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Review

Efficiently Optimizing 5G Network Resources for Application-Specific Quality of Service and Quality of Experience

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ABSTRACT

The latest improvements to the capabilities and efficiency of the Internet of Things are detailed in this article. It provides an all-inclusive plan for pushing improvements in the Internet of Things (IoT) from the following angles: power, coverage, cost, complexity, device density, core network protocol, and spectrum efficiency. The Internet of Things (IoT) may benefit greatly from advancements in 5G network technology, millimeter wave, massive multiple-input multiple-output (MIMO), carrier aggregation, and loss-adaptive antennas (LAA), all of which can enhance mobile broadband experiences. Extremely low power consumption is necessary to provide Internet of Things (IoT) data speeds in the gigabit range. With VoLTE and mobility, eMTC (enhanced machine-type communication) maximizes support for the widest variety of Internet of Things (IoT) applications. The narrowband Internet of Things (NB-IoT) offers improvements for low-latency, high-throughput LPWAN IoT applications. Terms such as LTE IoT, eMTC, NB-IoT, QoS, and QoE are included in the index.

Keywords
FInternet of Things (IoT); Quality of experience (QoE); quality of service (QoS).

INTRODUCTION

Various factors will influence the needs and specifications of the Internet of Things (IoT), including the need to enable new features like multi-cast and location, improve efficiency in order to connect more devices, and meet quality of experience (QoE) and quality of service (QoS) standards. The success of the Internet of Things (IoT) depends on meeting the new 5G demand, RSMA for grant-free tiny data transfers, and multi-hop mesh to enhance network coverage. Providing ultra-high capacity per terminal and improving spectrum efficiency are two key goals of 5G services. There will be an exponential increase in the need for additional capacity as autonomous networks and industrial sectors continue to rise. It is anticipated that a vast majority of "Green" terminals, including smartphones, wearables, laptops, tablets, and smart automation equipment, will undergo an update. There will be a dramatic increase in the overall number of linked devices due to the widespread availability of machine-to-machine IoT services, which will lead to a proliferation of automated devices.

Delivering Internet of Things (IoT) services in preexisting network installations is made easy with LTE IoT [1]. An adaptable unified platform includes LTE IoT, which may meet the performance needs of various applications. Using the same network architecture, LTE can easily scale up to accommodate Internet of Things use cases that demand low latency and high bandwidth, and scale down to optimize for low-performance applications. Using licensed spectrum is one of the main advantages of LTE. in that it enables network operators to ensure QoS via efficient resource allocation, management, and mitigation of congestion and interference.

Here is the outline for the rest of the paper: Section

2, which looks at the key features of Internet of Things application cases that push 5G technology forward. Section 3 provides detailed information on new LAA technological advancements that foster the growth of the Internet of Things (IoT) and new MTC traits. Section 4 provides an overview of the 5G system's use of LTE MTC and discusses new innovations in mesh networking and coexistence architecture. In Section 5, we go over the key points that make up the advancement of the Internet of Things. Continued progression of LTE IoT to 5G expanding application cases is examined in Section 6. Section 7 finishes the letter with a summary.

IoT Use Cases

Ad Hoc Networking

IoT platform has rapidly self-organized networking capability and could interoperate with the network layer to support correspondending services. In order to transfer the information, the vehicle networks and transportation infrastructures can be quickly self-organized.

Sensor Network

IoT use sensor to collect information which is the fundamental component that experience the universe, and provides applications

and services. Due to the diversity of sensors such as speed, pressure, temperature, humidity, height, video, image, voice and location sensors, information detected by these sensors transform comprehensively.

LTE-A MTC

LTE-Advanced technology, the soul of 4G network connectivity, will evolve to supply attracting characteristics that provide a large number of high performance and low cost IoT devices. These devices extend coverage for

challenging locations, energy saving for applications requiring long battery life and optimizations to deploy very large numbers of devices per cell.

LTE-based MTC solutions create development in diverse entities of MTC ranging from home and industrial automation to consumer electronic devices such as connected wearables. LTE-based MTC solutions serve as one type of IoT service on the strength of its ubiquitous connectivity, more efficient energy saving, higher coverage and faster data rates of up to 1 Mbps [2].

Automotive

Cellular mobile services are enabled to supply connectivity to the surrounding automobile as the demand for ubiquitous coverage and bi-directional real-time communication to the advantages of vehicle networks.

The evolution of vehicle technology has foreseen an increment in Vehicle-to-Infrastructure (V2I) use cases such as telematics solutions, Vehicle-to-Cloud (V2C), Vehicle-to-Vehicle (V2V) and Vehicle-to-Pedestrian (V2P) communication such as vehicle safety management and real-time automobile control. IoT networks will further augment the capabilities of connected automobile and facilitate faster transmission of more information generated by V2V and Vehicle-to-Everything(V2X) use cases.

Fleet management

The cellular IoT fleet management application requirements include ubiquitous connectivity, extended coverage, accurate positioning, high data rates. Novel capabilities of 5G cellular technologies produce new generations of infrastructure that will empower superior capabilities and higher throughput such as wireless IP-based video which ultimately improves operation efficiencies.

Smart transportation

Cellular technologies LTE provide real-time collection of massive information from road sensors, cameras, vehicles, drivers and pedestrians to assist streamline monitoring traffic flow. Figure 1 summarizes the above application scenes in IoT use cases.

Functional architecture in IoT

Gateway

Figure 2 depicts the end-to-end architecture of IoT solution. The network device can be connected to a local gateway via a short distance network such as Wi-Fi, Zigbee, Bluetooth, directly to a wide area network such as the mobile cellular network. The gateway devices can be connected through a wireline access network.

The gateway connects the local communication between the IoT devices and bridges the local network to the wide area network. To support a larger number of devices per cell with new features such as group-based paging, messaging, and improved load management.

Access Network

Figure 2: The end-to-end architecture of IoT solutions.

The radio access network (RAN) is shared traffic across consumer and IoT. Traditionally, mobile networks have been planned for low latency, high throughput consumer traffic. MTC optimizations to 5G is used to extend coverage for low throughput devices deep deployed within buildings such as in basements

which consequentially reduce signaling traffic and device cost, and improve battery life. Meanwhile, IoT optimized wide area networks which are under developed and deployed.

Cellular Core Network

5G core network functions make two major forces for IoT services and devices. One is the current ongoing MTC and another is the application of Network Functions Virtualization (NFV) and Software-Defined Networking (SDN) technologies in the 5G core network that create novel capabilities that can enable a plenty of use cases more efficiently including IoT. MTC is concentrated on 5G cellular system enhancements for IoT services and develop for low complexity, low cost and low power consumption as well as efficient small data transmission devices.

NFV and SDN technologies build a modular based core network architecture where the core network can be dynamically 'scaled' and 'sliced' depended on IoT use cases, categories of devices. It is conceivable that a network operator can create mobile core instances suitable for IoT. The blending of these novel technologies will lead to an access agnostic and 5G core network that will back up the various use cases of telecommunications.

Connectivity Platform

By designing a platform for handling SIM pre-provisioning, provisioning, activation, deactivation and self-diagnosis of device communication issues, the demand for bulk provisioning has driven 5G operators to reduce their operations cost.

The connectivity platform comprises a communication server that analyzes, stores and transfers message routing and protocol translation, essentially collecting information from devices and making them available to applications. Data communications server is belonging to the application platform. The management platform consists of device management functions for firmware configuration, diagnostics and upgrades, and application life cycle management.

Application Platform

A Development and Execution Application Platform (DEAP) is planned to create and realize the application for IoT solutions. The application platform is consisted of the fundamental functions for diverse applications: collect, store and process data, and transmit valuable statistics to customers of frontal application. The application platform has the communication server, a rule engine for processing data and a database for storing device data. Application Program Interface (APIs) easily uses the services of the platform. It provides remote and automatic operation, administration, management and provisioning. Network domain virtualization includes virtual Radio Access Networks (vRAN)/ vAccess, vCore and virtual Operations Support Systems/Business Support Systems (OSS/BSS) for dynamic scalability.

Advancements in LTE for MTC

LTE IoT is a suite of two complementary narrowband technologies eMTC and NB-IoT. They deliver optimized

performance and efficiency for a wide range of low-power, wide-area (LPWA) Internet of Things. 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. Supporting narrowband operation, NB- IoT enables low-cost modules optimized for small, infrequent data transmissions. Utilizing a narrower bandwidth Positioning reference signal (PRS) with higher repetition factors that extends range.

Seamless Coexistence of Different Services

LTE IoT broadens IoT use cases and expands into unlicensed spectrum [3]. It established a solid foundation for connecting the massive IoT, by scaling down complexity, lowering power, deepening coverage, and increasing device density. It continues to extend into the unlicensed spectrum that will enable new standardization LTE-U, LAA, eLAA for private IoT networks.

Mesh networking is multiple-hop mesh with WAN management on unlicensed spectrum for LTE D2D low power devices. MTC/IoT services are promising to coexist seamlessly with 5G broadband services, therefore IoT operators can efficiently corporate them with existing LTE-A networks. Coexisting with LTE unicast services, eMTC single-cell multicast group messaging service and NB-IoT single-cell multicast firmware upgrade service facilitates the efficient communication. Downlink remains OFDM-based for coexistence with other services.

Mature, Interoperable Global Ecosystem

We are driving broad ecosystem adoption of LTE IoT. Global cellular connectivity to a wide variety of IoT applications generate LTE multimode modem supporting Cat-M1 + Cat-NB1 + E-GPRS which is one example of cost-optimized, flexible and scalable chipsets tailored to power IoT. Supporting dynamic mode selection with flexible configuration.

Always-Available, Ubiquitous Connectivity

LTE provides a scalable IoT connectivity platform. LTE Cat-1 delivers scalable performance and seamless mobility for high performance IoT use cases. eMTC Cat-M1 optimizes TTI bundling and repetitive transmissions for the broadest range of IoT applications with high-reliability and lower latencies. NB- IoT Cat-NB1 provides extreme optimizations on relaxed timing requirements, lower-order modulation and single-tone UL transmissions for low cost/power, high throughput, delay-tolerant IoT use cases.

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

Power Saves 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 intiates 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. Figure 3 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.

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.

Voice Service

VoLTE is critial Cat-M1 characteristic for wearables in IoT applications. Because of simplified 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 (100mW) from LTE 23 dBm (200mW), allowing the power amplifer (PA) for lower cost device.

Figure 3: Resource performance for LTE IoT devices.

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.

Continuous LTE IoT evolution to 5G

New 5G capabilities to enable massive IoT

Figure 5 addresses potential characteristics of 5G IoT technology [4]. 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.

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.

Figure 5: Scalable resource optimization requirements

Conclusion

In order to link the vast Internet of Things, this article spearheads the expansion of LTE IoT. The new LTE Radio Access Technology (RAT) solutions for grant-free uplink small data exchange transmission, Resource Spread Multiple Access (RSMA), are a step towards 5G cellular technology for mission critical MTC devices. These devices require low latency, low cost/power, high mobility/flexibility, high reliability, high data rates, and high coverage.

With narrowband LTE IoT technologies, we may expect less complexity, longer battery life, better coverage, and the ability to deploy more devices per network. To facilitate more efficient IoT communications, two new UE types were introduced: Cat-M1 for eMTC and Cat-NB1 for NB-IoT scaled down LTE. While Cat-NB1 provides the most cost-effective and power-efficient solution for high throughput and delay tolerance, Cat-M1 will provide the most comprehensive set of Internet of Things capabilities with support for advanced features like full mobility and VoLTE.

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