Paving the path to Narrowband 5G with LTE Internet of Things (IoT)

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The Internet of Things (IoT) is bringing a massive surge of smart, connected devices that will enable new services and efficiencies across industries. The IoT will transform businesses, change the way people live, and fuel innovations for many years to come. Over the next decade, it is predicted that there will be 10’s of billions of connected devices deployed globally, growing at unprecedented speed to generate multi-trillion dollars of economic value across many key markets. The Internet of Things is the foundation to a totally interconnected world, and it is only a matter of time before it evolves into the Internet of Everything.

In this vision of a totally interconnected world, cellular technologies will play an instrumental role – and they already have; 1G and 2G networks connected people to one another via voice, and 3G and 4G extended connectivity to the mobile Internet, delivering blazing fast mobile broadband services. Not only do cellular networks offer ubiquitous coverage, but they also bring unparalleled level of reliability, security, and performance required by the most demanding IoT applications. 3GPP technologies, such as 4G LTE, can provide wide-area IoT connectivity – LTE is established globally and the fastest growing wireless standard, already delivering over one billion connections worldwide. It will continue to gain momentum and proliferate even further in the decade to come. LTE has delivered on the promise of faster, better mobile broadband, and it is now scaling down for the IoT to bring multi-year battery life and lower cost devices. It is backed by a common global standard (3GPP) with support of a strong, interoperable, end-to-end ecosystem. Altogether, LTE provides a solid foundation for the future growth of IoT, bringing significant benefits over non-3GPP/proprietary solutions.

Release 13 of the 3GPP standard introduces a suite of new narrowband technologies optimizing for the IoT. Collectively referred to as LTE IoT, it includes two new User Equipment (UE) categories that can more efficiently support lower data-rate applications. LTE Cat-M1 (eMTC) enables the broadest range of IoT capabilities, and LTE Cat-NB1 (NB-IoT) scales down further in cost and power for low-end IoT use cases. Both device categories are part of the single, scalable LTE roadmap, and designed to coexist with existing LTE Advanced infrastructure, spectrum, and devices. LTE IoT brings many improvements, including complexity reduction to enable lower cost devices, more efficient low-power modes to deliver multi-year battery life, and new advanced transmission techniques to deepen coverage. Beyond air interface improvements, LTE IoT also enhances the core network to more efficiently handle IoT-centric traffic and to support large number of devices.

NB-IoT also establishes the foundation for Narrowband 5G, which will bring even more opportunities for the Internet of Things. 5G will enhance massive IoT with new capabilities such as Resource Spread Multiple Access (RSMA) for grant-free transmissions, and multi-hop mesh to further extend coverage. 5G will also enable new services, such as mission-critical control, with many innovative use cases in robotics, aviation, healthcare, industrial control, and vehicles, where enhancement dimensions such as sub-1ms latency, ultra-high reliability, and availability are required (but not simultaneously needed for all services). All in all, connecting the Internet of Things will be an integral part of 5G – a unified, more capable connectivity platform for the next decade and beyond.
The Internet of Things (IoT) broadly describes the concept of an interconnected network of physical objects, including machines, vehicles, buildings, and many other types of devices. And these connected “things” will deliver new services in the homes, businesses, cities, and across industries. The global IoT market is expected to grow aggressively over the next decade, and it is predicted that there will be 25 to 50 billion connected devices by 2020, fueling the multi-trillion-dollar economic growth across key markets. IoT will be much more than about connecting people to things, but extending existing networks to also bring machines and devices to work with one another, so they can deliver new levels of efficiency.

### 2.1 Connecting the IoT will require heterogeneous connectivity

The Internet of Things encompasses a wide variety of applications across many different industries, with devices that can drive very diverse computing and connectivity requirements. In some use cases, devices may only require short-range communication to the network access point, such as ones deployed in connected homes, while many other applications need wider-area, ubiquitous coverage. In essence, connecting the Internet of Things will require heterogeneous connectivity technologies that offer different levels of optimization to address the varying needs. Figure 1 provides a simplified illustration of the different wireless technologies often used to connect the IoT based on how far they can reach. For example, smart lighting in an office building may be best served with a short-range wireless technology, such as Wi-Fi, as light fixtures are usually deployed in areas with reasonable Wi-Fi coverage (i.e. indoors). In contrast, parking meters deployed across a smart city will most likely leverage a wide-area network. Such deployments will require a technology that can provide ubiquitous coverage in both outdoor (e.g. street parking) and indoor (e.g. parking structure) locations.

### 2.2 Cellular technologies will enable a wide range of IoT services

For the wide-area Internet of Things, cellular is evolving to become an attractive platform to address the growing connectivity needs. Already serving over 7 billion connections worldwide, cellular networks have proliferated in virtually all metropolitan cities,
suburban, and rural areas across geographic regions. Not only do cellular-based solutions offer ubiquitous reach into both outdoor and indoor locations, they also bring many additional benefits to the table. The highly-available network design allows IoT devices to reliably access application services around the clock; moreover, the tried-and-true cellular deployments already deliver end-to-end security required by the most demanding users such as governments and financial institutions. And most importantly, the mature ecosystem is backed by global standards that ensure seamless interoperability across regions and devices. Rest assured, cellular technologies will continue to evolve to deliver even better services for the fast-growing IoT markets, and the total number of cellular connections for IoT/M2M is expected to exceed 5B by 2025\(^6\). Figure 2 shows a few examples of IoT verticals and use cases that can benefit from adopting cellular-based solutions.

LTE is globally established and the fastest growing wireless standard, expected to reach 75% world population coverage by 2021\(^6\). LTE, originally introduced in release 8 of the 3GPP standard, was developed to provide faster mobile broadband access, offering a generational performance leap over 3G. The core LTE technology has evolved over time to adapt to the ever-changing market requirements, ensuring network longevity. LTE Advanced (3GPP release 10, 11, 12) evolved to optimize for better mobile broadband experience, enabling gigabit-class throughput with the introduction of advanced techniques, such as carrier aggregation and higher-order MIMO. While some IoT applications can benefit from the improvements introduced in LTE Advanced (e.g. HD security cameras), many IoT devices require optimizations for a much reduced set of functionalities.

![Figure 2: Cellular IoT enable a wide variety of services across many market verticals](image)

### 2.3 LTE is a unified, scalable platform for connecting the IoT

LTE is a unified, scalable platform for connecting the IoT. It provides a wide range of connectivity requirements through its various Release versions. Figure 3 illustrates this feature, showing the scalability and performance of LTE in comparison to its Narrowband IoT (NB-IoT) technologies. The figure highlights how LTE can address different connectivity requirements today and in the future.

![Figure 3: LTE is a scalable platform that can address a wide range of connectivity requirements](image)

*Figure 2: Cellular IoT enable a wide variety of services across many market verticals*

*Figure 3: LTE is a scalable platform that can address a wide range of connectivity requirements*
Release 13 of the 3GPP standard introduces a suite of new narrowband technologies optimizing for the Internet of Things. Collectively referred to as LTE IoT, it scales down LTE to more efficiently support lower data rate applications. LTE IoT is part of the unified LTE roadmap, providing a seamless path to deliver IoT service in existing network deployments; LTE can scale up to offer gigabit class data rates for high performance applications, or to scale down for applications requiring high power efficiency.

**2.4 LTE IoT is bringing significant benefits over non-3GPP LPWA solutions**

As the number of IoT applications continues to grow, it is expected that many new IoT-enabling connectivity technologies will emerge. While some of these new technologies can potentially address the wide-area coverage requirement, they are likely to fall short in other aspects compared to 3GPP standardized technologies such as eMTC and NB-IoT.

**Ubiquitous coverage:** LTE IoT leverages existing LTE networks without requiring a core network overlay. To date, there are already more than 500 LTE networks deployed in over 160 countries, with many more future deployments in planning.

**Scalability:** LTE IoT is a part of a unified platform that can adapt to application’s performance needs. LTE can easily scale up to support IoT use cases that require high bandwidth and low latency, and scale down to optimize for low-performance applications – all using the same network infrastructure.

**Coexistence:** LTE IoT is compatible with existing and planned LTE networks and spectrum, coexisting with regular LTE traffic without interfering with other devices or services.

**Mature ecosystem:** LTE IoT is backed by global 3GPP standards with a rich roadmap to 5G. Devices and networks are designed to interoperate across different vendors and regions.

**Managed quality of service (QoS):** One of the most important benefits of LTE is its ability to utilize licensed spectrum, as it allows network operators to guarantee QoS by effectively allocating network resources as well as managing and mitigating interferences and congestions. A redundant network design also helps to ensure service availability with minimal downtime.

**End-to-end security:** LTE IoT will inherit the established/trusted security and authentication features delivered by LTE, meeting the most stringent requirements of many high-security applications.

**3 Two new LTE IoT narrowband technologies – eMTC and NB-IoT**

3GPP Release 13 introduces two new User Equipment (UE) categories that scale down in functionalities to bring more efficiencies for connecting the Internet of Things.

LTE Cat-M1, defined by the eMTC (enhanced machine-type communications) standard, provides the broadest range of IoT capabilities, delivering data rates up to 1 Mbps, while utilizing only 1.4 MHz device bandwidth (108 MHz in-band transmissions of 6 resource blocks) in existing LTE FDD/TDD spectrum. It is designed to fully coexist with regular LTE traffic (Cat-0 and above). Cat-M1 can also support voice (VoLTE) and full-to-limited mobility. In enhanced coverage mode, it can deliver 15 dB of increased link budget, allowing LTE signals to penetrate more walls and floors to reach devices deployed deep indoors or in remote locations.
LTE Cat-NB1, or NB-IoT (narrow band IoT), further reduces device complexity and extends coverage to address the needs of low-end IoT use cases. Cat-NB1 leverages narrowband operations, using 200 kHz device bandwidth (180 kHz in-band transmissions of 1 resource block) in LTE FDD, to deliver throughputs of 10’s of kbps. NB-IoT supports more flexible deployment options: LTE in-band, LTE guard-band, and standalone. To further enhance coverage, it trades off spectral efficiency (e.g. data rate), and capabilities (e.g. no mobility or voice support) to achieve >5 dB of extra gain over Cat-M1.

Both Cat-M1 and Cat-NB1 can be deployed in existing LTE Advanced infrastructure and spectrum, efficiently coexist with today’s mobile broadband services. Cat-M1 utilizes 1.4 MHz bandwidth, leveraging existing LTE numerology (versus NB-IoT’s new channel bandwidth of 200 kHz), and can be deployed to operate within a regular LTE carrier (up to 20 MHz). Cat-M1 devices will leverage legacy LTE synchronization signals (e.g. PSS\(^7\), SSS\(^8\)), while introducing new control and data channels that are more efficient for low bandwidth operations. LTE network supporting Cat-M1 can utilize multiple narrowband regions with frequency retuning to enable scalable resource allocation, and also frequency hopping for diversity across the entire LTE band.

3.1 New LTE IoT devices can efficiently coexist with today’s services

![Figure 4: LTE IoT - Cat-M1 and Cat-NB1 devices](image-url)

![Figure 5: Cat-M1 (eMTC) can operate across entire regular LTE band](image-url)

\(^7\)Primary Synchronization Signal
\(^8\)Secondary Synchronization Signal
Cat-NB1 devices can be deployed in LTE guard-bands or as a standalone carrier in addition to LTE in-band. Nevertheless, the new 200 kHz device numerology (utilizing a single LTE resource block, or RB of 180 kHz) requires a new set of narrowband control and data channels. Unlike Cat-M1 in-band, Cat-NB1 does not allow for frequency retuning or hopping and occupies a fixed spectrum location. For guard-band deployment, NB-IoT leverages unused resource blocks without interfering with neighboring carriers. In standalone mode, Cat-NB1 devices can be deployed in re-farmed 2G/3G bands.

![Cat-NB1 flexible deployment options](image)

**Figure 6: Cat-NB1 (NB-IoT) flexible deployment options**

# 4 New IoT-optimized narrowband technologies

The new LTE IoT narrowband technologies are paving the path to Narrowband 5G, bringing four main areas of improvements to better support the Internet of Things: reducing complexity, improving battery life, enhancing coverage, and enabling higher node density deployments.

## 4.1 Reducing complexity to enable lower cost devices

The proliferation of IoT will bring significant benefits to a diverse set of industries and applications. While there are many IoT use cases that have the potential to drive higher ARPC (average revenue per connection) that is comparable to today’s mobile broadband services (e.g. smartphones, tablets), the majority of use cases will require much lower-cost devices and subscriptions to justify massive deployments. For example, the hardware and service cost of a smartphone is very different from a simple remote sensor that provides temperature measurements a few times a day. For this reason, both Cat-M1 and Cat-NB1 devices will scale down in levels of complexity to enable lower cost, while still meeting the IoT application requirements. Figure 7 summarizes the high-level complexity differences of the two new LTE IoT UE categories.

<table>
<thead>
<tr>
<th>LTE Cat-1 (Today)</th>
<th>LTE Cat-M1 (Rel-13)</th>
<th>LTE Cat-NB1 (Rel-13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak data rate</strong></td>
<td>DL: 10 Mbps</td>
<td>DL: 1 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL: 5 Mbps</td>
<td>UL: 1 Mbps</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
</tr>
<tr>
<td><strong>Rx antenna</strong></td>
<td>MIMO</td>
<td>Single Rx</td>
</tr>
<tr>
<td><strong>Duplex mode</strong></td>
<td>Full duplex FDD/TDD</td>
<td>Supports half duplex FDD/TDD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Half duplex FDD only</td>
</tr>
<tr>
<td><strong>Transmit power</strong></td>
<td>23 dBm</td>
<td>20 dBm</td>
</tr>
</tbody>
</table>

Higher throughput, lower latency, full mobility

**Figure 7: Reducing complexity for LTE IoT devices**
Peak data rate: Both Cat-M1 and Cat-NB1 devices will have reduced peak data rates compared to regular LTE devices (e.g. Cat-1). Cat-M1 has limited throughput of up to 1 MBps in both downlink and uplink directions, while Cat-NB1 further reduces peak data rate down to 10's of kbps. The reduced peak data rates allow for both processing and memory savings in the device hardware.

Bandwidth: LTE supports scalable carrier bandwidths from 1.4 MHz to 20 MHz, utilizing 6 to 100 resource blocks. For LTE Cat-M1, the device bandwidth is limited to 1.4 MHz only (108 MHz plus guard-band for 6 RBs in-band), to support the lower data rate. On the other hand, Cat-NB1 further reduces device bandwidth to 200 kHz (180 kHz plus guard-band for a single RB). The bandwidth reduction for Cat-M1 requires a new control channel (i.e. M-PDCCH) to replace the legacy control channels (i.e. PCFICH, PHICH, PDCCH), which can no longer fit within the narrower bandwidth. While for Cat-NB1, a new set of NB-IoT synch, control, and data channels are introduced to accommodate the narrower bandwidth.

Rx Antenna: Multiple antennas for MIMO (multiple-input, multiple-output) and receive diversity was introduced in LTE to improve spectral efficiency. For LTE IoT applications, there is little need to push for higher data rates, but important to reduce complexity. For both Cat-M1 and Cat-NB1, the receive RF is reduced to a single antenna, which simplifies the RF frontend. Though there is some RF degradation due to the lack of receive diversity, the lost signal sensitivity can be compensated by other advanced coverage enhancing techniques.

Duplex Modes: Due to the less frequent and latency-tolerant nature of IoT data transmissions, LTE IoT devices can reduce complexity by only supporting half-duplex communications, where only the transmit or receive path is active at a given time. Cat-M1 devices can support half-duplex FDD in addition to TDD, while Cat-NB1 devices only support half-duplex FDD. This allows the device to implement a simpler RF switch instead of a full duplexer that is more complex and costly.

Transmit Power: For both new LTE IoT UE categories, the maximum uplink transmission power is reduced to 20 dBm (100mW) from LTE's 23 dBm (200mW), allowing the power amplifier (PA) to be integrated for lower device cost.

Other simplifications: Other complexity reduction techniques include Cat-NB1's limited support for voice (VoLTE or circuit switched services), and mobility (no link measurement or reporting).

4.2 Improving power efficiency to deliver multi-year battery life

Many IoT devices are battery-operated, and it is highly desirable for them to last for as long as possible on a single charge. The associated cost for field maintenance can be quite daunting, especially in massive deployments. Not only would the planning of scheduled maintenance be an operational overhead, but physically locating these mobile devices (e.g. asset trackers sprinkled all over the world) can also become a nightmare. Thus, maximizing battery life has become one of the most important improvement vectors in LTE IoT. In addition to the power savings realized through reduced device complexity, two new low-power enhancements have been introduced: power save mode (PSM) and extended discontinuous receive (eDRx) – both are applicable to Cat-M1 and Cat-NB1 devices.

Power Save Mode (PSM): PSM is a new low-power mode that allows the device to skip the periodic page monitoring cycles between active data transmissions, allowing the device to sleep for longer. However, the device becomes unreachable when PSM is active; therefore, it is best utilized by device-originated or scheduled applications, where the device initiates communication with the network. Moreover, it enables more efficient low-power mode entry/exit, as the device remains registered with the network during PSM, without having the need to spend additional cycles to setup registration/connection after each PSM exit event.

9MTC Physical Downlink Control Channel
10Physical Control Format Indicator Channel, Physical Hybrid-ARQ Indicator Channel, Physical Downlink Control Channel
Example applications that can take advantage of PSM include smart meters, sensors, and any IoT devices that periodically push data up to the network.

**Extended Discontinuous Reception (eDRx):** eDRx optimizes battery life by extending the maximum time between data reception from the network in connected mode to 10.24s, and time between page monitoring and tracking area update in idle mode to 40+ minutes. It allows the network and device to synchronize sleep periods, so that the device can check for network messages less frequently. This, however, increases latency, so eDRx is optimized for device-terminated applications. Use cases such as asset tracking and smart grid can benefit from the lower power consumption realized through the longer eDRx cycles.

<table>
<thead>
<tr>
<th>Power consumption</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSM</strong></td>
<td>Sleep</td>
</tr>
<tr>
<td><strong>Data transfer</strong></td>
<td>Sleep</td>
</tr>
<tr>
<td><strong>Page monitoring</strong></td>
<td>Extended DRx</td>
</tr>
<tr>
<td><strong>Device not reachable</strong></td>
<td>Up to 40+ minutes vs. today’s upper limit of 2.56 seconds</td>
</tr>
</tbody>
</table>

**Figure 8: PSM and eDRx optimize device battery life**

### 4.3 Enhancing coverage for better reach into challenging locations

There are many IoT use cases that can benefit from deeper network coverage, especially for devices deployed in challenging locations such as utility meters. In many use cases, trading off uplink spectral efficiency and latency can effectively increase coverage without increasing output power that will negatively impact the device battery life.

<table>
<thead>
<tr>
<th>LTE Cat-NB1</th>
<th>Up to 164 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cat-NB1 only</strong></td>
<td></td>
</tr>
<tr>
<td>- Further relaxed requirements, e.g. timing</td>
<td></td>
</tr>
<tr>
<td>- Low-order modulation, e.g. QPSK</td>
<td></td>
</tr>
<tr>
<td>- Option for single-tone uplink transmissions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LTE Cat-M1</th>
<th>&gt;155.7 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cat-M1 and Cat-NB1</strong></td>
<td></td>
</tr>
<tr>
<td>- Repetitive transmissions &amp; TTI bundling for redundancy</td>
<td></td>
</tr>
<tr>
<td>- Narrowband uplink transmissions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LTE Cat-1</th>
<th>Baseline 140.7 dB</th>
</tr>
</thead>
</table>

**Figure 9: Advanced techniques to deepen coverage**
Redundant transmissions: Transmitting the same transport block multiple times in consecutive sub-frames (TTI bundling) or repeatedly sending the same data over a period of time (repetitive transmission) can significantly increase the probability for the receiver (cell or device) to correctly decode the transmitted messages.

Power Spectral Density (PSD) boosting: While the serving cell can simply increase transmit power in the downlink to extend coverage, it is also possible for the device to put all the power together on some decreased bandwidth (e.g. Cat-NB1 can transmit on 3.75 kHz sub-carrier spacing in a new numerology, vs. 15 kHz in Cat-M1 and LTE) to effectively increase the transmit power density.

Single-tone uplink: Similarly, Cat-NB1 device can utilize single-tone uplink (3.75 kHz or 15 kHz sub-carrier spacing) to further extend coverage, trading off peak data rate (limiting to 10’s of kbps).

Lower-order modulation: By utilizing QPSK instead of 16-QAM, the SINR (Signal to Interference plus Noise Ratio) threshold reduces significantly, trading off modulation efficiency (fewer bits per symbol).

With these new coverage enhancements, the link budget of a Cat-M1 device is increased to 155.7dB, a +15dB improvement over regular LTE. For Cat-NB1, it is further increased to 164dB.

4.4 Optimizing LTE core network to more efficiently support IoT devices

IoT is bringing a massive amount of connected devices that will push the capability boundary of existing LTE networks. And much different from mobile broadband services, network capacity will not be the limiting factor to support more low-end IoT devices (e.g. meters), as LTE IoT traffic only makes up for a small fraction of the overall capacity requirement, but the ability to handle the increased amount of signaling. Most IoT devices transmit small amount of data sporadically, rather than in large data packets; therefore, the LTE core network also needs to evolve to better support IoT traffic profiles by providing more efficient signaling and resource management.

More efficient signaling: New access control mechanisms such as Extended Access Barring (EAB) prevents devices from generating access requests when the network is congested, thus eliminating unnecessary signaling. The network can also utilize group-based paging and messaging to more efficiently communicate with multiple downlink devices.

Enhanced resource management: The network can allow a large set of devices to share the same subscription, such that resources and device management can be consolidated. For example, a group of water meters in a smart city can be collectively provisioned, controlled, and billed.

Simplified core network (EPC-lite): The LTE core network can be optimized for IoT traffic, allowing more efficient use of resources and consolidation of the MME, S-GW, and P-GW into a single EPC-lite. With this, the operators have the option to optimize for lower OPEX, or to minimize CAPEX spend by leveraging existing LTE core network to support LTE IoT.
4.5 Delivering an end-to-end LTE IoT platform

In order to make LTE IoT a success, the entire ecosystem needs to be involved to simplify the overall deployment and management of LTE IoT services. In many ways, this effort had already begun. Hardware manufacturers are accelerating device development by delivering certified modules, and the new embedded SIM (eUICC) initiative is picking up momentum, aiming to enable more flexible management of cellular services. For IoT software development, protocol standardization will ensure data transport efficiency and inter-vendor interoperability; for example, oneM2M is driving standardization of the communication protocols to deliver faster time-to-market and reliable end-to-end security.

5 Roadmap to 5G will bring even more IoT opportunities

5G will be a unified, more capable connectivity platform that will connect new industries, enable new services, and empower new user experiences. And the Internet of Things will be an integral part of 5G, delivering new classes of IoT services and efficiencies not possible with 4G LTE. The vision of 5G is now well defined, slated for commercialization by 2020, and it will further enhance mobile broadband, more efficiently support massive IoT, and enable new mission-critical services. Figure 10 below shows the ITU-R IMT-2020 vision of the next-generation 5G network.

5.1 Evolving NB-IoT toward Narrowband 5G

The new 5G platform will be defined in release 15 of the 3GPP standard and beyond, but many of the foundational technologies are already introduced as part of LTE Advanced Pro. NB-IoT will continue to evolve beyond 3GPP Release 13, taking another step closer to Narrowband 5G to enable massive IoT. Some of the proposed enhancements for Release 14 will include, but not limited to, voice/mobility, location services, and broadcast support for more efficient over-the-air (OTA) firmware updates.
## 5.2 Bringing new capabilities to the massive IoT

5G will improve upon LTE IoT’s ability to support higher node density by delivering a new uplink multiple access design called Resource Spread Multiple Access (RSMA). RSMA is an asynchronous, non-orthogonal, and contention-based access protocol that will further reduce device complexity and signaling overhead since it allows “things” to transmit without prior network scheduling.

To extend network coverage for IoT devices to the most extreme locations (e.g. hyper-remote, deep underground), 5G will support multi-hop mesh, allowing out-of-coverage devices to connect directly with devices that can relay data back to the access network. This essentially creates an edgeless network that extends coverage beyond the typical cellular access (e.g. base stations and small cells). More importantly, 5G core network will also take on WAN management for both devices in access coverage as well as those supported by the peer-connected mesh network.

![Image of new 5G capabilities to enable massive IoT](image.png)

**Figure 11: New 5G capabilities to enable massive IoT**

## 5.3 Enabling mission-critical control IoT services

LTE IoT efficiently scales down to optimize for infrequent and delay-tolerant communication; while satisfying many of the lower-end IoT applications, such as metering and sensors, there is a class of IoT applications that demand much higher performance. Such as mission-critical services that require end-to-end latencies down to 1ms, ultra-high reliability allowing extreme low loss rates, high availability through multiple links for failure tolerance and mobility, as well robust end-to-end security that cannot be compromised. All of these requirements have been taken into considerations by the design of 5G mission-critical control, and drones and industrial robots are just a couple of innovative use cases driving these extreme requirements (but not simultaneously needed for all services).
5.4 Delivering additional benefits with the new 5G network architecture

The new flexible 5G network will deliver uncompromised performance and efficiency, leveraging virtualized network functions to create optimized network slices for a wide range of services hosted on the same physical network (e.g. enhanced mobile broadband, mission-critical services, and massive IoT). Each network slice can be configured independently to provide end-to-end connectivity that is optimized for the application’s needs. And this is especially beneficial for the IoT, as its diverse set of requirements can dictate very different SLAs (service level agreement) for the different use cases supported by the same network deployment. In addition to allowing more efficient resource allocation and utilization, the enhanced 5G network also enables flexible subscription models and dynamic creation/control of services.

6 Conclusion

The Internet of Things is bringing a massive surge of smart, connected devices that will enable new services and efficiencies across industries. The IoT will transform businesses, change the way people live, and fuel innovations for many years to come. And cellular technologies will play an important role providing connectivity for a wide range of things; LTE is evolving to deliver a unified, scalable IoT platform that brings significant benefits over other non-3GPP LPWA solutions. It not only provides ubiquitous coverage through established global networks, but also brings unparalleled level of reliability, security, and performance required by the most demanding IoT applications.

LTE Advanced Pro is delivering new LTE IoT narrowband technologies that will lower complexity, increase battery life, deepen coverage, and enable high node density deployments. In release 13 of the 3GPP standard, LTE IoT introduces two new UE categories (Cat-M1 and Cat-NB1) that will scale down LTE to enable more efficient IoT communications. Cat-M1 will offer the broadest range of IoT capabilities with support for more advanced features such as mobility and VoLTE, while Cat-NB1 further scales down to offer the lowest cost and power for delay-tolerant, low-throughput use cases.

Building on top of LTE IoT narrowband technologies, 5G will bring even more opportunities for the Internet of Things. Narrowband 5G will enhance massive IoT with new capabilities such as RSMA for grant-free transmissions, and multi-hop mesh to further extend network coverage. 5G will also enable mission-critical services by delivering ultra-low latency communications, as well as providing significant improvements to system reliability, service availability, and end-to-end security. The new flexible network architecture will also enable uncompromised performance and efficiency for all services hosted on the next-generation 5G network. All in all, connecting the Internet of Things will be an integral part of 5G – a unified, more capable connectivity platform for the next decade and beyond.

To learn more about LTE IoT and 5G, please visit:

www.qualcomm.com/LTE-IoT

www.qualcomm.com/5G