Challenges and Features of IoT Communications in 5G Networks

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***Abstract*— The Internet of Things (IoT) will consume every part of our daily life through connecting everyone and everything, 24 hours a day, 7 days a week. Networks and ISP's will need to continually assess and upgrade their infrastructure to incorporate new architecture and technology, to support and improve services and device-to-device (D2D) capabilities. IoT applications require several requirements to perform well, such as high speed, low latency and minimal downtime while maintaining a high-quality service. At the same time, working on the next generation of cellular systems (5G) with its distinctive features makes it an enhanced solution for IoT communication requirements to maintain higher efficiency and effectiveness. This paper examines the definition of the IoT and its applications and requirements. Furthermore, new 5G technologies are investigated to support the IoT such as massive MIMO, cross-layer design, and relying on non-orthogonal multiple access and waveforms. The features and challenges of each technology are also discussed.**

Keywords: IoT; 5G; MIMO; D2D; Cross-layering.

I. INTRODUCTION

With the rapid and enormous growth in the number of people now using mobile phones and other devices, along with requirements to improve the quality of life, the vast evolution of the internet, and the connectivity of objects and devices have evolved as the IoT. This has enabled the collection and exchange of information and data globally between people, communities and more importantly, businesses. It is expected that by the year 2020, 50 billion IoT devices will be connected. The IoT has enabled new business to emerge for application developers in numerous areas, such as smart homes which connect domestic devices seamlessly to the internet and include household devices such as a fridge, lights, temperature, and home security. Also, significant advancements have been made in smart automobiles by improving emergency and safety aspects. In the health industry, the IoT has helped to monitor health care for infants and older adults, in addition to other industries such as manufacturing, emergency services, aviation, maritime, retail, transportation which require a vast number of devices to connect.

Researchers have described the IoT in many ways. The European Research Cluster (IERC) [1], described the IoT as "A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.

This definition has led to on-going work in mobile wireless technology to provide users with the ability to connect anywhere and anytime using high-speed protocols. Mobile wireless technology has evolved in several stages known as 'generations'. The main generations evolved from 1G to 4G, and more recently, work is progressing on 5G. However, 5G is not operational at this stage for users. With each generation, issues are resolved, and new features are added. Fourth generation (4G) started in 2011 and is continued to this very day. 4G technologies provide high-quality audio and video streaming over end to end IP with high capacity, high security, and high bandwidth speeds which can reach up to between 100 Mbps to 1 Gbps. Furthermore, 4G also introduced Long Term Evolution (LTE) technology, which is a standard that supports packet switching [2] and [3].

Fifth generation (5G) is the next generation of cellular networks and is expected to be operational in 2020. 5G will be an extension of 4G but with higher data rates, higher quality, enhanced wireless capability and enhanced support for the IoT. It is expected that 5G will support multimedia more attractively and efficiently, and all mobile applications and services will be integrated as part of the cloud computing environment. 5G is designed for the World Wide Wireless Web (WWWW) and will be more secure, cost effective, have greater capacitance, and capable of much higher speeds. Moreover, it will solve many of the current challenges and issues associated with using 4G. These features will certainly be expected to make 5G the optimal solution and network for IoT applications [4].

In this paper, we discuss IoT applications and requirements in Section 2, while in Section 3 we explain what many researchers are proposing for 5G to achieve these requirements.

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II. IoT Applications and Requirements

The future of the IoT will be to gather and to have boundless interconnectivity to mobile devices and other Internet devices or 'things' and technologies with everything, starting from domestic to business and industry. Researchers in [5] divided IoT applications into six main categories which include: smart cities, smart business, smart homes, healthcare, security, and surveillance. In smart homes, IoT technologies may help to reduce electricity and water consumption through regulated meter reading, while a smart fridge may detect missing food and beverages. In smart cities, IoT technologies may be used for car parking, traffic control systems, street lights, and detection of abnormal and emergency situations. In health-care, IoT technologies may improve the monitoring and tracking of patient temperature, pressure, medication and enhance their quality of life by taking rapid actions when and as needed. In the business field, using RFID in logistics to track goods is good an example currently used today. Fig. 1, shows the main applications of the IoT [6][17][18].

For the above mentioned 5G applications associated with the IoT, these produce a significant amount of communications, and networks, therefore, require specific requirements to ensure they operate efficiently, such as:

- High scalability
- Energy saving
- Quality of service (QoS)
- Efficient network and spectrum
- High capacity
- Reduced latency
- Security and privacy
- Built-in redundancy
- Heterogeneity

III. 5G as IoT Requirements Solution

The fifth generation of cellular networks (5G); planned to be introduced in 2020, is a convenient fit and highly applicable to the requirements of the IoT. 5G will support the IoT needs given the high density of devices anticipated by this time and is expected to support direct communication between devices. The main challenges will be satisfying higher data rates in all instances including congested areas and mobility, plus reduce latency and save energy. Based on these requirements researchers are contemplating many trends for 5G to appear as follows:

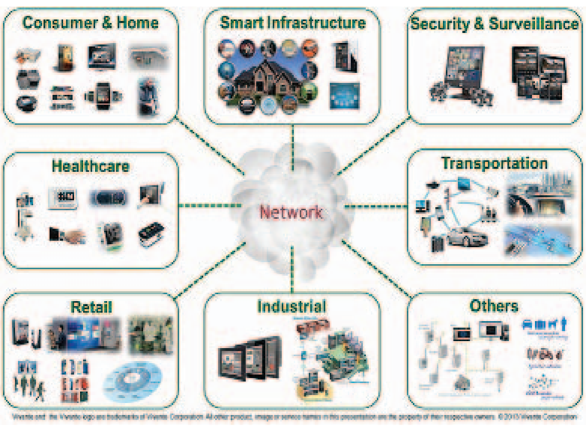

Fig. 1. Possible applications of the IoT [6]

A. *Massive MIMO (Multiple Input Multiple Output) Systems*

Massive MIMO [7] - or very large MIMO - is an extension and scale for Multiple Input Multiple Output (MIMO) systems, where a considerable number of antennas are used to present services for a substantial number of terminals. This system has many useful features such as increased capacity. Research has proven that using massive MIMO systems will increase the capacity by 10-fold or more. This is the result of using spatial multiplexing, whereby each antenna beam is directed and concentrated in a specific direction. Moreover, this is also reflected in the antennas' power consumption to reach 100-fold in energy savings, potentially more than conventional MIMO because using a large number of antennas, terminals receive a very high data rate. Massive MIMO systems reduce the extra overheads caused by the controlling information in the physical and mac layers since each terminal can be provided with full bandwidth and minimise latency, as it avoids fading.

MIMO systems are not expensive. Instead of using a few costly amplifiers, massive MIMO systems use a sizeable number of low-cost amplifiers. The system is characterised as being quite robust to potential interference and jamming since the failure of one or more antennas does not cause complete system failure. Massive MIMO systems also have their own challenges and limitations that researchers are working to resolve, such as their complexity, and fast and distributed signal processing. Since the amount of exchanged data is vast and needs to be processed in real time, the internal power consumption needs to be reduced to achieve higher energy efficiency.

B. *Non-Orthogonal Waveforms*

Orthogonal frequency division multiplexing (OFDM) is the physical layer waveform technology adopted in recent wireless communication standards. OFDM has many key features such as its robustness, ease of implementation and high spectrum efficiency. Similarly, OFDM has also disadvantages that conflict with 5G technologies in achieving IoT requirements for many reasons. These include high peak to average power ratio (PAPR), signalling overhead in time and energy caused by the synchronisation for maintaining orthogonality. Furthermore, it has high out of band emission (OBE), in addition to the overhead created using a cyclic prefix which needs space within the data streams. To overcome these limitations, new non-orthogonal waveforms are being introduced in 5G [8]. These waveforms are more efficient than OFDM such as filtered OFDM (FOFDM), windowed OFDM (WOFDM), filter bank multicarrier (FBMC), generalised frequency division multiplexing (GFDM), and universal filtered multicarrier (UFMC). Table 1 shows the differences between these waveforms schemes.

TABLE I. Different Waveforms Schemes

	Different Waveforms Schemes					
	OFDM	*FOFDM*	*WOFDM*	*FBMC*	*GFDM*	*UFMC*
PAPR	High	High	High	High	Mild	High
Spectral Efficiency	Low	Low	Low	High	High	High
OBE	High	Low	Low	Low	Low	Low
Complex-ity	Low	Mild	Mild	High	High	High

C. *Non-Orthogonal Multiple Access*

Sharing channels between users can be undertaken using different techniques by either time, frequency, or code domain to prevent interference such as FDMA (frequency division multiple access), TDMA (time division multiple access), CDMA (code division multiple access) and OFDMA (orthogonal frequency division multiple access). But all are classified as orthogonal multiple access (OMA) techniques, so they do not satisfy 5G requirements from the spectrum efficiency perspective.

Authors in [9] proposed a new channel sharing technique based on non-orthogonal multiple access (NOMA). This technique has many advantages over OMA; such as improving the spectral efficiency, extensive connectivity, low latency and low cost. Many schemes are proposed based on NOMA and grouping them into two distinct categories; power domain multiplexing and code domain multiplexing.

In power domain multiplexing, users allocate based on their channel power conditions, while in the code domain multiplexing different users are assigned to different codes, and then multiplexed over the same time or the same frequency resources. Most common NOMA schemes are SCMA (sparse code multiple access), RSMA (Receiver sense multiple access), PDMA (pattern division multiple access), MUSA (multi-user shared access), BDMA (beam division multiple access), IDMA (interleaved division multiple access), MUST (multi-user superposition transmission), SoDeMA (software defined multiple access) and BDM (bit division multiplexing).

D. *Device-to-Device (D2D) Communications*

Device to device (D2D) communication [10] is the most studied communications protocol undertaken by researchers as a 5G trend. It has two distinct approaches. First, the communication between terminals and the base station using other terminals and secondly, communications between the terminals directly without the participation of the base station. This trend does not support the current cellular network, as illustrated in Fig. 2 [11].

Although some of the current technologies such as Bluetooth or Wi-Fi provide some D2D functionality, many features of D2D outperform them. For example, D2D has higher data rates, a higher transmission range, higher transmission power, and will work on unlicensed spectrums (out-band) and licensed spectrums (in-band), guaranteeing the Quality of Service (QoS), dissimilar to Bluetooth and Wi-Fi.

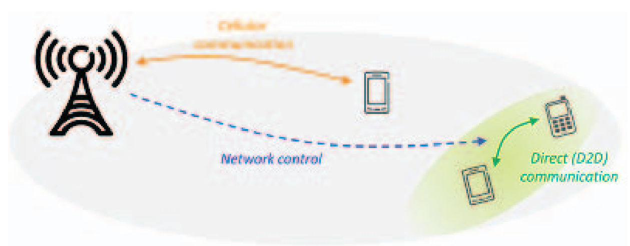

Fig. 2. D2D Communications [11]

Device to device communication has many advantages, such increasing system capacity, increasing spectral efficiency, increasing throughput, reducing power consumption, and reducing latency. At the same time, D2D communication has many challenges that researchers continue work to resolve such as security, interference management, mobility, and resource allocation.

E. *Millimetre Wave Communications*

The existing communication systems operate in bands below 6 GHz due to the propagation conditions within these bands. But to increase the data rates in 5G, it requires using higher frequencies in the millimetre wave band; since increasing frequencies increase channel bandwidth.

It is expected to use higher frequencies to reach l0+ GHz with millimetre wave deployment [12], but increasing the frequencies will cause signal loss and the signals becoming extremely weak. This is known as propagation loss which results in decreasing the millimetre wave communication range and is one of the millimetre wave communication challenges. This is in addition to its sensitivity to obstacles such as people and furniture plus it is also affected by weather conditions (i.e. rain, thunder and electrical storms).

F. *Small Cells*

Another 5G technology able to support the IoT is by using small cells [13]. Reducing the size of cells thereby increases spectral efficiency and conserves energy since transmission power is reduced. Unlike large cell towers used in cellular networks to serve a wide area, using small cells have many benefits such as lower costs and coverage improvement in indoor areas or in area edges by deploying small cells rather than traditional macro cells thereby giving greater connectivity. There are distinct types of small cells based on their size, which includes femtocells, picocells, and microcells; each provide for different coverages, which perform heterogeneous networks (HetNets) as illustrated in Fig. 3 [14].

G. *Cross-Layering*

Traditional network protocol architecture uses a standard layering model such as the Open System Interconnection (OSI) model, where each layer is responsible for some functionalities, and the details of each layer are hidden from the remaining layers, which provide security between the layers in addition to the organisation. But at the same time, this model limits the

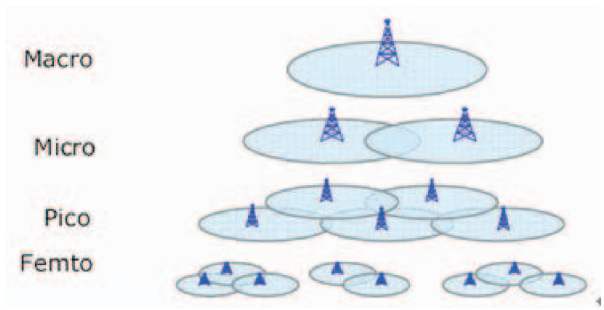

Fig. 3. Small Cells Types [14]

communication between the layers since each layer can only communicate with its predecessor layer and successor layer, especially in wireless sensor networks. As a solution to the limited communications, recently, an across layering design has been proposed enabling interactions and coordination between the layers which maintain the original functionality of each layer.

With the evolution of the IoT, it is anticipated that one billion devices will be connected. These devices are heterogeneous incorporating unique features, either from a hardware/architecture perspective such as computation, memory, and power or from a communication requirements perspective. And from the QoS requirements perspective: delay, reliability, and energy consumption. This heterogeneity leads to the cross-layering design to be adaptive in the next generation for the IoT.

There are many cross-layering protocol designs proposed. In [15] each time the device transmits data via the network, it will follow a procedure which initiates connection, authentication, which then sends or receives data. If it becomes inactive for a period or enters into an idle state; this then creates a network overhead. Since the network contains a large number of devices, this overhead is repeated each time by sending only a small amount of data. This increases the latency in addition to the control overhead. So, a cross-layering low latency and low overhead protocol are proposed between the physical and mac layers to support IoT traffic in 5G. This uses underlying CDMA for small packet transmissions by minimising the waiting time needed to access the channel in the mac layer. While in the physical layer by choosing the optimal waveform this is based on the traffic generation, packet size, and signal to noise ratio. And since the underlying CDMA does not require handshaking this enhancement will reduce the latency.

In [16], they propose a cross-layer communication protocol for the IoT between the physical layer, mac layer, and the network layer to achieve the required optimisation of parameters such as QoS, reduce delay to increase throughput, and reduce energy consumption to increase network lifetime. Since each application has different requirements, two types of cross-layer optimisation are presented which are single objective and multi-objectives. Some applications require optimising one of the previously mentioned parameters whereas other applications need two or a combination of them. After the communication between the access point (AP) and 'things' in the network, an optimisation algorithm is performed locally and performs mathematical functions to solve the required optimisation in the cross-layer. A comparison is made between their cross-layer design and existing layered designs like BPSK and 16QAM using simulation. They proved that their design had better performance than other layered designs regarding end-to-end delay and energy consumption either regarding the number of devices or items connected to the network or concerning distance as illustrated [16][17][19].

IV. Conclusion

The IoT will dominate the delivery of future services; given that it will connect a vast number of devices utilising different applications ranging from smart homes to smart cities and industries which will mean an enormous amount of communications and burst traffic. However, for these services and applications to be highly effective, it will require large capacity, high data rates, QoS, low latency, redundancy, and energy savings. In this paper, these requirements are combined with next-generation 5G and demonstrate how the features of 5G and technologies will become the solution to cater for IoT requirements such as massive MIMO systems, non-orthogonal waveforms and non-orthogonal multiple access, D2D communications, millimetre wave communications, small cells, and cross-layer design.

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