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Internet of Things: Communication Technologies, Features and Challenges

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Abstract—**The emerging Internet of Things is believed to be the next generation of the internet, in which communications are more than the communication of human-to-human and machine-to-machine. In the Internet of things, billions of things can communicate with each other and with the environment, and exchange information. Recently, research topics and new applications in the field of the Internet of things have been formed. In this article, we discuss the concept of the Internet of things, the barriers and challenges facing the development of the Internet of things, and its applications in the world around. Also, with the growing of IoT the set of IoT-Communication technologies is also continuously expanding. A general overview of the main communication technologies in the field of the Internet of Things which can have a beneficial impact in the realization of Smart World, will be mentioned and compared in different aspects.**

Keywords—**IoT, Applications, Communication technologies, Cellular Networks, LPWANs**

I. INTRODUCTION

Internet of things is a network of physical things or things that are equipped with sensors, software, electronic components and network connections, and can collect and exchange information [1]. In other words, the IoT refers to a network in which each physical object is identified by a label and forms a network with other objects. These objects can independently exchange data beside communicating with one another. In fact, the Internet of things contains physical objects, along with some electronic identifiers [51, 53].

In general, the Internet of things history refers to tagged objects that can be identified through radio frequencies. But RFID[1]is not the only form of the Internet of things; Wireless sensor networks can also create data for detecting objects through various environmental sensors. The Internet of things has some advantages and disadvantages. One of the most important advantages is the possibility of controlling objects for the promotion of everyday life, and for the unfavorable aspects, it can be pointed out the issue of compromising the privacy of individuals through the control of these systems and the unauthorized access to their generated data [55].

The primary purpose of the Internet of things is to collect data from communication devices (for example, sensors), processing them and becoming aware of the current situation. This goal allows applications, machines, and human users to understand their surroundings. Understanding of any situation or content, potentially allows applications and services to make smart decisions and respond to environmental triggers. The collected data from various sensors and devices are typically composite (light, sound, video, temperature, etc.) and are diverse. Diversity, instability and pervasive presence have transformed the task of integrating, processing and interpreting real-world data into a challenging task. At present, the volume of data on the web and the Internet is very high, and it is still growing at a glaring pace.

Data collected from various events can be transformed into practical knowledge after analysis and improve our understanding of the physical world; hence, it helps to enhance the production of products and services. Examples include Reading measurement devices to better predict and balance power consumption on smart grids; Processing and monitoring sensor devices attached to older adults or patients that can enhance distance healthcare; Combined analysis of air pollution, traffic, climates and massive sensory data that can lead to better urban management and traffic. This process of data conversion is better illustrated using the hierarchy of knowledge, including data (raw sensory data), information (structured data), knowledge (abstractions and perceptions) and wisdom (practical intelligence).

It should be noted that societies that have access to more data and information have more decision making power and progress in various issues of social, political, economic, welfare, etc. Therefore, individuals with more data, more information and knowledge will also gain more knowledge, wisdom and Vision. In **Figure 1,** these concepts are expressed.

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[1] Radio Frequency Identification

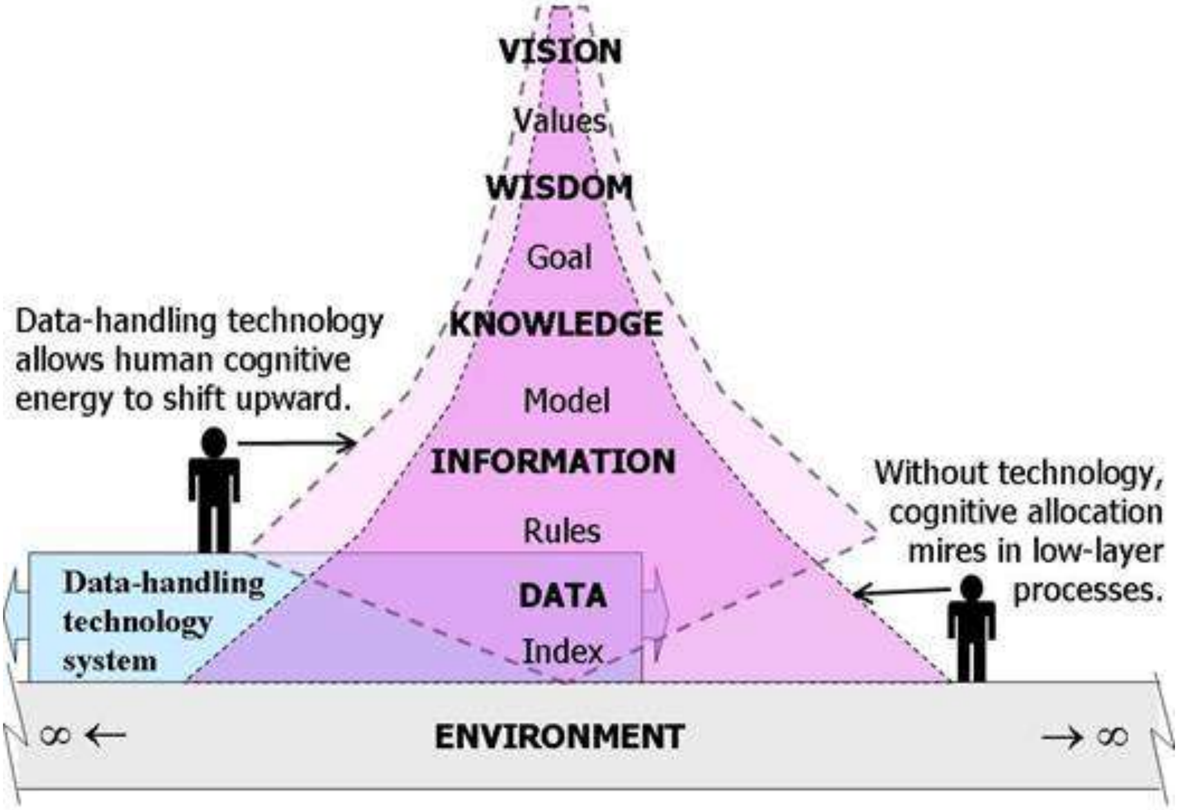

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Figure 1. The Pyramid of Data to Vision

Another topic in the IoT is the number of objects connected to each other and the Internet. In this regard, by 2020, experts estimate the number of objects by over 50 billion [2].The increase in the number of Internet-connected objects over the world's population and individuals is predicted by Cisco.

The company also predicts that the number of connected devices will be 50 billion by 2020 and predicted the population of the world 7.6 billion people. In other words, there will be 6.58 devices connected to the network and Internet per person, this indicates the penetration rate of the Internet and new communication networks, such as the IoT, in the world.

II. CHALLENGES AND BARRIERS TO THE DEVELOPMENT OF THE IOT

There are many obstacles and challenges in the development of the Internet of objects. One of the most important of cases is the deployment of IP version 6, the power of sensors and agreement on standards [2]. There are also issues such as reliability, privacy, heterogeneity and mobility are also on attention.

Deploying IP Version 6: All IPv4 addresses in the world in February 2010 are dedicated to systems and have been completed. And given the fact that there are billions of new sensors on the Internet of things that should be assigned a unique address, this will slow the progress of the Internet of things. Therefore, using IPv6 makes it easier to manage networks due to automatic configuration capabilities. It also provides some enhanced security features.

Sensor Power: The network will yield high efficiency if the sensors are automatically charged. Otherwise, the replacement of the batteries of billions of devices spread on the earth or space is impossible. Therefore, environmental methods such as vibration, light and air flow should be used to generate electricity in sensors [3]. Scientists have introduced a Viable commercial Nanogenerator. A flexible chip that uses body shacks to generate electricity [4].

Standards: Despite the fact that much progress has been made in the field of standards, there is a need for standardization in the areas of privacy, security, communications and architecture. The IEEE[2] is the largest organization that is trying to solve these challenges.

Privacy & Confidentiality: Due to the wideness of the network of things, their mobility and the relatively small complexity of objects, it is difficult to control and manage the cloud of objects. Therefore, a variety of standards and encryption algorithms have been made to increase reliability. In this case, the basic challenge is algorithm design which is faster, and have less energy consumption. There should also be Efficient Key Distribution Scheme. In small-scale systems, key distribution usually occurs at the factory or at the time of use and its expansion in the environment, but in Adhoc networks, new key distribution patterns have been proposed in recent years [52, 54].

It's also protecting the privacy of people at the start and childhood, and this subject raises questions about using the Internet of things. Therefore, mechanisms must be designed and implemented to protect the privacy of individuals.

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Heterogeneity and Mobility: The existence of different types of objects with different sizes and functions disturb their control and management. Also due to the mobility of some objects, tracking, routing them is facing with any challenges [5].

III. INTERNET OF THINGS APPLICATIONS AROUND THE WORLD AND IRAN

For the Internet of things technology, many applications can be imagined that only a number of these applications have been taken to action. In the not too distant future many Internet of things applications will be used in smart homes, smart factories, smart farms, smart offices, smart transportation systems, Smart hospitals, smart universities and more. In general, we can see the status and potential of different uses of the Internet of things in Iran in the **Table 1**.

Fields	**Home & Humanity life**	**Machinery industry**	**Agriculture**	**Aerospace & Aviation**	**Supply Chain**	**Medicine & Health**	**Animal husbandry**
Activities	Services	Manufacturing	Transportation	Manufacturing	Transportation	Services	Services
The current state of IoT in Iran	Low	Medium	Medium	Low	High	Low	Low
The potential of IoT Applications	High	High	High	High	High	High	High

Table 1. Status and Potential of different uses of the Internet of things in Iran

Therefore, given the widespread use of the IoT things technology and its widespread applications in various fields, the rapid pace of movement towards this technology is significant, and in most applications it is economical.

IV. COMMUNICATION TECHNOLOGIES USED IN THE IOT

Various communication technologies on the IoT are used depending on the size of the network. For example, Bluetooth, Bluetooth Low Energy, IrDA, ANT, Zig-Bee, Z-Wave, Wi-Fi, NFC, RFID, Thread (6L0WPAN) and various generations of GSM including 1G, 2G, 3G, 3.5G, 3.75G, 4G, 5G, each of which can be used depending on the type and extent of the network, whether personal, local, or widespread.

Following is the summary of some high-tech communication technologies in the Internet of things:

Bluetooth: Nowadays Bluetooth is used in the Wireless Personal Area Network (WPAN) and it is being developed by the Bluetooth SIG[3]. Bluetooth technology will enable digital and analog devices to automatically establish the wireless network within small scopes. Bluetooth has been designed for cell phones, laptops, tablets, and other devices, including wireless handheld, headsets, and wearable devices (like smart watches, smart shoes), and data-voice access devices. Bluetooth also provides auxiliary connections for PDAs, Printers, Fax Machines, Joysticks, Personal Computers, Laptops, Radio devices, Keyboards, Mouses and other digital devices [6-46].

The 4th generation of Bluetooth: It is known as BLE[4], was introduced in 2011. The difference between the fourth generation of Bluetooth and its older versions is in communicating with lower power consumption. With the lower use of this generation of Bluetooth, the network life expectancy increases significantly. Of course, it should also be noted that this generation of Bluetooth is designed for limited data and periodically and it's not suitable for applications such as telephone conversations.

IrDA: IrDA[5] has an important role in Wireless Personal Area Networks. Its key features (such as very low bit error rate, line-of-sight, short range, dynamic ad-hoc connectivity, low cost, low power, rapid connection setup and high data rates) make it an ideal technology for transmission [7-47].

Infrared is used to transfer data by these devices: Modems, Handheld computers, Desktop, Notebook, Printers, Pagers, Mobile Phones, Cameras, LAN access devices, Watches, Televisions, Industrial and Medical equipments [8-9].

ANT: ANT technology is a low-power dedicated wireless technology which operates in the 2.4 GHz spectrum. ANT technology was established in 2004 by the sensor company Dynastream. Typically, the ANT transceiver device is treated as a black box and shouldn't require much design effort to implement into a network. Its primary goal is to allow sports and fitness sensors to communicate with a display unit, for example, a cycle computer or watch. It also typically operates from a coin cell. The most important applications of ANT technology include: Health and Fitness, Intelligent Transport System (ITS), Assisted Living. ANT+ has taken the ANT protocol and made the devices interoperable in a managed network, thereby guaranteeing that all ANT+ branded devices work seamlessly. Similar to BLE, ANT devices may operate for years on a coin cell [10].

ANT+ introduced a new certification process in 2011 that is chargeable and a prerequisite for using ANT+ branding.

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[3] Special Interest Group
[4] Bluetooth Low Energy
[5] Infrared Data Association

Zig-Bee: The Zig-Bee is designed according to the IEEE 802.15.4 standard, which relates to the design of low-power wireless personal networks. Zig-Bee technology has been made because of simpler and cheaper than other technologies available on personal wireless networks such as Bluetooth and Wi-Fi. This technology, which works in most countries in the 2.4 GHz frequency band, can communicate up to 100 meters with other devices and can send data up to 250 kilobytes per second. This technology can be used in places that need to communicate with low cost and power, for example, it can be used to monitor and control household equipment.

6LoWPAN: 6LoWPAN is an acronym that combines the latest version of the IPv6[6] and Low-power Wireless Personal Area Networks. 6LoWPAN, therefore, allows for the smallest devices with limited processing ability to transmit information wirelessly using an internet protocol. 6LoWPAN is the newest competitor to Zig-Bee.

The concept was created because engineers felt like the smallest devices were being left out from the Internet of Things. 6LoWPAN can communicate with 802.15.4 devices as well as other types of devices on an IP network link like Wi-Fi. A bridge device can connect the two [11].

Z-Wave: Z-Wave reduces energy consumption. That's why it is suitable for devices with limited energy resources. The Z-Wave uses a frequency of about 900 megahertz for data transfer, and the maximum data transfer speed is 100 kilobits per second. Z-Wave can communicate up to 100 meters distance.

Wi-Fi: Wi-Fi which is also known as the IEEE 802.11 standard, uses 2.4 GHz and 5 GHz frequency band. This standard can communicate at a distance of 100 meters at a maximum speed of about 100 Mega bites per second, but this method has high power consumption and Wi-Fi connection cannot be used for devices that use non-rechargeable batteries. Wi-Fi has more complicated protocol than Z-Wave and Zig-Bee.

NFC: The NFC technology is a novel, short-range wireless connectivity technology that jointly developed by Sony and NXP Semiconductors. The NFC technology is based on Radio Frequency Identification and mainly targeted at cell phones [12]. Cell phones are equipped with NFC readers and NFC tags are placed in the environment. NFC tags are labels containing a chip with erasable and writable memory and a built-in antenna. When a user places a smart phone near a NFC tag, the smart phone reads the data stored in the NFC tag and processes it. A phone program can, for example, present the data to the user, store the data or perform some other operation. Near Field Communication technology is used for data transfer between two devices within four to nine-centimeter distance from each other. Near Field Communication technology operates in the 13.56 MHz band and permits a data rate between105 and 423 kbps. Near Field Communication technology supports three different communication modes, namely, Peer-to-Peer (P2P) mode, Card Emulation mode and Reader-Writer mode. In the P2P mode permits a bidirectional communication between two active NFC devices (for example readers). This NFC mode is fully similar to the Bluetooth. The Card Emulation mode permits using an NFC device as a contactless card (e.g. a credit card). This mode enables ticketing and payment applications. Finally, the Reader/Writer mode, an NFC reader can read data stored in an NFC tag and write data to it. The main disadvantage is the lower speed, while the main advantage over Bluetooth is that the initialization process is much easier and faster [13-48].

Sigfox: The first Low Power Wide Area Network technology proposed in the Internet of Things market has been Sigfox [39-49], which was founded in 2009, and has been growing very fast since then. Its current coverage includes Spain, United Kingdom and France. The Sigfox network employs a Ultra Narrow Band modulation, while the network layer protocols are the "secret sauce" of the Sigfox network and, as such, there exists basically no publicly available documentation. The first releases of the technology only supported uni-directional communication, i.e., from the device towards the aggregator, however bi-directional communication is now supported. Each base station can handle up to a million connected objects, with a coverage area of 30–50 km in rural areas and 3–10 km in urban areas.

Sigfox allows bidirectional communication using ISM[7] radio band, namely frequencies 902 MHz for USA and 868 MHz for Europe. Due to the physical nature of the UNB transmission with random channel frequency hopping, the noise contribution is very low, approximately −150 dBm at 290 K, and the link budget can reach up to 159 dB [40, 41]. The protocol exists currently in two versions. The original one where the up-link is using 48 kHz macro channel centered at 868.2 MHz, and the second version using a 192 kHz macro channel centered at 868.13 MHz, that is being deployed since the end of 2014 [42].

LoRaWAN: LoRaWAN [43] is a specification for Low Power WAN (LPWAN) network that provides bi-directional communication and, it is focused on battery-powered devices. It is supported by the LoRa Alliance, a non-profit organization made up of several companies that collaborate in the development of a common protocol. LoRaWAN is a good choice to develop IoT applications with excellent range and energy consumption, and it offers free access to the source code. Here are some of LoRaWAN's applications: Airport monitoring and management, Smart Metering (such as Gas meters, Electricity meters, and Water meters), Smart city (such as Infrastructure and Street light monitoring, Smart parking, and Waste monitoring), Tracking of Kids, Cars, bicycles, Ships, etc. **Figure 2 and Tables 2 and 3** have compared these technologies [11, 14-41, 50].

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[6] Internet Protocol version 6

[7] Industrial, Scientific and Medical

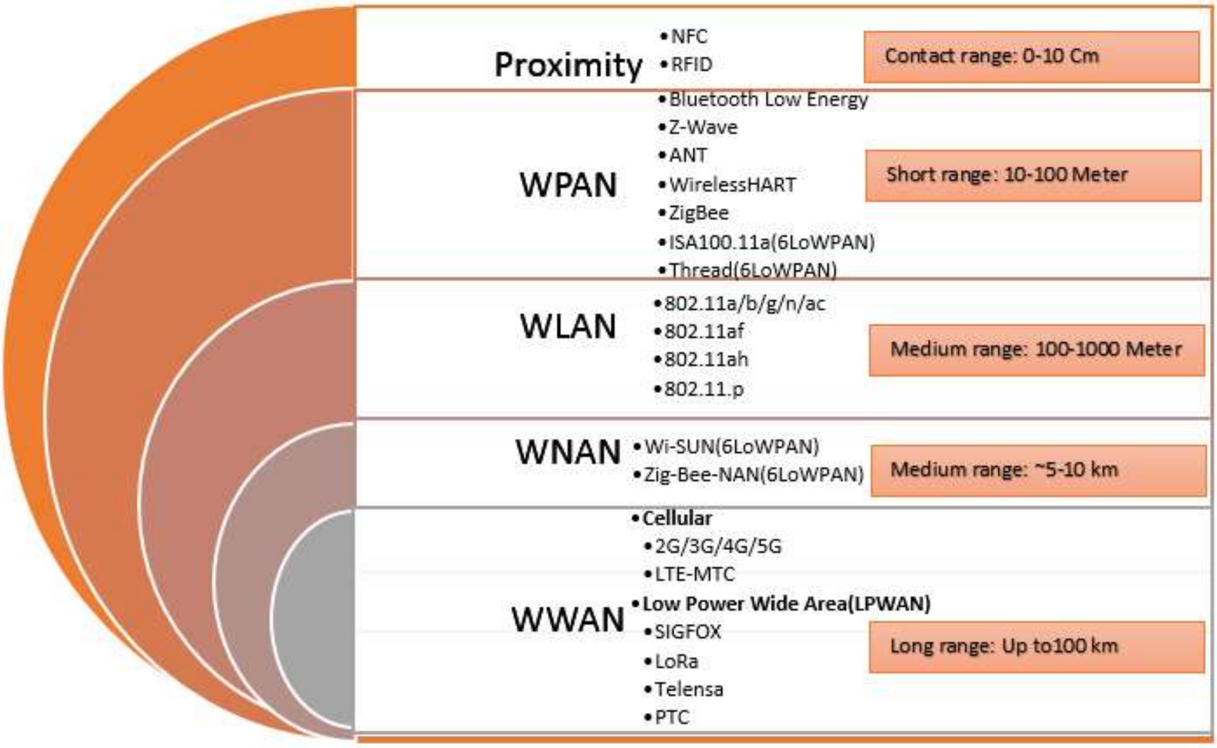

Figure 2. IoT communication technologies from the perspective of geographical coverage of communication

As you can see in this Figure, WPAN networks have vast range of wireless technologies, these range is suitable for Smart house and building management applications. WWAN with longest communication range split into two type of wireless technologies: (1) Cellular, (2) Low Power Wide Area Networks (LPWAN). LPWAN networks developed for sensors/devices with limited power source, which needs to last long.

Table 2. Communication Technologies from Aspect of Applications

Applications	Communication Technologies						
	BLE	**ANT**	**ANT+**	**Zig-Bee**	**Wi-Fi**	**IrDA**	**NFC**
Mobile Phones	✓	✗	✓	✗	✓	✓	✓
Security	✓	✗	✗	✓	✓	✗	✓
Smart Meters	✓	✗	✗	✓	✓	✗	✗
Health and Fitness	✓	✓	✓	✗	✗	✗	✗
Remote Control	✓	✗	✗	✗	✓	✓	✗
Heart Rate	✓	✗	✓	✗	✗	✗	✗
Automotive	✓	✗	✗	✗	✓	✗	✓
Positioning	✓	✗	✗	✓	✓	✗	✗
Blood Glucose	✓	✗	✓	✗	✗	✗	✗
Payment	✗	✗	✗	✗	✗	✗	✓
Tracking	✓	✗	✗	✓	✗	✗	✓
Key Fobs	✓	✗	✗	✗	✗	✓	✓
Gaming	✓	✗	✗	✗	✗	✓	✗
Smart Applications	✓	✗	✗	✓	✗	✗	✗
3D Television	✓	✗	✗	✗	✗	✓	✗
ITS[8]	✓	✓	✓	✓	✗	✗	✗
Personal Computers	✓	✗	✗	✗	✓	✓	✓
Televisions	✓	✗	✗	✗	✓	✓	✗
Animal Tagging	✓	✗	✗	✓	✗	✗	✓
Assisted Living	✓	✓	✓	✗	✗	✗	✓

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[8] Intelligent Transport Systems

In this table, some popular wireless technologies compared in the aspect of applications. As you can see BLE is the most applicable technology in this table, NFC and Zig-bee with different communication range placed second and third.

All technologies listed here are suitable for indoor/short range communication.These technologies mostly uses license free frequencies. BLE and Zig-bee with supporting of different network topologies are more popular in IoT. From the aspect of network security Zig-bee, BLE, 6LowPan and Z-Wave with AES128 encryption have acceptable security option. According to the studies, the most important technologies used in the Internet of things by corporations, according to Figure 3, are dedicated to LPWAN and Cellular Networks technologies: LoRaWAN, SigFox, NB-IoT, Weightless, LTE-M, RPMA, 3G, 4G and 5G in the red circle. Other BLE, ANT, Zig-Bee, Z-Wave, NFC, RFID in the green circle are also important, and in the future, these technologies play an important role. It can be expected that competition will be driven by quality of service, costs, Energy Consumption, Compatibility, network availability, and technical characteristics [44].

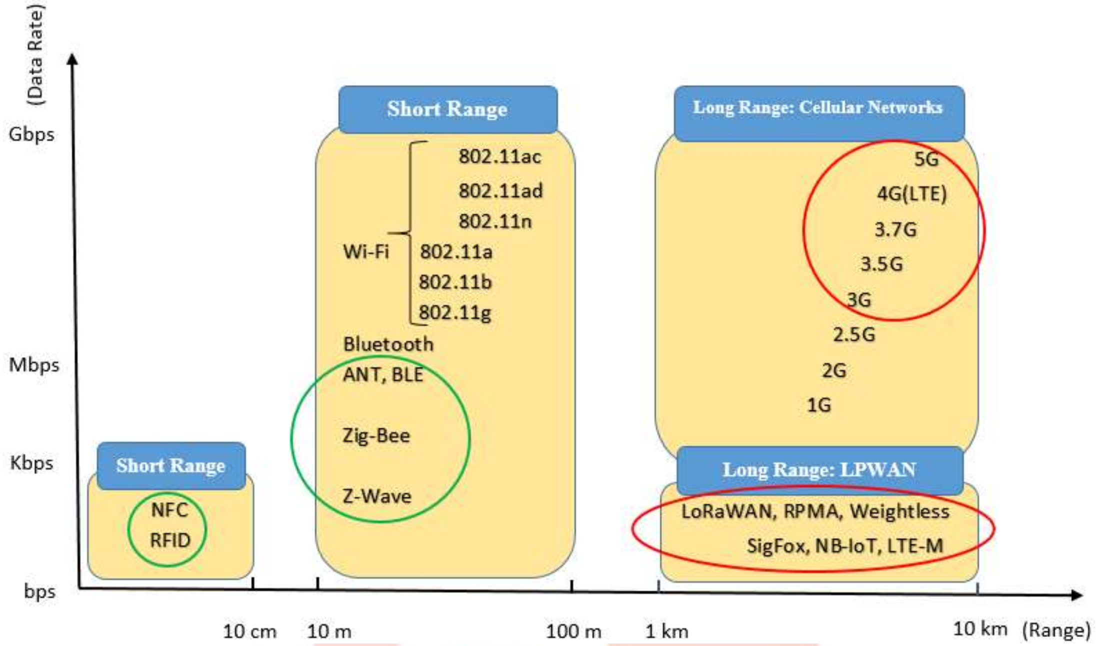

Figure 3. Status of Using from IoT communication technologies

V. DIFFERENT GENERATION OF CELLULAR COMMUNICATION TECHNOLOGIES

A mobile network or cellular network is a radio network distributed over land areas called cells; each cell served by at least one transceiver, known as a base station. In a cellular network, each cell uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed bandwidth within each cell. When joined together these cells provide broad radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., pagers, mobile phones, etc.) to communicate with fixed transceivers and with each other and telephones anywhere, anytime in the network, via base stations [45].

Mobile telephones have become very important part of our life. Their current development is the outcome of various generations. In the Table4, we review the various generations of mobile cellular technology from the perspective of Access technology, Data rate, Frequency Band, Bandwidth, FEC, Switching and Applications of one generation over other [35-37].

Table 3. IoT Communication Technologies

Communication Technologies	Cost	Topology	Data Rate	Frequency Band	Channel width	Modulation	Range	Security	Standard	Power	Battery life
Bluetooth	Low	Star Scatternet	723kbps to 3Mbps	2.4-2.485 GHz	1 MHz	DQPSK 8DPSK GFSK	10-100 Meters	AES, Pin Code	IEEE 802.15.1	0 dBm (1 mW) 4 dBm (2.5 mW)	1 to 7 days
BLE (Bluetooth Low Energy)	Low	P2p Star Broadcast Mesh	1Mbps	2.4 GHz	2 MHz	GFSK OFDM	100 Meters	AES 128 bit,Key Generation	IEEE 802.15.1	Low	Several Years
ANT	Low	P2p Star Mesh	1Mbps	2.4 GHz	1 MHz	GFSK	50 Meters	64-bit Key		Low	Long
Zig-Bee	Ultra Low	Mesh Star P2p	20 kbps 40 kbps 250 kbps	868 MHz (Europe) 915 MHz (us) 2.4GHz to 2.483GHZ	5MHz	O-QPSK BPSK	10 to 300 Meters	AES 128 bit	IEEE 802.15.4	Very Low 0 dBm (1 mW)	100 to 1000 days
Wi-Fi	Medium	Star P2p	11Mbps to 7Gbps	2.4GHz 5.2GHz 60 GHz	20MHz	OFDM	75 to 125 Meters	WPA,WEP	IEEE 802.11.a,b,g,n,ac,ad	High	1-5 days
Z-Wave	Medium	Mesh	9600bps 9.6/40 kbps 100kbps	908.42MHz (US,Canada) 868.42MHZ (Europe) 916MHZ (Israel) 919.82MHZ (HongKong) 921.42MHZ (Australia,Newzealand) 865.2MHZ (india)	300KHz	GFSK BFSK	30 -100 Meters	AES 128 bit	IEEE 802.15.4	0 dBm (1 mW)	Several Years
6LoWPAN	Low	Star Mesh	20 kbps 40 kbps 250 kbps	868-868.6 MHz(Europe) 902-928 MHz(USA) 2400-2483.5 MHz(Global)	0 2 MHz 5 MHz	BPSK QPSK	10 meters	AES 128 bit	IEEE 802.15.4-2003	0.5mW	Several Years
LoRaWAN	Low	Star	250bps-5.5kbps 11kbps/50kbps	433/868/780/915MHz	125KHz 250KHz	CSS (G)FSK	2-15km	AES128 in Counter mode (CTR)	N/A	Low	>10 Years
SigFox	Low	Star	100bps	868MHz/902MHz	100Hz	DBPSK GFSK	3-50km	AES 128 bit	N/A	Low	>10 Years

Table4: Cellular Communication Technologies

Generation	Access Technology	Data Rate	Frequency Band	Bandwidth	FEC	Switching	Applications
1 G	AMPS/FDMA	2.4 kbps	800 MHZ	30 KHZ	N/A	Circuit	Voice
2 G	GSM/TDMA /CDMA	10 kbps 10 kbps	850/900/1800 /1900 MHZ	200 KHZ 1.25 MHZ	N/A	Circuit	Voice + data
2.5 G	GPRS/EDGE	50 kbps 200 kbps		200 KHZ 200 KHZ	N/A	Circuit / Packet	Voice + data
3 G	WCDMA /UMTS	384 kbps	800/850/900/ 1800/1900/2100 MHZ	5 MHZ	Turbo codes	Circuit / Packet	Voice + data Video calling Mobile Internet
3.5 G	HSDPA /HSUPA EVDO	5-30 mbps 5-30 mbps		5 MHZ 1.25 MHZ	N/A	Packet Packet	Voice + data Video calling Mobile Internet
3.7 G	LTE OFDMA/SC-FDMA	100-200 mbps	1.8 GHZ , 2.6 GHZ &	1.4 MHZ 20 MHZ	Concatenated code	Packet	Online gaming+ High Definition Television Mobile Internet
	WiMAX Fixed WiMAX SOFDMA	100-20 mbps	3.5 GHZ 5.8 GHZ	3.5 MHZ & 7MHZ in 3.5 GHZ band 10 MHZ in 5.8 GHZ band		Packet	
4 G	LTE-A OFDMA/SC-FDMA	DL 3Gbps UL 1.5Gbps	1.8 GHZ 2.6 GHZ	1.4 MHZ to 20 MHZ	Turbo codes	Packet	Online gaming+ High Definition Television IP Telephony 3D Television Video Conferencing Cloud Computing
	WiMAX Mobile WiMAX	100-200 Mbps	2.3 GHZ 2.5 GHZ 3.5 GHZ	3.5 MHZ 7 MHZ 5 MHZ 10 MHZ	Turbo codes	Packet	
5 G	BDMA FBMC	10-50 Gbps	1.8 , 2.6 GHZ 30-300 GHZ	8.75 MHZ 60 GHZ	LDPC	Packet	Ultra high Definition video+ Virtual reality applications

VI. CONCLUSION

Undoubtedly, when the Internet of Things becomes widespread, it has a tremendous effect on our lives. The above changes will be as tangible as possible that in the near future without this concept we won't be able to control the digital objects of our lives. But in order for the IoT to come into our lives, we need a pre-defined structure in communication. In other words, rather than the concept of the IoT, it is important to provide the infrastructure and communication technologies on the Internet of things. Since large companies working on the Internet of Things use platforms and different communication technologies, the cluster's connection between all the components of the Internet of Things is subject to the establishment of standards in this field which can have the significant effect at the rate of growth and the spread of this technology. Since this technology is very young, there are concerns about data security and their confidentiality, which should be carefully reviewed in the future and come up with some solutions.

Also, there are lots of improvements from 1G, 2G, 3G, 4G to 5G. In this research, we have discussed and compared five cellular and wireless mobile technologies namely 1G, 2G, 3G, 4G and 5G.

REFERENCES

[1] "Internet of Things Global Standards Initiative". ITU. Retrieved 26 June 2015.http://www.itu.int/en/ITU-T/gsi/iot/Pages/default. aspx

[2] Dave Evans, "The Internet of Things: How the Next Evolution of the Internet Is Changing Everything", (April 2011), Cisco, Retrieved 4 September 2015.

[3] Yee WinShwe and Yung C. Liang, "Smart Dust Sensor Network with Piezoelectric Energy Harvesting", ICITA, 2009, http://www.icita.org/ papers/34-sg-Liang-217.pdf

[4] "First Practical Nanogenerator Produces Electricity with Pinch of the Fingers," http://www.physorg.com/ news/2011-03-nanogenerator-electricity-fingers.html, PhysOrg.com, March 29, 2011,

[5] Debasis Bandyopadhyay, Jaydip Sen, "Internet of Things: Applications and Challenges in Technology and Standardization", **journal of Wireless Personal Communications,** Volume 58, Issue 1, (2011), pp 49–69

[6] Tom Sheldon, "Encyclopedia of networking and Telecommunications", Osborne/McGraw-Hill.

[7] https://faculty.cs.byu.edu

[8] http://www.irda.org/

[9] Dave Suvak, http://alumni.cs.ucr.edu/~csyiazti/courses/cs260/ downloads/IrDA_vs_Bluetooth.pdf

[10] https://www.digikey.com/en/articles/techzone/2011/aug/comparing-low-power-wireless-technologies

[11] https://www.link-labs.com/blog/6lowpan-vs-zigbee

[12] NFC Forum. 4.1.2011. NFC Forum Specifications. http://www.nfc-forum.org/specs/

[13] Riekki J., Cortés M., Hytönen M., Sánchez I., Korkeamäki RL. (2013) Touching Nametags with NFC Phones: A Playful Approach to Learning to Read. In: Pan Z., Cheok A.D., Müller W., Iurgel I., Petta P., Urban B. (eds) **Transactions on Edutainment X. Lecture Notes in Computer Science**, vol 7775. Springer, Berlin, Heidelberg

[14] https://www.ietf.org/proceedings/62/slides/6lowpan-3/6lowpan-4.ppt, Nandu Kushalnagar & Gabriel Montenegro

[15] IEEE Std 802.15.4-2003. Technical Report 802.15.4-2003, IEEE, October 2003.

[16] IEEE Std 802.15.4-2006. Technical Report 802.15.4-2006, IEEE, September 2006.

[17] IEEE Std 802.15.4a-2007. Technical Report 802.15.4a-2007, IEEE, August 2007.

[18] https://www.utwente.nl/ewi/dacs/colloquium/archive/2010/slides/2010-utwente-6lowpan-rpl-coap.pdf

[19] https://www.bluetooth.com/what-is-bluetooth-technology/how-it-works/le-mesh

[20] https://www.link-labs.com/blog/ble-range

[21] https://www.link-labs.com/blog/bluetooth-vs-bluetooth-low-energy

[22] http://www.electronicdesign.com/communications/fundamentals-short-range-wireless-technology

[23] https://en.wikipedia.org/wiki/Bluetooth#Bluetooth_4.0_.2B_LE

[24] http://www.ieee802.org/15/

[25] Raj Jain, Washington University in Saint Louis, http://www.cse.wustl.edu/~jain/cse574-14/ftp /j_11ble.pdf

[26] Vadym Samosuyev, "Bluetooth Low Energy compared to ZigBee and Bluetooth Classic", Thesis, Mikkely University of AppliedSciences,(2010), https://publications.theseus.fi/bitstream/ handle/10024/15812/FinalThesis_Samosuyev.pdf

[27] Cory Beard, William Stallings, "Wireless Communication Networks and Systems", chapter12, 1 st edition, (2016).

[28] http://ieeexplore.ieee.org/browse/standards/get-program/page/ series?id=68

[29] Helen Fornazier, Aurélien Martin, Scott Messner, "Wireless Communication: Wi-Fi, Bluetooth, IEEE 802.15.4, DASH7", (2012)

[30] Joe Decuir, "Bluetooth 4.0: Low Energy", **IEEE,** https://californiaconsultants.org/wp-content/ uploads/2014/05/CNSV-1205-Decuir.pdf

[31] Carles Gomez, Joaquim Oller, Josep Paradells, "Overview and Evaluation of Bluetooth Low Energy: An Emerging Low-Power Wireless Technology", **Journal of Sensors**, Vol. 12, (2012) pp. 11734-11753

[32] "Z-Wave Alliance Recommendation", (2014) http://z-wavealliance.org/wp-content/uploads/ 2015/02/ZAD12837-1.pdf

[33] https://en.wikipedia.org/wiki/Z-Wave

[34] "Building Value from Visibility", Forrester Consulting, June (2012), survey on behalf of Zebra.

[35] Nitish Aggarwal, Rachit Gupta, Pallavi Saxena, "Comparative Study of 1g, 2g, 3g and 4g Technologies", International Journal of Research (IJR), Vol. 01, Issue 10 November (2014), pp. 1219-1223.

[36] K. Pandya, " Comparative Study on Wireless Mobile Technology: 1G, 2G, 3G, 4G and 5G", **Journal of Recent Trends in Engineering & Research (IJRTER)** Vol. 01, Issue 01; September– (2015), pp. 24-27.

[37] Sucheta1 , Dr. K P Yadav , "A COMPARATIVE STUDY OF 1G, 2G, 3G AND 4G", **International Journal of Advances in Engineering Research**, Vol. 3, Issue 3, March (2013), pp. 31-46.
[38] LoRaWAN: What is it? A technical overview of LoRa and LoRaWAN, LoRa Alliance Technical Marketing Workgroup 1.0, November (2015)
[39] http://www.sigfox.com/. Accessed 10 August 2015
[40] Do, M.-T., Claire Goursaud, J. M. G., "Interference modelling and analysis of random fdma scheme in ultra narrowband networks" (2014).
[41] SIGFOX: Sigfox specifics. http://makers.SIGFOX.com/#about
[42] Smierzchalsk, S.: Sigfox technical specification
[43] Semtech. LoRa Technology (2015). http://www.semtech.com/wireless-rf/lora.html. 10 Nov (2016)
[44] Vannieuwenborg F, Verbrugge S, Colle D., "Choosing IoT-connectivity? A guiding methodology based on functional characteristics and economic considerations", **Journal of Trans Emerging Tel Tech**,(2018);e3308. https://doi.org/10.1002/ett.3308
[45] https://en.wikipedia.org/wiki/Wireless_network
[46] http://www.linktionary.com/b/bluetooth.html
[47] Knutson, Charles & Joos, Derek & Woodings, Ryan. (2018). Infrared Data Communications in Wireless Personal Area Networks.
[48] http://ubicomp.oulu.fi/files/toe13.pdf
[49] Vangelista, Lorenzo & Zanella, Andrea & Zorzi, Michele. (2015). Long-Range IoT Technologies: The Dawn of LoRa™. 51-58. 10.1007/978-3-319-27072-2_7.
[50] Khutsoane, Oratile & Abu-Mahfouz, Adnan & Isong, Bassey. (2017). IoT devices and applications based on LoRa/LoRaWAN. 10.1109/IECON.2017.8217061.
[51] https://en.wikipedia.org/wiki/Internet_of_things
[52] https://www.iottechexpo.com/2017/07/blockchain/secure-model-iot-blockchain/
[53] http://www.information-age.com/impact-internet-things-iot-123467503/
[54] https://iot.ieee.org/newsletter/march-2017/three-major-challenges-facing-iot.html
[55] https://www.accenture.com/us-en/insight-industrial-internet-of-things