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Efficient Resource Optimization of 5G Networks Enabling QoS and QoE in IoT Applications

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Abstract

This article elaborates the recent enhancements on IoT capabilities and efficiencies. From power, coverage, cost, complexity, device density, core network protocol, spectrum efficiency perspectives, it describes a comprehensive blueprint for driving IoT optimizations. For better mobile broadband experience, enabling Gigabit-class throughput with advanced 5G network techniques, millimeter wave, massive MIMO, carrier aggregation, and LAA benefit massive IoT improvements. Supporting Gigabit-class data rates for high-performance IoT requires high power efficiency. eMTC (enhanced machine-type communication) optimizes for the broadest range of IoT applications with VoLTE and mobility. NB-IoT (Narrow Band IoT) provides optimizations for high throughput and low delay LPWAN IoT use cases.

Keywords: LTE IoT; eMTC; NB-IoT; QoS; QoE

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Introduction

Enabling new capabilities such as multi-cast and positioning, and enhancing efficiencies to connect more devices, Quality of Experience (QoE) and Quality of Service (QoS) requirements will affect IoT requirements and specifications. Accomplishing with new 5G demand RSMA for grant-free small data transmissions and multi-hop mesh to extend network coverage will achieve the QoS and QoE that is essential for IoT to be successful.

LTE IoT provides a seamless path to deliver IoT service in existing network deployments [1]. LTE IoT is a part of a unified platform that can adapt to application performance demands. 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 using the same network infrastructure. One of the most important benefits of LTE is 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.

The remainder of this article is structured as follows:

Section 2 provides details on the essential aspects that encompass the development of IoT improvements. Section 3 examines continued LTE IoT evolution to 5G broadening use cases. A summary concludes the letter in Section 4.

Massive IoT Enhancements

Energy reduction and coverage extension optimizations are shared by eMTC and NB-IoT, taking additional capabilities and efficiencies for the massive IoT. Shared eMTC and NB-IoT delivers new efficiencies for the massive IoT such as single Rx antenna, half-duplex, PSM, eDRx, TTI bundling, overload control, overhead optimizations.

Improving power efficiency to deliver longer battery life

Maximizing battery life has become one of the most important improvement vectors in LTE IoT. To our best knowledge, reducing device complexity can save power.

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IoT imports two new low-power enhancements modes applicable to Cat-M1 and Cat NB1 devices for optimizing device battery life.

Power Save Mode (PSM): PSM 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, it is best utilized by scheduled applications, where the device initiates communication with the network. Furthermore, it enables more efficient low-power mode entry/exit, as the device remains registered with the network during PSM, without additional cycles to setup registration/connection after each PSM exit event. Smart meters, sensors, and any IoT devices periodically push data up to the network.

extended Discontinuous Receive (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 longer than 40 minutes. It allows the network and device to synchronize sleep periods for checking network messages occasionally. This increases latency, therefore, eDRx is optimized for device-terminated applications. Asset tracking can reap the benefits of lower power consumption during longer eDRx cycles.

Enhancing coverage for better reachability

The tradeoff between spectral efficiency and latency can effectively increase coverage without increasing output power that will negatively impact the device battery life.

Repetitive 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 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 to effectively increase the transmit power density. Cat-NB1 can transmit on 3.75 kHz sub-carrier spacing while Cat-M1 and LTE can occupy 15kHz sub-carrier spacing.

Single-tone uplink: Cat-NB1 device can utilize single-tone uplink 3.75 kHz or 15 kHz sub-carrier spacing to further extend coverage with peak data rate 10 kbps.

Lower-order modulation: By utilizing QPSK instead of 16-QAM, the SINR threshold reduces significantly, whereas modulation efficiency with fewer bits per symbol.

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

Reducing complexity to enable lower cost devices

Both Cat-M1 and Cat NB-1 devices can scale down in complexity to enable lower cost, while fulfilling the application requirements. **Table 1** summarizes the high-level performance disparities among LTE IoT devices. Peak data rate: Both Cat-M1 and Cat-NB1 devices will have reduced peak data rates. Cat-M1 has limited throughput of more than 1 Mbps in both downlink and uplink directions, while Cat-NB1 further reduces peak data rate down to 100 kbps. The reduced data rates allow for data analytics and edge computing.

Table 1: Resource performance for LTE IoT devices.

	LTE Cat-1	eMTC Cat-M1	NB-IoT Cat-NB1
Peak data rate	>10 Mbps	>1 Mbps	<100 kbps
Bandwidth	>20 MHz	1.4 MHz	200 kHz
Duplex mode	Full FDD/TDD	Full/half FDD/TDD	Half FDD
Rx antenna	Dual Rx	Single Rx	Single Rx
Mobility	Full	Limited to full	Cell reselection
Transmit power	23 dBm	23, 20 dBm	23, 20 dBm
Voice	VoLTE	VoLTE	No support

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 1.08 MHz guard-band for 6 RBs in-band to support the lower data rate. Cat-NB1 further reduces device bandwidth to 180 kHz guard-band for a single RB. The bandwidth reduction for Cat-M1 requires a new control channel M-PDCCH which is not suitable for the narrow band. While for Cat-NB-1, NB-IoT synch, control, and data channels can accommodate the narrower bandwidth.

Rx-antenna: Multiple antennas and receive diversity in LTE can improve spectral efficiency. For both Cat-M1 and Cat-NB1, the receive RF is reduced to a single antenna for simplifying the RF frontend.

Duplex modes: LTE IoT devices can reduce complexity by only support half-duplex communications where only the transmit or receive path is active at a given time. Cat-M1 devices can support half-duplex FDD and TDD, while Cat-NB1 devices only support half-duplex FDD.

Mobility: Only Cat-M1 devices support limited-to-full mobility, which is a differentiating feature where devices can frequently move between different cells. Cat-NB1 devices support cell reselection only.

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Voice service: VoLTE is critical Cat-M1 characteristic for wearables in IoT applications. Because of hardware and limited bandwidth, Cat-NB1 does not support voice service.

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

Optimizing LTE core network to more efficiently support IoT devices

Most IoT devices transmit small amount of data sporadically, LTE core network evolves to better IoT traffic profiles by 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, eliminating unnecessary signaling. The network can 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. Water, electricity, and gas in a smart city can be collectively provisioned, controlled, and billed.

Simplified core network: 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. The operators optimize for lower OPEX or minimize CAPEX by leveraging existing LTE core network to support LTE IoT.

Enabling higher device density

Core network enhancements include software upgrades for service differentiation handling, signaling optimization and high-capacity platforms more than 30 million devices per node. To increase device density, RSMA (resource spread multiple access) enables grant-free transmissions.

RSMA is an asynchronous, non-orthogonal, and contention-based uplink multiple access design that reduces device complexity and signaling overhead since it allows IoT devices to transmit without prior network scheduling.

Expanding into unlicensed spectrum

The MulteFire is adapting LTE IoT to operate in the unlicensed spectrum to expand beyond mobile broadband and high-performance IoT. This enables LPWA (low-power, wide-area) use cases, leveraging both eMTC and NB-IoT.

Figure 1 depicts the overall IoT enhancement aspects mentioned above. These new capacities and improvements will propel LTE IoT to become more efficient.

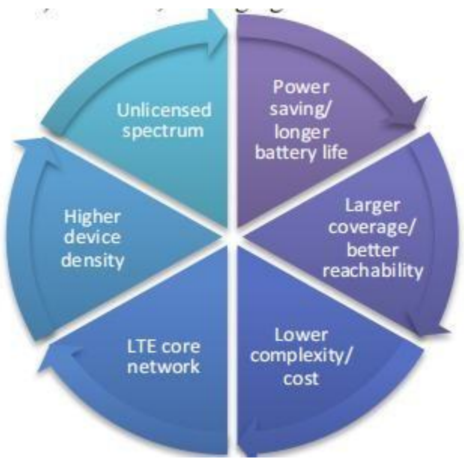

Figure 1: IoT enhancement aspect

Continuous LTE IoT Evolution to 5G

New 5G capabilities to enable massive IoT

Figure 2 addresses potential characteristics of 5G IoT technology [2]. A 5G NR-based massive IoT design is expected to elevate massive IoT connectivity to the next level. 5G Multi-RAT Core Network (MR-CN) supports multiple RATs among 5G, LTE and WLAN, improves end-to-end performance for LTE IoT. 5G enables separation of control and user planes based on SDN, allows more fine grain traffic management. Multi-RAT Access Network (MR-AN) assigns one or more cells for each RAT and supports inter and intra RAT mobility and aggregation.

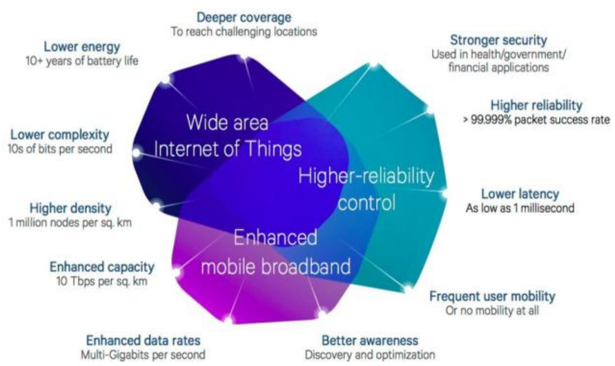

Figure 2: Scalable resource optimization requirements.

To extend network coverage for IoT devices, multi-hop mesh will allow out-of-coverage devices to connect directly with devices that can relay data back to the access network. The core network will take on WAN management for devices in both access coverage and peer-connected mesh network.

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Conclusion

Narrowband LTE IoT technologies are delivering lower complexity, increase battery life, deepen coverage, and enable high device density deployments. Two new UE categories Cat-M1 for eMTC and Cat-NB1 for NB-IoT scaled down LTE to enable more efficient IoT communications. Cat-M1 will offer broadest range of IoT capabilities with support for more advanced features such as full mobility and VoLTE, while Cat-NB1 offers the lowest cost and power for delay-tolerant, high throughput.

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