5G Connectivity Technologies for the IoT: Research and Development Challenges

Zoran Bojkovic(✉) and Dragorad Milovanovic

University of Belgrade, Studentski Trg 1, 11000 Belgrade, Republic of Serbia
z.bojkovic@yahoo.com, dragoam@gmail.com

Abstract. This work seeks to provide the 5G connectivity technologies for the Internet of Things (IoT) research and development together with future directions in the field. The requirements of Massive IoT and Critical IoT use cases and communication technologies are reviewed from the point of view for 5G devices and the corresponding low-power networks. 3GPP cellular networks are addressed as a major connectivity solution for IoT applications. Also, one of the main focus is to support the traffic growth for enabling the IoT. Market drivers and requirements for IoT use cases are included, too. Thus, 5G connectivity has a huge influence in the move of IoT from infrastructure to business models. This article presents a comparative study of cellular IoT support and evolution for the 5G system. Research activities including the area of software-defined sensor networks, network function virtualization, cognitive radio technology, network management, interoperability, and new radio access are also presented.

Keywords: eMTC · Massive IoT · Critical IoT · eMBB · 5G New Radio

1 Introduction

One of the primary goals of fifth generation (5G) wireless networking is integration of heterogeneous access technologies facilitating connectivity of physical or virtual *things* with the Internet. Internet of Things (IoT) enables data communication between heterogeneous devices with modest or no personal intervention [1]. The goal of IoT to move towards more autonomous, scalable, connected and location independent infrastructure leads to urgent research of 5G technologies. IoT network has constrained nature, thus presents more challenging issues for service management [2]. Depending on applications to be deployed there are **Massive** IoT and **Critical** IoT networks. Massive applications have specific requirements of extended coverage area and high scalability, low-energy consumption, and low-cost user equipment [3]. Examples of Critical IoT applications include healthcare system, traffic and industrial control, smart grid. Also, lower latency for acceptable end-user experience as well as higher availability and reliability are desirable [4–6]. 3GPP has proposed technical specifications in enhanced machine type communication **eMTC** based on cellular based low-power wide-area technologies with extended coverage system for narrowband-IoT [7]. The new 5G air interface enables to start bringing IoT services to market [8–12].

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Research activities in the area are centered on the questions how the 5G mobile network responds on the different IoT requirements. It is expected that high throughput and low latency connectivity solutions would be accomplished for the end user including scalability for massive number of diverse devices with efficient energy consumption. Next, the development of 5G New radio (NR) is a challenging task from the research point of view, requiring at the same time activities in standardization and industry [13]. Technical areas include multiple access, channel coding, frame structure, multiple-input multiple-output and device-to-device communications.

In order to study 5G connectivity technologies for the IoT, this work is structured as follows. The first part reviews requirements and characteristics for the IoT use cases. 3GPP LTE and 5G technical specifications of IoT enhanced solutions are presented. Research activities are also outlined.

2 Requirements of Massive IoT to Critical IoT

Practical and theoretical constructions are required before the IoT can present its potential. The practical models behind IoT are established around cloud-assisted IoT where devices capture data that are transmitted to cloud services. Internet of everything (**IoE**) is connecting people, things, processes and data in a networked environment. The area where specific infrastructure is implemented includes smart homes, smart meters, smart grid, smart manufacturing, infrastructure management, etc. [15]. IoE deals with three types of connections. The first one is machine-to-machine in direct communication between devices. Person-to-machine involves an increment control in smart home, parking solutions, patient monitoring, etc. As for person-to-person connections, interpersonal communication are more multimedia oriented (telemedicine, telework, networked learning) in social networks.

In general, IoT ensures users and objects to be in connection *anywhere*, *anytime*, with *anyone* and *anything* using any service. The most important elements in IoT technology are Internet, hardware, middleware and presentation. Internet serves to provide communication including IP protocol and the cloud computing. The communication hardware contains sensors, actuators and transceivers. Middleware is used for contextual data storage and computing. Finally, presentation involves visualization tools in various applications.

IoT applications have varying requirements in diverse domains: smart home, smart healthcare, smart city, intelligent transportation system, data reliability in the industrial IoT [14]. An outline of the differences in requirements is presented in Table 1. Characteristics are application domain, tolerable delay, reporting intervals, and data rate [7].

Table 1. Short overview of characteristic of IoT applications with significant parameters [7].

Application	Domains	Tolerable delay	Update frequency	Data rate
Video surveillance	smart city	sec	real-time	*high*
Structural health	smart city	30 min	10 min	*low*
Patient's monitoring	healthcare	low (sec)	1 report per hour/day	*high*
Emergency response and remote diagnostics	healthcare	low (sec)	ad-hoc communication	*high*
Air quality monitoring	smart home	5 min	30 min	*low*
Monitoring and supervision	industrial	sec or ms	sec	*low*
Closed loop control	industrial	ms	ms	*low*
Supply chain	transportation	low (sec)	1 report per hour/day	*high*

Current IoT wireless technologies available for the corresponding applications are shown in Table 2.

Table 2. Current IoT wireless connectivity technologies.

Technology	Frequency band	Range	Maximum data rate	Channel bandwidth
LoRa	868 MHz, 915 MHz	15 km	50 kbps	125, 250, 500 kHz
Bluetooth	2.4 GHz	50 m	2 Mbps	2 MHz
WiFi	2.4 GHz, 5 GHz	100 m	54 Mbps	22 MHz
ZigBee	868 MHz, 915 MHz, 2.4 GHz	less than 1 km	250 kbps	2 MHz
DASH7	433, 868, 915 MHz	0–5 km	167 kbps	up to 1.75 MHz
Weightless SIG	multiple bands in sub-GHz	5 km	100 kbps	200 Hz to 12.5 kHz
Ingenu-RPMA	2.4 GHz	15 km	20 kbps	1 MHz
SigFox	915 to 928 MHz	20 km +	100 bps	100 Hz

In that way, design engineers can easily find which one of the offered alternatives is best suited for current IoT use cases. Key design requirements support massive devices, extended coverage, network cost, long battery lifetime, device and data reliability, security and privacy. For example, the total cost of devices should be as low as possible to support the massive deployment. It implies the reduction in the device complexity and production cost. Also, the total cost of network connectivity should be kept at a minimum in massive IoT deployment.

The more densely number of devices require simultaneously connectivity handling. Most IoT devices operate for a long time period without any human intervention. Thus, energy efficient design of hardware and software is required. In the case of massive IoT connectivity, extended coverage design is also important. Location privacy and user's identity are issues in protection from the public.

3 5G Enhancement for IoT

The 3GPP idea is that the 5G NR has two paths. In the **Phase 1** (Release-15) which has to be completed in 2018, an urgent subset of the commercial needs will be addressed. This will ensure the first 5G network to be deployed in 2020. As for the **Phase 2** (Release-16), it will be completed for the International Mobile telecommunications IMT-2020 by identifying use cases and requirements. Anyway 5G NR standard requires a lot of interest from the theoretical and practical point of view related to research work, industry and regulatory authorities. To arrive at the deployment of new radio access technology (New RAT), the standardization process takes care of the schedule. The design process of RAT is focused on enhanced mobile broadband (eMBB) in order to support 5G characteristics such as high speed, large capacity, and low latency (Fig. 1).

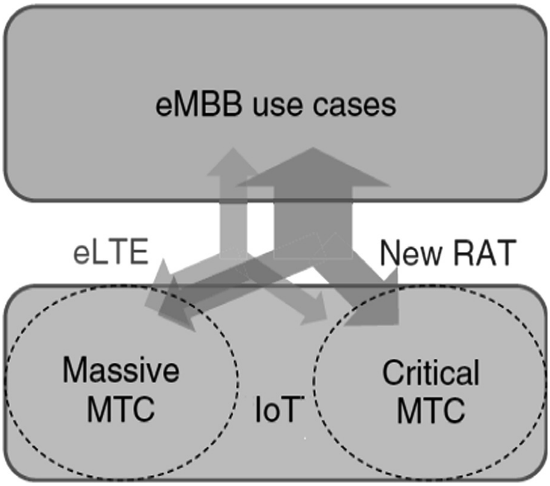

Fig. 1. Use case perspective for 5G phased standardization process.

3.1 3GPP LTE Enhancement

The 3GPP technical specification of Long-Term Evolution (LTE) enables wide coverage area, spectrum allocation and efficient management as well as low cost of development and deployment. Standardization Release-13 introduces three key technical specifications: EC-GSM-IoT [15], eMTC [16], and NB-IoT [17] (Table 3).

With these low-power wide area technologies for the IoT, the requirements are achieved in comparison to the rest of cellular networks ensuring compatibility. The final goal is to achieve extensive coverage area, complexity reduction as well as long battery lifetime.

Table 3. Summary of 3GPP LTE Release-13 IoT specification [8].

	eMTC (LTE Cat M1)	NB-IoT	EC-GSM-IoT
Deployment	in-band LTE	in/guard-band, standalone	in-band GSM
Coverage	155.7 dB	164 dB for standalone, FFS others	164 dB with 33 dBm 154 dB with 23 dBm
Downlink	OFDMA, 15 kHz tone spacing, TurboCode, 16QAM, 1Rx	OFDMA, 15 kHz tone spacing, TBCC, 1Rx	TDMA/FDMA, GMSK and 8PSK (optional), 1Rx
Uplink	SC-FDMA, 15 kHz tone spacing, TurboCode, 16QAM	Single tone, 15/3.75 kHz spacing, TBCC	TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 kHz	200 kHz per ch. 2.4 MHz
Peak rate	DL 1 Mbps	DL 250 kbps	4 time slots: 70 kbps
DL/UL	UL 1 Mbps	UL 250 kbps, 20 kbps	GMSK, 240 kbps 8PSK
Duplexing	FH&HD (type B), FDD&TDD	HD (type B), FDD	FH, HD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, TBD	33 dBm, 23 dBm

EC-GSM-IoT is an enhanced GPRS technology improvement that in combination with Power Saving Mode (PSM) makes EDGE technology ready for the IoT. The objectives are low device cost compared to GPRS/GSM devices, long battery life ($\sim$10 years of operation with 5 Wh), extended coverage, support for massive number of devices ($\sim$50.000 per cell) and improved security.

eMTC enhanced machine type communications technology is a solution for LTE networks in support IoT. One of the reasons for inclusion eMTC is to ensure the up to 20 MHz operation coverage extension for IoT devices in remote regions. The enhancements are developed on the new power saving mode started in Release-12. The objectives are low device cost, long battery life, extended coverage and variable rates (10 kbps to 1 Mbps depending on coverage requirements). eMTCis deployed in-band, coexists with other services and reuses existing base stations with a software update. It supports FDD, TDD and half duplex (HD) modes.

NB-IoT represents a further development of narrowband eMTC optimized for the low-end massive IoT. It is possible for a telco operator to deploy NB-IoT within a small part of the existing network and in available spectrum. The objectives are massive number of devices with long battery life and extended coverage. NB-IoT supports three modes of operation: stand-alone (stand-alone carrier), in-band (resource blocks within a normal LTE carrier), and guard band (the unused resource blocks within a LTE carrier's guard-band).

3.2 5G NR Radio

The 5G radio network is expected to provide massive and critical IoT connection for smart devices. 3GPP technical specification Release-14 specifies further enhancements in NB-IoT connections: reduce the access latency, extend battery life, reduce the signaling overhead as well as operation in unpaired spectrum. 3GPP Release-15 specifies a proposal for New Radio (NR) that was submitted to International Telecommunication Union (ITU) as the official standard. The 5G NR areas are as follows:

- new modulation and coding algorithms including multi-use superposition and shared access, enhanced waveform generation as well as advanced error correcting coding;
- new network and system architecture including network slicing, device-to-device (D2D), cloud radio access network (C-RAN) and ultra-dense network (UDN);
- new spatial-domain processing in massive multiple-input multiple-output (MIMO), adaptive 3D beamforming and multi-antenna diversity;
- new spectrum opportunities including millimeter-wave band and license assisted access (LAA).

Research and development of 5G radio technologies represent to day a part of many projects carried out by operators and vendors. There are two basic technologies for New RAT: subframe structure in down/uplink and multi-antenna used in spatial multiplexing.

Frame Structure as a Radio Parameter. One of the most important parameter is high frequency bands for 5G because it allow broader sub-carrier spacing comparing to that with Long Term Evolution (LTE). For the realization of the time division duplex (TDD) for *switching* between uplink and downlink within the same carrier, the self-contained subframe that suits low latency *retransmission* control is under consideration. It consists of the head of a subframe to the downlink control signal and the tail of the subframe to that of the uplink. In the middle of the subframe, data signal of downlink and uplink is allocated together with other reference signals.

Transmission Technology with Multi-antenna. Multiple-input multiple-output technology is used to achieve increases in capacity for 5G. The reason is simple because MIMO improves frequency efficiency when *spatial multiplexing* is taken into account. As for, the propagation loss in higher frequency bands is compensated with *beamforming* gain. Supporting beam *search* and *tracking* together with diversity control of spatial multiplexing is one of the most important issues in radio interface design. The 5G field experiments in the 15 GHz band, achieved aggregated throughput of more that 20 Gbps when two users allocated four beams at the same time [18].

4 Research and Development Activities

Many efforts have been made in 5G technologies and future IoT, in the past years. However, there are many challenges in designing IoT based systems for 5G integration. Massive IoT systems based on improved system coverage and reduced terminal cost. Critical IoT has small data packets and delay intolerant communication. 5G system is characterized with high degree of heterogeneity using services, device classes, deployment types, environments, and mobility levels. This is our motivation for surveying research and development activities in the area. It should be pointed out that flexible network architecture based on software-defined networking and network function virtualization, cognitive radio, scalability, network management and mobility, are key enablers.

Software Defined Networking. SDN technology separates the data and control planes, *centralize* network control and allow *programmability* of the network by external applications [19]. In that way, reconfiguration is provided as dynamic, flexible, and automatic method. At the same time, network design and management are simplified. However, it is not convenient to manage the volume of devices and the amount of data in massive IoT. The most important issues are to avoid collapse of network and guarantee quality of services (QoS). Applying SDN model into existing wireless sensor networks (WSN) is arrived at the software-defined wireless sensor network, while providing programmability for the 5G network. This simplify the network infrastructure and manage the system, while enabling various IoT use cases in the future.

Network Function Virtualization. The main idea behind NFV is to virtualize a set of network functions implemented into software packages which are now possible to configure for some services provided by network. Software Virtual machines (VM) are installed on various operating systems on the same hardware server. NFV offers scalability and flexibility in operations as well as managing mobile devices. NFV is highly complementary to SDN. However, it is possible that both solutions can be combined to achieve optimal performance for management of critical and massive IoT applications [20].

Cognitive Radio Technology. CR technology utilizes the limited licensed spectrum resources in an opportunistic mode in order to support new service requirements in 5G mobile networks for IoT applications. The CR operates in the best available channel using dynamic spectrum access techniques. This kind of technology provides the detection of users present in the spectrum (*sensing*). Next, it identifies available free spectrum, based on spectrum management, spectrum sharing, and spectrum mobility [21].

IoT Scalability. Introducing new heterogeneous devices, applications and functions are based on scalability. For scale efficiency, optimization of massive deployment of IoT has to be provided [22]. In that way, network capacity becomes scalable to accommodate as much connected devices as possible.

Network Management Solutions. Efficient network management solutions provide monitoring, remote control, and maintenance concerning network equipment, services and devices. The criterion is operation in minimal time frame with low energy consumption. IoT networks have constrained nature that present more challenging issues in terms of data acquisition and aggregation, service provisioning and system performance. The management functions in the IoT carry out remote tasks across heterogeneous interconnected networks. Such a system enables diagnostic of IoT devices and real-time control. In that way, the cost of operations would be managed in terms of resource-constrained networks.

Interoperability and Heterogeneous Nature. A major challenge in heterogeneous IoT networks is interoperability deployment across devices among all network technologies, provider, and vendors [22]. It should be pointed out that the heterogeneousness of the IoT makes interoperability between different devices more difficult and complex. For massive IoT applications, interoperability and standardization process of the various communications technologies are significant issues.

Network Mobility and Coverage. As most of the massive and critical IoT users are mobile, network coverage, remain open research area for effective deployment scenarios. As a result of user mobility, connected devices undergo service interruption. This is the reason why an efficient mobility management mechanism is needed to control the connected devices in IoT networks.

Network Congestion in the Evolution of IoT. Ahuge traffic generated from IoT devices causes network congestion and degrades the performance and quality of service. Different protocols are applied to handle congestion control. The existing Transmission Control Protocol (TCP) is not convenient for the IoT applications. The reason is that the traffic of the IoT network is different comparing to the existing conventional networks. Hence, the new protocol CoAP (Constrained Application Protocol) is developed. Research is going to continue on congestion control mechanism especially in the area of efficient network handling and bit error rate considering the packet loss as well as delay in the IoT environment. The congestion control provides a safe network operation and efficient utilization of network resource.

New Security and Privacy Issues. The massive number of connected devices causes new security issues. IoT threat analysis and risk assessment is in the focus of research. Device identity and new authentication schemes are basic components. Key security requirements are authentication, authorization, confidentiality, data security, and non-repudiation.

5 Conclusion

The 5G networks are required to additional satisfaction for massive machine type connectivity in contrast to cellular technologies that were introduced only for broadband communication. This fact makes 5G connectivity technologies of particular interest for IoT deployments in the near future. The availability of technology for reliable, scalable and cost-efficient connectivity is of a huge significance. Thus in this paper, we review current and future research and development challenges. The work is driven by guidelines of International Telecommunication Union (ITU) and 3rd generation Partnership Project (3GPP). ITU has identified three service families: massive machine-type communications (mMTC), and ultra-reliable and low-latency communication (uRLLC) and enhanced mobile broadband (eMBB).

This article presents a comparative study of cellular IoT support and evolution for the 5G system. Service mMTC has been already developed as part of 3GPP Release 13 and Release 14, which introduced eMTC, and NB-IoT as low power wide area (LPWA) technology. Mission critical applications that are especially latency-sensitive require wide coverage, which is highly unlikely in early 5G deployments, so this development will come later. On June 2018, 3GPP formally completed the Release 15 of 5G NR Phase 1 and recently defined Phase 2. Study items Release 16 will focus on identifying solutions for the 5G core network that will enable it to provide at least the same basic set of features that are required to make massive IoT possible with diversified connectivity, improved operation and resource-usage efficiency.

IoT connections are inherently resource-constrained network. Thus, the future evolution of the IoT is promising and challenging at the same time. The focus is on finding the way between challenges and technical proposals from the practical point of view. In such away, we arrive at the requirements for the research work in the field of overall system design, software implementation, and service applications including 5G connectivity standardization in the field. However, effective management and control of the IoT networks are still open research challenges.

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