LPWA segment, to the high-end segments of in-car entertainment and video surveillance. One network connecting the whole diversifying IoT market will guarantee the lowest possible TCO, as well as fast time to market.

Evolving standards

To meet the new connectivity requirements of the emerging Massive IoT segment, 3GPP has taken evolutionary steps on both the network side and the device side. The key improvement areas addressed in 3GPP up to Release 13 are:

- **Lower device cost** – cutting module costs for LTE devices by reducing peak rate, memory requirement and device complexity. The LTE module cost-reduction evolution started in 3GPP Release 8, with the introduction of LTE-M Cat-1 devices which reduced peak rate to a maximum of 10Mbps. This continued in 3GPP Release 13 with reduced device complexity for lower performance by introducing a new half-duplex bandwidth limited UE category for LTE-M, Cat-M1, and a completely new radio access technology (NB-IoT) using a single narrowband carrier to cut costs further.
- **Improved battery life** – more than 10 years of battery life can be achieved by introducing PSM and/or eDRX functionality for use cases transferring small and infrequent amounts of data. These features allow the device to contact the network – or to be contacted – on a per-need basis, meaning that it can stay in sleep mode for minutes, hours or even days.
- **Improved coverage** – an improvement of 15dB on Cat-M and of 20dB on NB-IoT and GSM, which translates into a seven-fold increase in the outdoor coverage area and significantly improves indoor signal penetration to reach deep indoors. This supports many IoT devices like smart meters, which are often placed in locations with poor coverage, such as basements.
- **Support for massive numbers of IoT connections** – specifically, one LTE cell site can support millions of IoT devices, depending on the use case. Core network enhancements include software upgrades for service differentiation handling, signaling optimization and high-capacity platforms (more than 30 million devices per node).

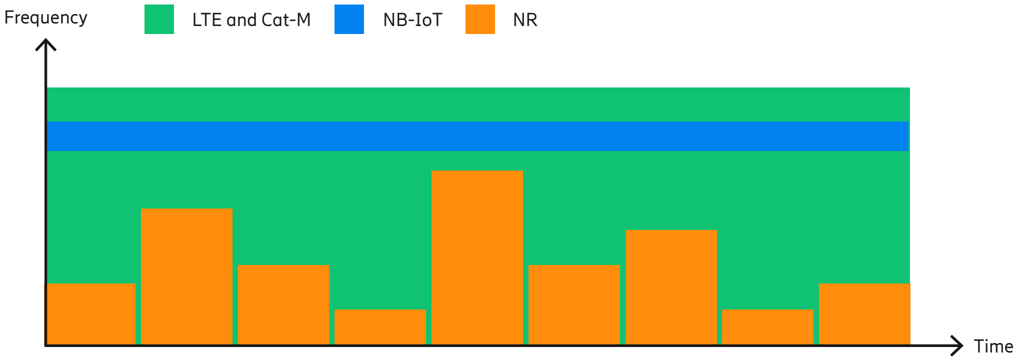
Improvements to Massive IoT technologies
In 3GPP Release 14/15, new features and enhancements have been made to the Massive IoT technologies Cat-M and NB-IoT. This includes important improvements in the areas of system capacity, performance and UE power consumption. It has been concluded[6][7] that both technologies fulfill the IMT-2020[8] and 3GPP[9] requirements for a 5G system when using the Release 15 version of the 3GPP specifications. These fulfilled performance requirements are summarized below:

1. **Connection density**
   At least one million devices per square kilometer (km^2) shall be supported in four different deployment scenarios (as described in [9]) where each device transmits a small UL packet once every two hours.
2. **Coverage**
   The coverage corresponding to a maximum coupling loss (MCL) of 164dB shall be supported.
3. **Data rate**
   The sustainable uplink and downlink data rates shall be at least 160 bits per second (bps) at an MCL of 164dB.
4. **Latency**
   An uplink packet of 105 bytes shall be received in the network within 10 seconds at an MCL of 164dB.
5. **UE battery life**
   Ten-year battery life using a 5Wh battery for a traffic model will be achieved, with a daily delivery of an uplink message of 200 bytes followed by a 20-byte downlink message.

In addition to being key components of a 5G system, both Cat-M and NB-IoT can efficiently coexist in the same band as an NR carrier. Dynamic spectrum sharing in the same band between all four technologies Cat-M, NB-IoT, LTE and NR is already supported in 3GPP Release 15 and additional enhancements are being standardized as part of Release 16. This is being achieved (and still being further evolved) by:[1]
- a flexible NR numerology and frame structure compatible with LTE
- an NR frequency duplex configuration allowing NR, NB-IoT and LTE-M subcarrier grids to be aligned
- support for “forward compatibility” configuration, making it possible for NR user equipment (UE) to rate match around radio resources that are taken by non-dynamically scheduled NB-IoT and LTE-M signals

Cat-M and NB-IoT have a smooth and future-proof evolution in 5G networks when combined with dynamic spectrum sharing (DSS) features, a dual-mode core network solution (5G Core) and continued standardization in 3GPP.[10][11]

Figure 8: Massive IoT access technologies coexisting with LTE/NR DSS in the same carrier[10]



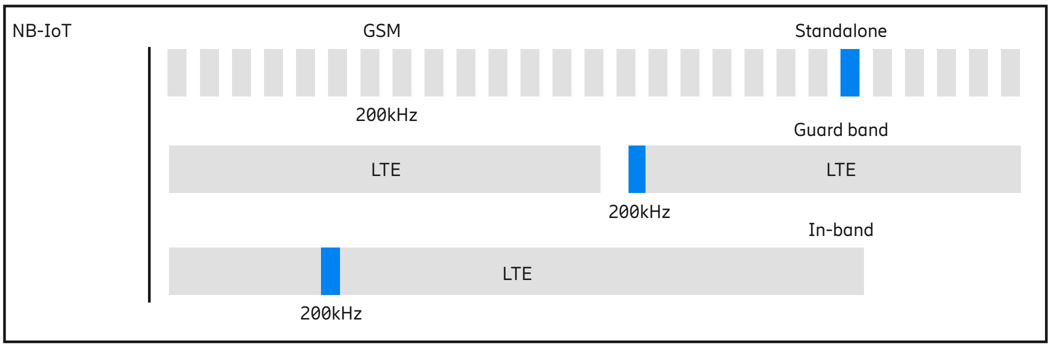
A full range of cellular LPWA solutions

No single technology or solution is ideally suited to all the different potential Massive IoT applications, market situations and spectrum availability. As a result, the mobile industry has standardized several LPWA technologies, including Cat-M and NB-IoT.

These are both superior solutions for meeting Massive IoT requirements as a family of solutions, and can complement each other based on technology availability, use case requirements and deployment scenarios. Cat-M supports a wide range of IoT applications, including those that are somewhat more content-rich, e.g. by using voice. NB-IoT covers ultra-low end IoT applications with a cost and coverage advantage over Cat-M.

Both technologies provide considerable coverage improvements from 15dB (Cat-M) to 20dB (NB-IoT). On top of this, Cat-M provides support for Voice over LTE (VoLTE). Cat-M1 can be deployed in a 1.4MHz wide sub-carrier inside an LTE carrier. NB-IoT

Figure 9: NB-IoT alternative deployment modes



can be deployed in three alternative ways.

- **Standalone deployment** in a GSM band – this is an option when LTE is deployed in a higher band and GSM is still in use, providing coverage for basic services.
- **Guard band deployment**, typically next to an LTE carrier – NB-IoT is designed to enable deployment in the guard band immediately adjacent to an LTE carrier, without affecting the capacity of the LTE carrier.
- **In-band deployment**, allowing flexible assignment of resources between LTE and NB-IoT – it will be possible for an NB-IoT carrier to time-share a resource with an existing LTE carrier. The in-band deployment also allows for highly flexible migration scenarios. For example, if the NB-IoT service is first deployed as a standalone deployment in a GSM band, it can subsequently be migrated to an in-band deployment if the GSM spectrum is re-farmed to LTE.

Cat-M and NB-IoT both also fulfill all 5G requirements from ITU and 3GPP for massive MTC.[8][9] While Cat-M is an extension of LTE in the area of MTC, NB-IoT is a complementary radio access technology based on fundamentals of LTE.

In the Massive IoT ecosystem, both dual-mode (NB-IoT and Cat-M1) and single-mode devices (NB-IoT or Cat-M1) are available to either address use cases requiring both technologies' main capabilities or, in a very cost-efficient way, match specific use case needs in terms of throughput, coverage, mobility, voice support and device positioning. A dual-mode device may operate in Cat-M1 mode when in Cat-M1 coverage and can switch to NB-IoT access when out of Cat-M1 coverage.

Conclusion

Cat-M and NB-IoT are taking off, and service providers have a unique opportunity to capture new business opportunities by offering affordable connectivity on a global scale, as well as a combination of a larger cellular IoT connectivity offering with several 3GPP access technologies, i.e. for a collection of industrial applications.

For IoT applications, existing 3GPP cellular networks offer distinct advantages over alternative WAN technologies, such as unlicensed LPWA. The global reach, QoS, ecosystem, TCO, scalability, diversity and security of cellular networks are all vital factors that can support the fast uptake and success of cellular IoT. Enabled by new software in existing legacy networks, cellular networks can support a diverse range of IoT applications – ensuring the lowest possible TCO.

3GPP standardization work for Cat-M and NB-IoT is further improving the ability of cellular networks to address the Massive IoT market, where ultra-low end-to-end cost is a firm requirement. With 3GPP Rel-15, the coexistence of NR with both Cat-M and NB-IoT is secured and is further evolving. This provides the opportunity to seamlessly introduce NR in carriers where Cat-M and NB-IoT are already in operation without an impact on already deployed Massive IoT use cases. Cat-M and NB-IoT will continue to provide Massive IoT connectivity, and also do so in NR deployments as a low-end and low-complexity interface.

New generations of energy-efficient dual- and single-mode NB-IoT and Cat-M chipsets, designed for MTC, and features that improve both coverage and device battery life will boost the ability of cellular infrastructure to address the Massive IoT market. One network that supports all applications – from advanced critical IoT enabled by NR, down to Cat-M and NB-IoT enabling cost-efficient, low-complexity and long-lasting use cases – creates a very strong value proposition.

Glossary

3GPP	3rd Generation Partnership Project
5GC	5G Core Network
AR	Augmented Reality
cIoT	cellular IoT
CAGR	compound annual growth rate
Cat-M[x]	LTE device category for machine type communication, e.g. Cat-M1
Cat-[x]	LTE device category, where x is a category class in numbers, e.g. Cat-1
CSP	Cellular Service Provider
eDRX	extended discontinuous reception
EPC	Evolved Packet Core
eUICC	embedded Universal Integrated Circuit Card
GSM	Global System for Mobile Communications
IoT	Internet of Things
KPI	key performance index
LPWA	low power wide area
LTE	Long Term Evolution
LTE-M	LTE for machine type communication
M2M	machine-to-machine
MIMO	multiple-input, multiple-output
MIoT	Massive IoT
ML	Machine Learning
MTC	machine-type communication
NR	New Radio
NB-IoT	Narrowband IoT
PRB	Physical Resource Block
PSM	power saving mode
QoS	Quality of Services
RAN	Radio Access Network
TCO	total cost of ownership
UAV	Unmanned Aerial Vehicle
UE	user equipment
UICC	Universal Integrated Circuit Card
VoLTE	Voice over LTE
VR	Virtual Reality
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access

References

[1] GSMA Mobile IoT report, January 2020, available at:
https://www.gsma.com/iot/mobile-iot-commercial-launches/

[2] Ericsson, Ericsson Mobility Report, November 2019, available at:
https://www.ericsson.com/en/mobility-report

[3] Ovum, The Voice of the IoT Enterprise Customer: Ovum IoT Enterprise Survey 2019/20, December 2019, available at: https://ovum.informa.com/resources/product-content/iot-enterprise-survey-201920-interactive-analyzer-tool-pt0195-000001

[4] TBRI, 3Q19 Telecom IoT Market Landscape,
October 2019, available at: https://tbri.com/research/telecom-iot-market-landscape/

[5] Ericsson, White Paper: Machine-to-Machine – exploring potential operator roles,
September 2014, available at:
https://www.ericsson.com/en/reports-and-papers/white-papers

[6] 3GPP TR 37.910 v16.1.0 "Study on self-evaluation towards IMT-2020 submission", available at:
https://www.3gpp.org/ftp/Specs/2019-12/Rel-16/37_series/37910-g10.zip

[7] 3GPP Tdoc R1-1907398 "IMT-2020 self-evaluation: mMTC coverage, data rate, latency & battery life", available at:
http://ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_97/Docs/R1-1907398.zip

[8] ITU-R, Report ITU-R M.2410-0, "Minimum requirements related to technical performance for IMT-2020 radio interface(s)," November 2017, available at:
https://www.itu.int/pub/R-REP-M.2410-2017

[9] 3GPP TR 38.913 v15.0.0 "Study on Scenarios and requirements for next generation access technologies", available at:
https://www.3gpp.org/ftp/Specs/2019-12/Rel-15/38_series/38913-f00.zip

[10] Ericsson, White Paper: Cellular IoT in the 5G era,
February 2020, available at: https://www.ericsson.com/en/reports-and-papers/white-papers

[11] GSMA Whitepaper, Mobile IoT in the 5G Future – NB-IoT and LTE-M in the Context of 5G,
April 2018, available at:
https://www.gsma.com/iot/wp-content/uploads/2018/05/GSMA-5G-Mobile-IoT.pdf

[12] Ericsson, White Paper: Cellular IoT Evolution for Industry Digitalization, January 2019,
available at: https://www.ericsson.com/en/reports-and-papers/white-papers

Author biographies

Christian Kuhlins is Strategic Product Manager for Massive IoT and the new IoT use case areas UAV, railways and utilities at Ericsson. After completing his education in Microelectronics at the Fachochschule Nürnberg, he joined Ericsson in 1998. Christian 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 a Product Manager, Christian worked with a variety of RAN products within Ericsson and is now a passionate advocate of cellular IoT.

Bela Rathonyi currently works as Principal System Developer focusing on the Radio Access Network parts of Cellular IoT technologies. He joined Ericsson in 1995, where he has held various positions within R&D. For many years he worked with the 3GPP-based network access functionality (2G/3G/4G) of mobile phones, platforms and chipsets and since 2014 with radio base stations. During 2016 he was one of Ericsson's 3GPP RAN2 standardization delegates, developing the first releases of the Massive IoT technologies NB-IoT and LTE-M.

Ali Zaidi is a Strategic Product Manager for Cellular IoT at Business Area Networks, Ericsson. He received an MSc and a PhD in Telecommunications from KTH Royal Institute of Technology, Stockholm, Sweden, in 2008 and 2013, respectively. Since 2014, he has been working with technology and business development of 4G and 5G radio access at Ericsson. Ali is currently responsible for LTE-M, URLLC, Industrial IoT, V2X and local industrial networks. He is also Head of IoT Competence at Ericsson. Ali has co-authored more than 50 peer-reviewed research publications and 2 books, filed over 20 patents and made several 3GPP and 5G-PPP contributions, spanning communications, control and automation technologies.

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 continued demands on existing LTE networks and the early deployment and optimization of 5G radio access solutions. One of Marie's main focus areas is to enable new use cases by driving the evolution of cellular IoT across the Massive IoT, Broadband IoT and Critical IoT technology segments. 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.

Acknowledgments
The authors would like to thank Alexandra Martido and Shanqing Ullerstig for their valuable contributions to this paper.