The Role of 5G Wireless Networks in the Internet-of-Things (IoT)

Mashael M. Alsulami
Department of Computer Science
King Abdul-Aziz University
Jeddah, KSA
malsulami0485@stu.kau.edu.sa

Nadine Akkari
Department of Computer Science
King Abdul-Aziz University
Jeddah, KSA
nakkari@kau.edu.sa

Abstract__ The number of mobile hosts that will be used in 2020 will be exceeding 50 billion hosts [5]. This increase in the amount of mobile devices is intersected with the evolution of the Internet of things (IoT) technology. The demand to create intelligent environments such as smart cities and smart homes is increased. The evolution in this area results on the concept of IoT where devices of everyday are connected [5]. These interactions between a large numbers of heterogeneous devices increase a substantial demand on providing high connectivity, extremely high data rates, low latency, designing special applications to serve the IoT and many other communication requirements [8]. Thus, the promising 5G cellular networks can be considered as the key enabler for IoT technology. Moreover, the 5G wireless networks can be used to achieve the high communication requirements of the IoT. This survey is conducted to investigate the role of 5G cellular networks in the evolution of IoT. Also, this survey aims to compare existing wireless networks to emphasize the role of 5G as enabler driver for IoT. This survey highlights both requirements and enabling technologies of the IoT. Furthermore, it discusses some of the challenges that face the evolution of IoT.

Keywords – Internet of Things, IoT, 5G, cellular networks, D2D communication, mm wave technology, relay, wireless software defined network, and network function virtualization.

I. INTRODUCTION

A. Motivation of the paper

Due to the massive data exchanged among large numbers of connected devices to form the IoT, the need to provide extremely increased capacity, high data rate and high connectivity is increased. Thus, 5G wireless networks considered as a key driver for IoT. Satisfying the increased requirements of IoT drives several types of network to compete to provide the connectivity need by the IoT applications. Thus, this survey aims to highlight how the 5G can power the IoT enabling technologies by providing brief comparison over the existing wireless networks that are considered as options for IoT to provide high connectivity such as cellular networks, low-power Wide Area Networks (LPWAN), and Short-Range networks.

B. Background Overview

The idea of the Internet of Things (IoT) is to connect the everyday physical objects such as microwave, doors, lightings and so on. The technical concept of the IoT is to enables these different physical objects to sense information using sensors and sends these information to a server. This server analyzes this information to gain some knowledge and translates them to certain behaviors or actions. These actions format intelligent environments such as smart homes. The evolution of the IoT enables billion of connected devices to connect to the Internet, which impact on the way people live. As stated previously, the number of connected devices is expected to exceed 50 billion devices by 2020s. [4]

Furthermore, IoT can be roughly divided into two categories as suggested by [8] into: consumer IoT (cIoT) and industrial IoT (iIoT). The idea of cIoT is to improve the way people live by saving their time and money. Examples of the connected objects in the cIoT include microwave, lightings, mobile and any objects that belong to a certain user. The cIoT indicates the machine-to-user communications. [8]

On the other hands, the idea of iIoT is to integrate various technologies to improve business services in different sectors. It implicitly indicates the behavior of machine-to-machine communications. Each of cIoT and iIoT as service domains has its own communication requirements that are measured differently in both such as reliability, Quality of service (QoS), and privacy. Nevertheless, they share some common communication requirements such as scalability. The features of cIoT include low power consumption, ease of installation and integration. [8]

Wireless networks have improved their features as attempts to keep up with the growth of technologies. Various wireless cellular networks generations have been designed until the advent of 5G cellular networks. The development of the 5G promises to provide extremely high data rates, significantly low latency and high integrity. Also, the nature of the 5G cellular network supports the heterogeneity of connected device in the IoT. In fact, the 5G could play a potential role as a foundation to facilitate the connectivity of the large amount of connected devices to the Internet. [8]

C. Organization of the paper

The remaining of this survey is organized as follows. Section 2 is a literature review of the ongoing works regarding IoT and 5G networks. It discusses the challenges, components, characteristics and technologies of IoT. Also, an overview of 5G wireless networks is given including challenges and enabling technologies. Section 3 is a conducted comparative analysis of the available IoT connectivity options. In section 4, a discussion on the enabling technologies of IoT via 5G is given. Finally, section 5 is a conclusion of the survey.

II. LITRATURE REVIEW

Internet of things (IoT) can be defined according to [10] as a dynamic global network infrastructure with ability of self-configuration. It has a concept of connecting various types of physical or virtual objects. [11]

In this section, the key characteristics of IoT to be supported by the 5G systems are discussed. Also, a brief discussion is given regarding the challenges or open issues in the IoT and the main technologies that are used by IoT systems.

A. Challenges of IoT

1) Energy Efficiency

One of the major challenges that characterizing the IoT is to provide efficient energy consumption. The idea is how to achieve high-energy efficiency among IoT communications. In fact, most of the energy challenges in the IoT are related to the connected devices. These connected devices are usually depending on batteries or on harvesting energy systems. Also, sometimes especially on applications that required remote communication, the energy consumption can be problematic in case of requiring recharging or replacement of energy systems. IoT achieves the energy efficiency or consumption by the mean of direct communication between connected devices, which allows sort of local connectivity among devices that is usually provided by wireless technologies. [7]

2) Scalability

Since sensors are cheap and available, deploying many of them to connect objects on different places is easy. This increase in the number of connected devices raise many challenges regarding provide coverage to all these connected devices in reliable manner. Furthermore, the overhead of signaling and connection setup must be reduced. Due to the increase number of connected devices, the handover between cells is increased. These issues related to scalability feature of IoT can be handled by technologies such as SDN. [4]

3) Intelligent processing and storage

As stated previously the concept of the IoT is to have number of connected devices via several sensors, which are responsible of sending information, after sensing them from these devices, to a remote server. This remote server is responsible of translate and process these information to knowledge that represented as certain actions or behaviors. Usually these remote servers are hosted in cloud providers. Since collecting and processing all information from different devices are complex processes, the IoT cloud providers must have certain capabilities to handle these complicated tasks. [4]

Moreover, cloud providers in this context are required to provide on demand computational capability. There are two ways or approaches to handle the complexity of IoT cloud providers and computational load that need to be performed in the server providers' side. First, several cloud providers can be used for the same IoT network. Second, to reduce the delay that could occur because of the complexity of the processing, the computing service could be moved to the edge of the network.

4) Security

The security challenge is illustrated in the idea of having diversity of connected devices with different hardware and platforms. The communication among these devices can be hacked since providing a security mechanism that is compatible with all these different devices is a complex task. In fact, threats could come from two aspects: among communication of devices or in the communication between these devices and remote servers. [6]

5) Interoperability

One of the most obvious challenges that face the IoT is interoperability. Due to the diverse range of devices that need to be connected, the need to coordinate these different devices is increased. These devices use different hardware, run over different platforms, and manufactured by different vendors. There are many IoT devices in the market today but each of them uses its own standards and interfaces in order to communicate with other devices or remote servers. This could cause a conflict when different devices are used in the same domain. The incompatibility among devices, sensors, and even interfaces of remote servers is a main reason that causes the interoperability challenge in IoT. [4]

B. Characteristics of IoT

IoT is not a single technology itself. It is a concept of many integrated technologies. It has several characteristics that shape the purposes and functionalities of IoT. These characteristics or features are elaborated as follows:

1. *Interconnectivity:* In the IoT, everything can be connected including any virtual or physical objects. The interconnectivity feature is illustrated by the connection among these different objects and the communication infrastructure.

2. *Things-related services:* The concept of this characteristic is to provide services that can be applied to several connected things based on constraints of these things. For instance, privacy protection as a service can be applied to same things with their constraints.

3. *Heterogeneity:* The heterogeneity feature of the IoT comes from the idea of connect different devices that are built using different hardware and run over different platforms.

4. *Dynamic changes:* IoT can handle dynamic changes that are required by involved different objects. Several dynamic changes could occur in term of state changes such as idle, connected and disconnected, or in term of context changes such as changing locations. [10]

C. IoT Technologies

Many studies have been focused on the technologies that are used to allow the communications that are required by the IoT. Several techniques are used to provide a communication between devices in the IoT. In order to connect devices, each device needs to be identified by a unique identifier. Basically these technologies are used to implement the real idea of the IoT and make the interactions between different devices possible. Below some of these technologies and approaches are listed:

1. *Radio Frequency Identifications (RFID):*

RFID is a wireless system that consists of two parts: tags and readers. Tags are attached to objects or devices that aimed to be connected and they contain stored information that is usually read by readers. These tags use radio waves with different frequencies from different antennas to form a communication among devices. Also, these tags can be passive where they powered by reader or they can be active where they powered by batteries. [9]

2. *Near Field Communications (NFC):*

NFC is based on the same mechanism of RFID in the mean of having tags and readers. However, the idea is to integrate this concept into smart phones. NFC illustrates the concept of short-range low power wireless networks where all devices are connected in the same domain of other mobile phones. It allows sending small amount of data under a specific domain between two devices. The typical range of NFC is 20m. NFC can be considered as one of the most significant radio technologies that allow wireless communications to enable IoT. In fact, this technology will enable using smart phones as other objects connected to it. [9]

3. *Machine-to-Machine Communications (M2M):*

The concept of M2M is too similar to the concept of IoT. In IoT, diversity of connected objects is the key driver while in M2M communications; the communication is among different machines such as computers, processors, sensors and smart phones. According to [9], M2M is structured into five parts: M2M Device, M2M Gateways, M2M communication network, M2M Area network, and M2M applications. All technologies that are used to enable M2M communications can be used to enable the IoT. [9]

4. Vehicle-to-Vehicle Communications (V2V):

This kind of communication requires a complex network infrastructure since it involves communication via vehicles. Vehicles usually move from one place to another, which cause a non-fixed topology. To describe the V2V communication, two types of interactions are involved: interaction between vehicle to vehicle and the interaction between vehicle and road infrastructure. [10]

D. Overview of 5G

In order to enhance the capabilities of LTE, a fifth generation of cellular network (5G) is under investigations and discussions. [3] Also, the 5G has certain requirements and challenges that need to be satisfied and solved using variety of technologies. The challenges that faced the 5G are regarding:

IV Increase capacity,
V High data rate,
VI Low latency,
VII Huge number of connections, and
VIII Low cost and quality of service (QoS). [4]

To achieve these requirements, or on other words, to solve these challenges, certain technologies have been involved as enabling technologies for the 5G. These technologies are: massive MIMO, D2D, Network Function Virtualization, Wireless SDN, IoT, ultra-densification, Radio Access technologies, Green communication, and big data and mobile cloud computing.

The 5G is expected to achieve certain requirements to be able to serve the various types of devices and applications. Each of these requirements is discussed below:

1) High data rate

With the explosion on using networks in applications that required fast communications, the need for high data rate is rapidly increased. Over years, reaching high data rate in the wireless networks is one of the most important factors to evaluate the performance of such networks. Nevertheless, LTE has provided a data rate that reached up to 15 Mbps, however; new applications such as ultra-HD video streaming need higher data rates (up to 25 Mbps) than the ones that is currently available. [4]

Data rate has two main metrics that characterized the network: cell-edge data rate and area capacity. Cell-edge data rate indicates the rate of the data in the edge of the cell where the signal of connection is in the weakest point. The cell-edge data rate should be improved to achieve high data rate for the overall system. Furthermore, when a user is close to the cell-edge in a network, the interference will be high which led to weak signal. On the other hands, when a user is close from the cell center, the interference will be low which led to strong signal. The goal is improve the data rate in the cell edge to improve the user experience. [4] One of the most effective ways to do that is via the use of small cells. [3] The use of small cells improves the coverage of cellular networks as well as the capacity. The second metric that impacts that data rate is the area capacity. Area capacity indicates the total data rate that a network can serve per unit area. In 5G, data rate are expected to reach 10 Gbps with 100 Mbps for cell-edge data rate. [4]

The enabling solutions/technologies that have been used to gain high data rate are as follows:

1. MIMO
2. Relays
3. Small cells
4. Millimeter wave communication
5. Wireless SDN

2) Reduced latency

Latency is the time required to transfer data from source to destination via a network. The importance of reducing latency of a network is derived from the application that highly affected by delay such as gaming. In fact, the RTT latency of LTE is about 15 milliseconds and expected to be reduced to 1 ms to satisfy the requirements of the 5G. The reason of such a need to reduced latency within 5G is the increasing use real-time interactions in many applications, which required no delay to enhance the user experience. Also, the idea of the Internet of things and machine type communication where everything is connected and delay is not acceptable. [4] The enabling technologies that have been used to reduce latency are:

1. D2D communication
2. All optical networks
3. Big data and mobile cloud computing

3) Low energy

One of the enabling technologies that are supported by 5G is IoT where devices are connected using sensors without need to always connect to a base station. This scenario indicates that these devices will only switched on when they needed. This means that 5G required reducing energy and supports no synchronizations. [4]

4) High scalability

With designing LTE and then 5G wireless networks, the increase number of mobile phone devices should be taken into consideration. The number of devices connected to a cellular network is expected to grow as indicated in [4] to 50 billion by 2020. Serving and handling that number of devices need an efficient scalable network. Providing high scalability for cellular networks require enough frequency spectrum resources and efficient media control. [4]

III. COMPERISON OF IOT CONNECTIVITY OPTIONS

The main goal of this section is to compare current wireless networks that are used to enable IoT and provide the promising connectivity to IoT devices. After the comparison, the role of 5G networks can be drawn and discussed on how 5G can power the connectivity of IoT.

The three connectivity landscapes that are being compared are: cellular networks, low-power wide area networks (LPWAN), and short-range networks. In fact, two perspectives of the comparison are given. First, a comparison among connectivity options in term of their characteristics. Second comparison between the main protocols of these connectivity options is given in term of IoT requirements.

Table 1 compares the current alternatives connectivity tracks that are used by several IoT applications and these connectivity options are: cellular networks, LPWAN, and short-range networks.

Basically, many of IoT devices will be served by radio technologies as discussed in section 2.1.3. [5] Usually the connectivity required by these applications are designed as applications for indoor environments such as smart homes.

Table 1 compares these connectivity options based on their characteristics and the requirements of IoT. The criteria that are used in the comparison are: data rate, bandwidth, coverage, range, latency, scalability and power use. More precisely, two protocols for each type of these systems are included in the comparison.

Cellular networks are mainly designed to provide coverage for long distances or wide areas with high speed and low power in LTE and 4G. However, the cost of using cellular networks is expensive in term of providing reliability because of the handover process. Some protocols that are used in cellular networks are: 2G, 3G, LTE, and future 5G [5].

LPWAN is a new emerging technology that aims to serve wide area on low-end IoT applications [8]. As shown in table 1, LPWAN provides low power consumption, long range and low cost. It is mainly designed to provide machine type communications (MTC). Some protocols examples for this type of wireless system are SigFox and LoRa [5].

Short-range network is another emerging technology that mainly served indoor environments and cIoT devices since the coverage area is short and considered as home or personal area. In contrast, it provides low power consumption and low cost. In fact, this kind of wireless networks is widely used by many current IoT applications since these applications still operate over short-range area coverage. Some protocols examples are ZigBee and Z-Wave. [8]

TABLE I. COMPARISON OF IOT CONNECTIVITY OPTIONS

Wireless Systems / IoT Requirements	Cellular Networks		LPWAN		Short-Range Networks	
	3G	4G/ LTE	SigFox	LoRa	ZigBee	Bluetooth
Data Rate	High 3.1 Mbps	High 100 Mbps	Low < 100 bps	Low < 10 Kbps	Low < 250 Kbps	Low < 1 Mbps
Coverage	Large	Large	Large	Large	Small	Small
Range	Long	Long	Long	Long	Short 10 – 100 m	Short 10 m
Bandwidth	200 KHz- 900 MHz	200 KHz- 900 MHz	100 Hz- 900 MHz	500 KHz - 900 MHz	< 2.4 GHz	< 2.4 GHz
Latency	Low	Low	High	High	Low About 30 ms	High About 10 sec
Scalability	Yes	Yes	No	No	No	No
Power Use`	High	Low > 10 years	Low > 10 years	Low > 10 years	Low For years	High For days
Cost	Expensive	Expensive	Cheap	Cheap	Cheap	Cheap

Based on table 1, SRLD can include protocols such as ZigBee, Bluetooth and even more Wi-Fi. For SRHD, this group is needed for cIoT applications where the distance between connected devices is short but a high data rate is needed. LRLD can include protocols such as SigFox and LoRa. It serves personal area networks. Finally, providing high data rate in long range is classified as LRHD and includes cellular networks protocols such as 3G, 4G, and LTE.

A. Classification of IoT connectivity protocols

In this section, a classification of current IoT connectivity protocols is presented. It classifies the protocols that could be used in the IoT applications into four groups based data rate and range criteria. The classification is as follows:

1. Short-Range, High Data rate protocols (SRHD).
2. Short-Range, Low Data rate protocols (SRLD).
3. Long-Range, High Data rate protocols (LRHD).
4. Long-Range, High Data rate protocols (LRHD).

This classification is illustrated in Figure 1. In this classification, any range that is less than 10m considers as short range while any range above that considers as long range. Also, any data rate that is less than 1 Mbps considers as low data rate while any data rate above that considers as high data rate.

Basically, this classification aims to show the role of 5G in providing two aspects of connectivity to the IoT applications: SRHD for cIoT applications and LRHD for iIoT applications.

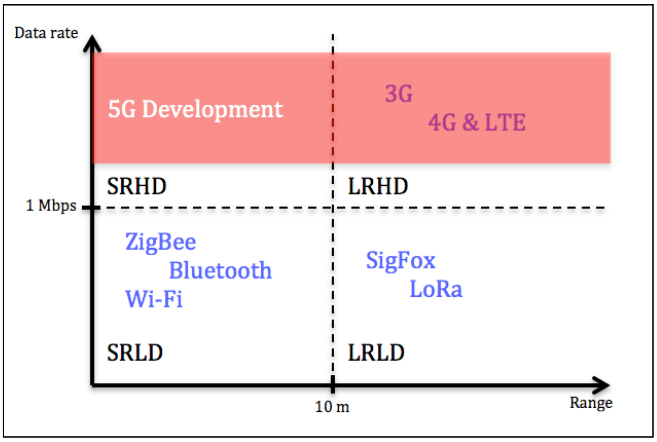

Figure 1. Classification of IoT connectivity options protocols

IV ENABLING TECHNOLOGIES OF 5G IN IOT

As a result of the evolution of IoT systems, many features and functionalities need to be involved in designing the next generation of cellular networks. Many studies show that 5G is the key driver of IoT because of its enabling technologies that take into considerations the variety of IoT requirements. Moreover, providing reliable connectivity for IoT devices is a task involving coordination and integration of several enabling technologies.

To satisfy IoT requirements such as long coverage, extremely high data rate, scalability, and capacity, several technologies are used from 5G designs to enable IoT communications. These technologies are discussed in the incoming subsections.

A. Device to Device Communications

The main idea of device-to-device communication (D2D) is to allow two devices to communicate with each other without an intermediate base station (BS) that controls the communication. Also, the main benefit of such a technology is the use of licensed spectrum rather than unlicensed spectrum used by technologies such as Wi-Fi and Bluetooth [8]. This type of communication provides high data rate and low latency due to the efficient and direct communication between the two connected devices. Naturally, in order for two devices to be communicated over cellular system, they need to be connected to each other through a base station (BS), which in turn results in low data rate and delay [4].

5G systems are expected to allow the direct communication illustrated in D2D communications to support many IoT applications that required such communication [4].

As stated previously, the use of licensed spectrum in D2D communication improves the quality of service (QoS) by increasing the data rate and reducing latency. Also, D2D communication allow for better user experience especially when the capacity of a BS is reached because of data traffic [4]. Furthermore, D2D communications can be used as a foundation for many technologies such as machine type communication (MTC) and vehicle-to-vehicle communications (V2V). There are four types of D2D communication:

1. Device relaying with *BS* controlled link establishment.
2. Device relaying with *device* controlled link establishment.
3. Direct D2D communication with *BS* controlled link establishment.
4. Direct D2D communication with *device* controlled link establishment.

Using D2D communication to enable IoT applications has a potential benefit in group communications via IoT devices [8]. However, several open issues need to be investigated in D2D communication including: security, discovery of resources and interference managements [8].

B. Millimeter Wave Technology

One of the promising technologies that show a substantial impact on improving capacity and throughput of mobile communications is the use of millimeter frequencies bands. The frequencies bands in the mm wave are at 30 to 300 GH_z [4]. Furthermore, mm wave carrier frequencies increase the data rates by allowing large bandwidth allocations [8].

In term of IoT applications, the use of mm wave could enable high data rates for these kinds of applications with great capacity [8]. As discussed in the previous point, the short-range communication that is offered by mm wave technology can be attractive for D2D communications [1].

C. Relays

A relay network can be considered as a network topology that used mainly in wireless network to improve its performance. The idea of relays is to have a relay node (RN) in between UEs and eNBs. Furthermore, these RNs have the functionality of both UEs and eNBs. They are responsible of receiving and transferring information through a wireless network from UEs/eNBs to eNBs/UEs. There are four main advantages of relay nodes. First, they provide temporary network deployments since RNs are easy to be deployed and removed more than eNBs. Second, they increase the cell-edge throughput because locating the RNs close to cell-edge improves the cell-edge throughout. Third, most important benefit of RNs is increasing the data rate by locating RNs in low signal level areas. Finally, in some cases multiple users (UEs) move together from one location to another and that required a mobility feature, which is supported by co-located RNs. [2]

In term of IoT systems, relaying is a key technology that provides scalability for IoT applications. In case of having sort of traffic over one base station (BS), IoT devices can be connected to several relay stations (RSs), which in turn allow for better connectivity and coverage.

D. Wireless Software-Defined Network (WSDN)

Many studies have considered SDN as one of the enabling technologies for 5G cellular systems [4][8]. SDN is an emerging paradigm that based on the idea of separate the data plans from control plan, which increase the flexibility of network performance [1]. By splitting the control plans from data or user plans, capacity and data rates can be increased by reducing the overhead that can be occurred by control plans [1].

Furthermore, SDN can be used in the evolution of IoT systems to highlight flexibility and interoperability challenges. In term of flexibility, SDN allows dynamic IoT architecture that can deal with the amount of connected devices and data being exchanged [1]. In term of interoperability, splitting control from data plans allows for independent use of resources. In fact, SDN allows several different services having different quality of service QoS to exist in the same domain [8].

E. Network Function Visualization

Network Function Virtualization NFV is a complementary concept of SDN. The concept of NFV is basically coming from the idea of having several virtual machines running on different operating systems working over different hardware [1]. The goal of this technology is to virtualize several network functions. This virtualization can increase the flexibility and scalability in the IoT applications [8].

TABLE II. MAPPING IOT REQUIRMENTS TO THEIR ENABLING TECHNOLOGIES

IoT Requirements	Enabling Solutions
Long Coverage	• Relay
Large Capacity	• MM wave
Low latency	• D2D communication
Scalability	• Relay • MM wave
Flexibility	• WSDN • NFV
Interoperability	• WSDN • NFV

IV CONCLUSION

IoT is the very near future concept that shape our lives. It is one of the enabling technologies for 5G cellular systems. To enable IoT applications, several requirements must be satisfied each of them using certain technologies. These technologies considered as IoT enabling technologies, which are mainly used to enable 5G cellular systems too. This survey condiucts a comparative analysis between several IoT connectivity options to inesigate which of them is most suited for IoT applications. However, the comparison shows that all these wireless networks are capable of serving IoT systems each under certain circumstances. This paper provides in-depth state of knowledge regarding the role of 5G cellular systems in the development of IoT systems and it provides a comparative analysis for some of IoT connectivity landscapes. This survey starts by giving overviews of both IoT and 5G systems including their requirements and challenges. More preciecly, IoT characteristics and technologies have been discussed. After that, comparison of IoT connectivity options has been proposed from two prespectives: based on the characteristics od these options and based on IoT requirements. Several enabling technologies for IoT have been highlighted from the 5G point of view. This survey predicts that many IoT applications will use the currently available cellular networks such as 4G and LTE until the complete arrival of 5G in 2020s.

REFERENCES

[1] Agiwal, M., Roy, A., & Saxena, N. (2016). Next Generation 5G Wireless Networks: A Comprehensive Survey. *IEEE COMMUNICATIONS SURVEYS & TUTORIALS*, *18*(3).

[2] Akyildiz, Ian F., David M. Gutierrez-Estevez, Ravikumar Balakrishnan,, and Elias Chavarria-Reyes. "LTE-Advanced and the evolution to Beyond 4G (B4G) systems." *eLSERVIER*, vol. 10, 2014, pp. 31-60.

[3] Akyildiz, Ian F., Elias Chavarria-Reyes, David M. Gutierrez-Estevez, Ravikumar Balakrishnan, and John R. Krier. "Enabling next generation small cells through femtorelays." *eLSERVIER*, vol. 9, 2013,pp. 1-15.

[4] Akyildiz, Ian F., Shuai Nie, Shih-Chun Lin, and Manoj Chandrasekaran. "5G roadmap: 10 key enabling technologies." *ELSERVIER*, vol. 106, 2016, pp. 17-48.

[5] Ericsson, White Paper: Cellular networks for massive IoT, January 2016

[6] Gupta, R., & Gupta, R. (2016). ABC of Internet of Things : Advancements, Benefits, Challenges, Enablers and Facilities of IoT. *Symposium on Colossal Data Analysis and Networking*.

[7] Militano, L., Araniti, G., Condoluci, M., Farris, I., & era, A. (2015, October). Device-to-Device Communications for 5G Internet of Things. *EAI Endorsed Transactions on Internet of Things*, *1*(1).

[8] Palattella, M. R., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., & Engel, T. (2016, March). Internet of Things in the 5G Era: Enablers, Architecture, and Business Models. *IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS*, *34*(3).

[9] Shah, S. H., & Yaqoob, I. (2016). A Survey: Internet of Things (IOT) Technologies, Applications and Challenges. *The 4th IEEE International Conference on Smart Energy Grid Engineering*.

[10] Vermesan, O., & Friess, P. (2014). *Internet of Things – From Research and Innovation to Market Deployment*. N.p.: River Publishers.