Comparative Analysis of Wireless Communication Technologies for IoT Applications

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1 Introduction

In 1999, Kevin Ashton coined the word “Internet of things” when he was connecting various devices in supply chain management using RFID tags [1]. But the concept of connected devices is way back from 1832 as when the first electromagnetic telegraph was designed. IoT history was started after the invention of major component Internet in 1960s; thereafter, the growth of IoT gained rapid action over the next decades. Presently, we are living in the era of Internet of things, where each and every activity of living and non-living things are tracked and performed with necessary action. Internet of things is characterized in several ways by various researchers. Hear, two of simple and common definitions are: Vermesan et al. [2] described the Internet of things as an interface between the physical and the digital worlds. The digital world interacts with the physical world via a plethora of sensors and actuators. Another definition by Pena-Lopez et al. [3] describes the Internet of things as a concept in which computing and networking abilities are incorporated in any entity imaginable. With the use of internet of things, we are able to perform the complex task by simple objects which are combined with intelligence. Sensors, actuators, pre-processors, and transceivers are used to provide connectivity and intelligence in IoT devices [4].

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IoT is not a single innovation, it is a compound of different technologies and distributed among various industries. But all the IoT interventions share the same goal regardless of the application. Those unique goals are minimizing the power requirement, decreasing the complexity of design, minimizing the cost and area, effective utilization of resources and increasing overall efficiency of the system [5]. To enable IoT devices with all the mentioned requirements, various wireless technologies are emerged. As per the standard definitions given by IEEE, Wireless Personal Area Networks (WPAN), Low Rate Wireless Personal Area Networks (LRWPAN), Wireless Body Area Networks (WBAN), and Wireless Local Area Networks (WLAN) are classified as short distance protocols because of their most range of one kilo meter. While Wide Area Networks (WAN) and Low-Power Wide Area Networks (LPWAN) comes under long-range technologies as they support ranges of more than 1 km [6].

Short-range technologies are employed by critical IoT applications which have the requirements of low latency and high availability, where battery life is not considered as major parameter. In this paper under short-range technologies, Radio Frequency IDentification (RFID), Near Field Communication (NFC), Bluetooth Low Energy (BLE), Wireless HART, Zigbee (IEEE 802.15.4), Z-wave, IEEE 802.11ah (WiFiHalow), and ANT are investigated. Long-range technologies are ideal for massive IoT applications require broad coverage and long battery life. Under long-range technologies, LTE MTC Cat M1, EC-GSM-IoT, NB-IoT, 5G, LoRa, Sigfox, Weightless, Ingenu, and DASH7 are investigated.

2 Short-Range Wireless Technologies

Short-range technologies are used for applications which require connectivity within small area of coverage. These technologies are favourable to local area networks as these are easy to deploy, configure and to maintain. The features given by short-range technologies are high data rates, high availability, and occasional latency.

As per IEEE standards [7], we have various categories of short-range technologies like:

Wireless Personal Area Network (WPAN):

This kind of network is preferable for sending information over short distances which includes private, familiar class of devices. It establishes the network with devices surrounding the human body. WPANs are used in personal or wearable devices for implementing easy connectivity and power efficient solutions.

The IEEE 802.15.1 standard is defined for WPAN. One of the maximum used WPAN technology is Bluetooth. Its architecture and operation of physical, MAC layers are specified by this standard. Bluetooth has several versions from V1.0 to V5.0. In 2010, Bluetooth Low Energy (BLE) was launched with greater and more suitable capacities for devices with low power [8].

Low Rate Wireless Personal Area Network (LRWPAN):

The IEEE 802.15.4 standard specified for LRWPAN. LRWPAN represents low cost, very low-power, short-range wireless communications. It insists on easy installation, data reliability, extreme low cost, and decent battery life while being versatile protocol. By using this standard as base, many short-range technologies like Zigbee, Wireless HART, and 6LoWPAN are designed to operate within range of 10 m with 250 kbps of data rate.

Wireless Local Area Network (WLAN):

WLAN is a network of two or more devices connected using wireless communication to construct a Local Area Network (LAN). LAN referred to areas under particular limits such as a house, office, school, or any other building. The users in LAN are free to move in that limited area and stay connected to network by using WLAN technologies. WLANs can extend the area of coverage by deploying the gateways.

The IEEE 802.11 standard specifies the physical and MAC layer protocols for implementing WLAN. This is the utmost popular widely used standard for accessing Internet wirelessly. The primary standard was launched in 1997 and later supported with amendments and gained popularity as WiFi standard. Among the family of 802.11 standards, IEEE 802.11ah is currently most popular, as it defines the WLAN system working at sub-1 GHz license free bands. This standard is being used in large-scale sensor networks because the transmission range is improved comparatively with traditional standard [9].

2.1 Comparison of Short-Range Wireless Technologies

The available wireless technologies for short-range communication are investigated, and analysed. Every technology is having different features compare to others [10]. These technologies are compared by considering the major parameters like operating frequency, data rate, range, and power consumption in order to elect the best performed technology for the requirements of application. The comparisons are presented in Table 1.

3 Long-Range Wireless Technologies

In this section, we elaborate an outline of the wireless long-range technologies that currently exist [11, 12]. It is not fair to categorize those based on their exclusive or inclusive features because some may be member of both aspects, as LoRa does. Rather, we suggest collecting them focusing on which frequency spectrum they are using either the authorized cellular frequencies or the unlicensed ISM bands [13].

Table 1 Comparison of short-range wireless technologies

Name of the parameter	RFID	NFC	BLE	Zigbee	WiFiHaLow	WirelessHart	Z-Wave	ANT
Standardization	ISO/EPC	ISO/IEC 14,443	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.11ah	IEEE 802.15.4 PHY HART MAC	Proprietary	Proprietary
Frequency	125–135 kHz, 13.56 MHz, 868–930 MHz, 2.45 and 5.8 GHz	13.56 MHz	2.4 GHz	2.4 GHz, 868 and 915 MHz	900 MHz	2.4 GHz	900 MHz	2.4 GHz
Range (meters)	0.1–5	0.1	50	10–100	Upto 1000	10–600	30	<30
Data rate	500 kb/s@ payload of 16–32 bits	106 kb/s or 212 kb/s or 424 kb/s 848 kb/s	1 Mb/s	20, 40, 250 Kb/s	150–400, 650–780 Kb/s	250 kb/s	9.6, 40, 100 Kb/s	1 Mb/s
Power consumption, mA	Varies with frequency	<5	<12.5	<40	low	<50μA	<23	<16
TX output power, dBm	1.5 mw	20 or 23	<19	−3 to 10	10 to 30	10	<0	−20 to 0
Multiplexing	TDMA	Antenna Multiplexing	FHSS	DSSS	OFDM	TDMA	FHSS	TDMA
Modulation	Proximity	ASK, BPSK	GFSK	OQPSK, BPSK	BPSK, QPSK, QAM	OQPSK, BSPK, ASK	FSK, GFSK	GFSK
Topology	P2P, Point to multipoint	Peer to peer	P2P, star	star, tree, mesh	One-hop	star, cluster mesh	star, mesh	P2P, star, tree, mesh
Packet length	16–64 kbps	segments	8–47 bytes	100 bytes	100 bytes	250 bits	255 bits	32 bit

Through using the licensed mobile frequencies, it certifies that the band is used lucidly through approved devices. However, the use of such frequencies involves subscription fees, and they could already be occupied due to the extensive usage of mobile devices, particularly in densely populated urban areas. On the alternative, the unlicensed ISM bands does not guarantee that the frequencies are used rationally, as everyone is approved for transmitting and several devices may intervene. The limitations of the duty cycle must be understood depending on the range of frequencies used, power and the physical positioning of the device. Around the same time, using unlicensed bands often means, we can easily extend the network with new base stations, build private networks, and use certain technologies for peer-to-peer communication. For two key purposes, one may wish to install one's own infrastructure: either because the region to be tracked is not served by any other technology or to retain control over infrastructure maintenance. LPWAN is currently powered to meet the needs of nascent IoT implementations to deliver a range of features like wide area communications and wide-scale networking for minimum power, small-cost and low-data tolerance devices. Typically speaking, LPWAN can be classified into two groups—unlicensed and licensed LPWAN. Unlicensed LPWAN technologies [14, 15] state that they use unlicensed spectrum frequencies over the ISM band. Acknowledgments for the use of the unlicensed band do not necessarily reimburse the unlicensed LPWAN suppliers for spectrum licenses. As a result, it reduces the cost of implementation. LPWAN also offers solutions using approved bands for long-range applications as per the 3rd Generation Partnership Project (3GPP). The solutions for the licensed LPWAN [16] are Extended Coverage GSM for Internet of things (EC-GSM-IoT), Long-Term Evolution Machine-Type Communications Category M1 (LTE MTC Cat M1), Narrowband IoT (NB-IoT) [17] and 5G [18].

3.1 Comparison of Long-Range Wireless Technologies

All the long-range technologies are studied and compared with specific parameters like frequency, data rate, range, power consumption, and battery life and presented in Table 2 [13], which will be feasible to understand about the performance of technology based on the parameters and can select the suitable technology based on the requirements.

4 IoT Applications

The IoT transforming traditional objects into smart objects by enabling physical things to sense and perform with the use of intelligence and technologies. By using the IoT technology, lifestyle of people become smart and secure. To improve overall

Table 2 Comparison of long-range wireless technologies

Name of the prameter	LoRa	Sigfox	Weightless	Dash7	LTE-M	EC-GSM	NB-IoT	5G
Standardization	LoRa WAN	Sigfox	Weightless SIG	ISO/IEC 18,000–7	3GPP	3GPP	3GPP	3GPP
Frequency	868 MHz 433/ 915 MHz 430 MHz	868 MHz 902 MHz	433/470/ 868 MHz, 915 GHz, 430 MHz	433/868/ 915 MHz	Licensed	Licensed	Licensed	24–100 GHz
Data rate	250 bps–50 kbps	100 bps (UL) 600bps (DL)	200 b/s–100 kb/s	167 kb/s	UL/DL: 1 Mb/s	70 kb/s	DL– 234.7 kb/s UL– 204.8 kb/s	20 gb/s
Range (km)	5(urban)15(rural)	10(urban) 50(rural)	2	5	11	15	15	1000 feet
TX output power, dBm	EU: 13 US: 20	EU:14 US: 21.7	17	433 MHz: +10 868/ 915 MHz: + 27	23	20 or 23	23	49
Band width per channel	0.3 MHz: 863–870 MHz 2.16 MHz: 902–928 MHz	100 Hz (600 Hz USA)	12.5 kHz	1.75 MHz	1.4– 20 MHz	200 kHz	180 kHz	1000/area
Modulation	Proprietary CSS	DBPSK (UL) GFSK (DL)	GMSK offset QPSK FMDA + TDMA	GFSK	OFDMA SC-FDMA	GMSK, 8PSK	GFSK BPSK	OFDM, CP-OFDM
Transmission technique	FHSS (Aloha)	UNB	TDMA	BLAST	FDD/TDD	FDD	FDD	FDD

(continued)

Table 2 (continued)

Name of the prameter	LoRa	Sigfox	Weightless	Dash7	LTE-M	EC-GSM	NB-IoT	5G
Battery operation	Many years	Many years	10 Years	Upto 10 years	+10 Years	+10 Years	+10 Years	+10 Years
Security	AES CCM 128	Key generation	AES-128	AES-128	AES 256	AES 256	NSA AES 256	EAP–AKA
Mobility	Yes	No	Yes	Yes	Yes (limited)	Yes	No	Yes

quality of life, different IoT applications are emerged almost all in every domain related to everyday life of a human being [19, 20].

There is no such domain where IoT cannot be implemented; it can be in every field; various IoT devices are developed to satisfy the customers and still developing as per customer specific requirements. Here in this paper, the numerous, diversified IoT applications are broadly categorized as follows:

4.1 Consumer Applications

Consumer application refers to the applications designed for the use of individual or a group of people for the ease of performing tasks. Many IoT applications are designed for consumer use, which includes smart home, wearables, general health care, asset tracking, remote access of workplace and entertainment appliances. Requirements of consumer applications include short-range, peer-to-peer communication, and small amount of data.

4.2 Commercial Applications

Commercial IoT is applicable for the environments where gathering of people on regular basis happens like offices, schools, hotels, hospitals, shopping center's etc. For satisfying the commercial requirements, many applications are available in present market such as smart office, location services, monitoring environment, connected lighting, asset tracking, medical health care and many more.

4.3 Industrial Applications

Industrial Internet of things (IIoT) is buzz word among different industries and IoT providers. IIoT exactly means to be industries with decades of expertise start developing or upgrading their hardware equipment's and software methods to integrate with IoT solutions [21]. IIoT devices gather the information from connected equipment's and analyzes the data to regulate and monitor the system. Gateways are most essential to provide IoT solutions to industries. Manufacturing units of any industry might be installed a decade back so to analyze the system and to provide scalability, we need to transfer the data to cloud for processing. Gateways act as a bridge between sensors or controllers and cloud. Gateways also used for data logging and processing solutions. The revolutions in present industrial fields are driving toward the smart industry which will be mention as fourth generation as Industry4.0 where every industry will be connected with the internet.

4.4 Infrastructure Applications

IoT takes a big part in developing, monitoring and controlling of any type of infrastructure. Infrastructure development and upgradation is essential to sustain for the technological changes. Infrastructure IoT can be applied for monitoring the structural health of buildings, bridges, and railway tracks, and it also helps to minimize the time and cost of infrastructure development [22].

5 Matching Application Requirements with Available Technologies

IoT is a collection of various technologies and endless applications. Billions of devices are connected to the internet to provide the smart services. The reason for the emergence of huge number of applications in IoT is that the requirements of applications vary from one domain to another. So there is a driving force toward development of new technologies to meet the application specific requirements. The existing traditional technologies also participating in this drive by updating like Bluetooth smart from classic Bluetooth, and Zigbee-IP from Zigbee to address the IoT requirements. New standard of technology such as IEEE 802.11ah is released for satisfying the key requirements of IoT like low-power consumption, reduced operational cost, low computations, and a wider coverage range.

Electing the perfect technology is the vital step of designing process of the application. To achieve this, some considerations must be in account like reliability, security, speed, power consumption, cost, etc. In previous sections of this paper, the various available technologies are described, and compared with metrics, later IoT applications are explained with their requirements. In this section, we are trying to match the application requirements with the technologies which help the customers to choose the best fit for their application.

However, all the technologies will have their own advantages and disadvantages. There will be always trade-off between power consumption, range, and data rate. As mentioned in the last section applications of IoT falls into different categories. Few require only peer -to-peer communication, other may operate in personal area network, and high end applications may involve heterogeneous devices over a wide area. So the technology suitable for one application may not be suitable for other applications. IoT develops an ecosystem to integrate the different technologies and devices to be communicated from anywhere and anytime.

For low-power applications, IEEE 802.11.ah is preferable over BLE and Zigbee as it able to cover the area of 1 km. For long range with low-power applications, LoRa is preferable with the range of 15 km. If application consists of large number of nodes, Zigbee may be the best choice due to its mesh networking and even provides high data rate. In long-range technologies, cellular technologies like NB-IoT have large network size but as it uses licensed frequencies which increases the cost involved. Whereas LoRa can also accommodate larger number of devices and comparatively with lesser cost but the QoS matters. In view of energy consumption, IEEE 802.11.ah is specifically designed for low-power consumption but Zigbee considerably showing less power requirements in congested networks. In long-range technologies, the low-power requirement will be satisfied by LoRa, contrarily NB-IoT is having high-power requirements. As per the applications and specific requirements, suggested technologies are tabulated in Table 3.

Table 3 Application specific requirements and suitable technologies

Domain	Application	Application specific requirements	Suitable technology
Smart home	Smart appliances	Peer-to-peer communications, short range, low data	BLE, Zigbee, IEEE 802.11.ah
	Intrusion detection	Large amount of data	WiFi
Smart city	Structural health monitoring	Long battery life, low amount of data	LoRa
	surveillance	High speed, QoS	Wifi, 5G
Smart Energy	Smart grid	Reliability, security	NB-IoT
	Renewable energy management	Reliability, security	NB-IoT
Retail	Smart Payments	Nearby communication	NFC
	Inventory Management	Identification and monitoring	RFID
Logistics	Shipment Monitoring	Long range, connectivity, Long battery life	LoRa
	Remote vehicle diagnosis	Frequent transmission, mobility	LoRa, NB-IoT
Agriculture	Pest control	Long range, connectivity	LoRa
	Cattle monitoring	Long range, connectivity	LoRa
Industry	Machine diagnosis	Short range	Zigbee, Wireless HART
	Indoor air quality	Low data, short range	Zigbee
Healthcare	Wearable's	Low-power consumption, less data	BLE
	Medical equipment monitoring	Identification	RFID
Environment	Weather monitoring	Reliability, security	NB-IoT
	Forest fire detection	Long range, connectivity, Long battery life	LoRa

6 Conclusion

The IoT is capable of becoming a transformative power, having a positive effect on the lives of millions around the world. It aims to bring about a big shift in the efficiency of individuals quality of life and of companies via a massive, regionally sensible network of smart devices. IoT has the capacity to allow extensions and advancements to simple offerings in delivery, logistics, defense, utilities, education, healthcare, and other areas. It also offering brand new surroundings for the development of applications. To participate in this ecosystem, we tried ourselves to study about the available wireless communication technologies for the IoT and made an attempt to indicate the excellent applicable technology for the utility primarily based on precise requirements of specific application. For this, we provided records of well-known wireless technologies within the market with the aid of classifying them depending on the variety and compared with their parameters; later, IoT application areas and their necessities have been discussed. And eventually, we provided excellent matched technology based on the utility particular necessities.

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