Comparison of the Wireless Technologies applied to Internet of Things (IoT)

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Abstract: Internet of Things (IoT) is rigorously growing as the corporates are applauding the necessity for the efficient connectivity among the devices. IoT integrates numerous short-distance, long-distance and wireless technologies in the outline of the IoT applications. In brief, IoT points to a vastly expanding group of objects connected, which can gather and interchange information by making use of the embedded sensors. SigFox, Narrowband-IoT (NB-IoT) and LoRa technologies are acquiring a proficient quantity of recognition globally. The aim of these wireless technologies is to encourage the operators of the mobile networks to embrace their technology for the implementation of IoT applications. The other wireless technologies like Bluetooth, ZigBee, GPRS and Wi-Fi are also discussed. The paper assesses the potential and conduct of the following technologies by taking many factors in to account, such as data rate, range of communication, bandwidth, power consumption. It is established that, a multifarious technology is required to be unfolded to allow practical and reliable communications in the field of IoT.

Index Terms **- Bluetooth Low Energy, Internet of Things, LoRa, NB-IoT, SigFox, ZigBee IP.**

I. INTRODUCTION

IoT or Internet of Things is an emerging trend and is gaining high popularity in modern world. Every object is connected to every other object over a network. New technology and ideas are emerging up day by day to improve the products in the market and make our lives easier. IoT enables the control and monitoring of various object without the presence of human on the spot. It has eased the human life. Controlling street lights from a remote distance, smart food order system, etc., is no longer a dream. IoT connects objects such as sensors, electronics, actuators etc. with network connectivity. They can then stay connected with each other and exchange data between them to achieve a certain functionality. Experts say that around 30 billion IoT connections will be made by 2020. At present around 16 billion objects are connected by IoT. The concept of IoT was seeded in early 1982 when the first coke machine connected to the internet was invented. It reported its inventory whether the newly loaded drinks were cold or not. Now at 2016 the Internet of Things has bloomed tremendously as multiple technologies such as wireless communication, machine learning, real time analytic and embedded systems come together. That is IoT is nothing new but the various old and traditional technologies working together. Many technologies together are responsible for creating an IoT application. But the most crucial is the network that enables the devices and objects to communicate between them. The network can be created using any wired or wireless technologies. These range from short range, medium range to long range technologies. Some of the examples are Bluetooth, ZigBee, Wi-Fi, ethernet, cellular, low power wide area network communication etc. All these technologies have their own advantages and disadvantages. Based on the application, the technology best suited for the application must be chosen to get an effective and efficient output. Out of these technologies LoRaWAN is an upcoming technology that has added itself to the family of IoT due to its long-range capability and less power consumption capability. These are a good choice for battery operated embedded systems. In the paper a comparative study is done on the wireless technologies evolving in the field of IoT

II. LOW POWER WIRELESS TECHNOLOGIES CONCERNED WITH IOT

The wireless technologies serving the IoT is required to have some specific attributes, such as prolonged lifetime of the battery, economical device cost and installation cost, wide coverage. The Internet of things incorporates a wide assortment of devices and accomplishments. One of the pioneer networks to be used for the services related with small data rate is GPRS. In the case of GPRS, the nodes are required to send the periodic summons to find the appropriate base station to do the signaling efficiently. This consumes more power, as the device must wake up at regular intervals to check for the signals. Another technology which a suitable aspirant for IoT is the protocol 802.11. Illustrations pertaining to the application of Wi-Fi in the field of IoT are mentioned in [1]. Wi-Fi has evolved to be a favored wireless technology for connecting to the internet. The extensive adoption of Wi-Fi makes it as an effective selection for many of the applications pertaining to IoT. The selection of technology in few IoT implementations is narrowed by requirements such as low power consumption, hardware proficiency and the total cost. Most of the applications requisite the adoption of low power and economic cost technologies to connect to internet [2]. The power consumption has been a restraint in various devices working via the wireless technologies. Along with this, the cost and security of technology, range of communication, data dates and ease of use must also be considered [3]. ZigBee and Bluetooth are the other advancing wireless technologies offering connectivity with low power features. LoRa and LPWAN are among the significant developments in the field of IoT [4]. The wireless technologies offering low power features are developing the connectivity of the devices to the cloud and in addition they are also offering a very reliable and efficient operation.

a. Wi-Fi (IEEE 802.11)

Presently the widely used technology to obtain the connectivity to the cloud is Wi-Fi. It is the most commanding WLAN standard technology for the broadband access in the indoor scenarios [6]. The operating frequency bands of Wi-Fi are 2.4 GHz and 5GHz bands. When operating in 5 GHz band, the data rate is high, and the number channels are also more. The coverage distance of 5 GHz is shorter than 2.4 GHz in the indoor regions. Two variants of Wi-Fi, IEEE 802.11b and IEEE 802.11g operate in the license free band known as ISM band. The range of Wi-Fi inside the buildings is around 20 meters and it is marginally higher in the outdoor scenarios. Multiple inputs and multiple outputs are pioneered in the IEEE 802.11n version [7]. The supported data rate is in the sweep of 54 Mbit/s to 600 Mbit/s. The improved version of IEEE 802.11n is IEEE 802.11ac, which has a higher throughput networks in the frequency band of 5 GHz. It gives a higher data rates up to 433.33 Mb/s along with prominent modulation with MIMO. IEEE 802.11ah is another version of Wi-Fi, that operates in the 900MHz frequency band, which is also unlicensed. These signals have the capability to perforate through the walls with a restricted bandwidth in the range of 100Kbps to 40Mbps. The power consumption in the Wi-Fi is excessive when compared to other wireless technologies, which is a concern in case of battery operated devices. The advantages and disadvantages of the Wi-Fi for the IoT are shown in Table 2.1. The power-hungry nature of the technology is a major setback, along with this the spectrum congestion and low distance coverage adds to the limitations. Hence, it can be concluded that Wi-Fi is not a feasible candidate for IoT and it is more flexible with smartphones and medium for internet connection.

Table 2.1: Advantages and disadvantages of wi-fi applied to IoT

Pros	Cons
Economical: The cost of the devices and infrastructure is low. Efficiency: the data rate is high and hence the communication is more efficient. Flexibility: The users are confined to a single location while accessing the network. This allows additional organized use of the areas within the office or home premises. Accessibility: Wi-fi is commonly found in public places like hotels, railway stations, bus stands, café etc. Its handy signal makes it simple and straight-forward to bind to the internet	High power consumption: The power consumed is higher and hence cannot be used for low power applications. Speed: The rate of data transmission is slow when compared to other technologies. Limited Coverage: Wi-Fi has a limited range of 20 meter. Security: Wi-Fi is very much prone to security attacks. According to researchers, the security protocols of Wi-Fi can be broken, and malicious eavesdropping and attacks can be hatched easily. It may also lead to unapproved access to the personal data of the user and stealing of sensitive data such as passwords, bank information etc.

b. SigFox

SigFox is the name of the company as well as the name of a technology. It us a narrowband technology that makes use of binary phase-shift keying. BPSK is a standardized method of radio transmission. The technology encodes the data by taking small chunks of the spectrum and modifying the phase of the carrier signal. The radio required has an affordable price, while the base station needs to be more advanced to organize the network. The sensitivity of the base station should be in the range of -142dBm for 100 b/s uplinks and for the downlink of 600b/s the sensitivity should be -134dBm [5]. The bidirectional communication is extended by SigFox, although the downlink capacity is finite. The limitation of the technology is that only a single SigFox network can be implemented in a region, as it requires exclusive alignments with the operator providing the network. Apart from this, the other constraint is that the technology cannot be relevant for continuous communication. the reason for this shortcoming is large latency with a very small certainty. The advantages and disadvantages of the SigFox for the IoT are shown in Table 2.2.

Table 2.2: Advantages and disadvantages of SigFox applied to IoT

Pros	Cons
Low power: due to the absence of the circuitry for the receiver side. Long range: obtained by compromising with slow modulation. High network Capacity: SigFox can accustom large number of channels in the identical space as it is a narrow band technology. Hence effective utilization of physical channels is achieved. Robust to interference: uses sophisticated signal processing algorithms to attain resistance against various interferences	Not an open standard. Lower data rate: since it has low data rates, it cannot be deployed in the applications requiring high data rates. Testing is less robust: It has different architecture for US and Europe due to FCC regulations on length of transmission. Hence testing is not much robust as expected to be. Less secure: It has minimum security as it adopts 16-bit encryption. Mobility issues: It incurs interference and frequency imprecisions in the scenarios involving mobility. Unidirectional Communication: It doesn't send back the acknowledgement. This creates the certainty of multiple transmission of the same data even if it received by the other end without any errors. This leads to the slight increase in the power consumption.

c. Bluetooth Low Energy

Bluetooth is a wireless technology suitable for short distance communications. It allows the functioning of electronic gadgets without any wired connections. For instance, cordless mouse, Bluetooth headphones, syncing of devices etc. The Bluetooth transceiver functions in the 2.4 GHz in the license free ISM band. Bluetooth Low Energy (BLE) is an improved version of the standard Bluetooth technology [8]. BLE is associated with low power consumption features. The BLE creates remarkable openings for multiple IoT applications. Some of the illustrations are health monitor device in e-health, home automation applications, retail appliances etc. Apart from these, BLE finds significant accomplishment in various fitness devices and wearables that blend with smartphones. For the communication within the range of 100km, along with the requirements of low cost and low power, BLE has dominant possibility of turning in to a requisite technology for IoT [9]. The advantages and disadvantages of the BLE for the IoT are shown in Table 2.3. The smartphones have become a vital part of our day to day lives, BLE performs a remarkable role in furnishing the medium for communication between the IoT devices and the gateway. The throughput of BLE is 0.27 Mb/s and the data rate over the air is 1 Mb/s [10].

Table 2.3: Advantages and disadvantages of Bluetooth Low Energy applied to IoT

Pros	Cons
Minimized power consumption: Power consumed is less in comparison with the basic Bluetooth, while preserving the equivalent range. Ideal for battery operated applications: BLE enters sleep mode when it not in use. It gets triggered upon receiving of data and wakes up. Power is conserved, and it is suitable to be used for applications running on battery. Real-time operation: The connectivity between the node and the master can be done, the data can be sent, and the connectivity can be terminated within 3ms. Simplicity: The design of the radio is like that Bluetooth radio. It can be handled by simple protocol stack.	The initial setup time is large. It can deal only with less amount of data. Low range: The range of BLE is limited to 33 feet. It is not ideal to be utilized for attending calls over phone like Bluetooth headset, as it is accustomed to deal with small chunks of data.

d. ZigBee IP

ZigBee is an IEEE 802.15.4 standard, that is exclusively developed for the sensor and the control networks. It defines the MAC layer and the physical layer to manage the devices at small data rates. The range of ZigBee is around 10-100 meters. It is more economical when compared to other wireless technologies like Bluetooth and Wi-Fi. The battery can be conserved as it offers multiple modes of operation. For building a wide area network, ZigBee can be expanded to utilize router and multiple interconnected nodes. ZigBee IP is an advancement to the standard ZigBee protocol, that integrates the low power WAN technologies [11]. This collaboration of technologies provides a resolution that permits the expansion of the networks based on IEEE 802.15.4. The data rate of ZigBee in the range of 20 kbps to 250 kbps [12]. It works in the 2.4 GHz license free band. The IPv6 based networking is supported by ZigBee- IP. The pros and cons of ZigBee IP for the IoT are shown in Table 2.4.

Table 2.4: Advantages and disadvantages of ZigBee IP applied to IoT

Pros	Cons
Conserves Battery life: The power consumption in ZigBee IP is very much lesser than Wi-Fi. For an application, with the same batter, the Wi-Fi will last only for few days, while the ZigBee IP lifetime will be in the range of several weeks. Cost: It is economical. The terminal unit cost is also less. Linking time: It has very short linking time of 30 ms. Design complexity: It has a simpler design.	Low data rate: The data rate is low when compared to Wi-Fi. No smartphone support: Digital devices like laptop, phones, tablets, iPod are not furnished with any chip to support ZigBee IP within them. Maintenance: Many engineers and IoT tools are provided to constantly configure the Wi-Fi. This facility is yet to be provided for ZigBee IP.

e. Narrowband IoT (NB-IoT)

It is the contemporary communication technology that transmits compact chunks of data for long intervals to the distant locations. It is one of the LPWAN type, that is enlarged to maintain a series of devices and application of IoT. It offers a long lifetime of battery up to 10 years for different scenarios. NB-IoT was mainly developed to offer the solution to the rapidly growing demand for long range communication in both the urban and rural places. The price of this technology is comparatively same as that of GPRS. With the increasing demand, it is awaited that the cost will drop down. The mobile network characteristics such as, verification, identification, integrity, confidentiality is beneficial to NB-IoT [13]. NB-IoT can synchronize with 2G, 3G and 4G networks as it is assisted by leading mobile resources and module fabricators. The advantages and disadvantages of the NB-IoT are discussed in Table 2.5. The initiation of NB-IoT is accomplished and it is expected to be accessible by 2018.

Table 2.5: Advantages and disadvantages of NB-IoT applied to IoT

Pros	Cons
Low power consumption: 1nA of power allows the devices to	NB-IoT is not suitable to be used in applications where data

function for nearly 10 years on a lone charging cycle. Low cost: The device and the module costs are economical Better Coverage and Penetration: It has reasonably high range of communication. Along with this it has enhanced penetration in bot indoor and outdoor scenarios. Reliable: The bi-directional is secured with intense authentication. Physical infrastructure already available: Fast roll-out and ready to be released to the market. Telco provided: Demonstrated capacity to furnish the bundle of mobile networks with superior service level. International standard: Roaming can be awaited shortly.	must be stored in-house, on physically secured servers. Lack of flexibility: The NB-IoT standards and the operators put forth many restrictions on the configurations and capacity, which diminishes the user flexibility. Security: Since it makes use of the prevailing cellular framework, NB-IoT comes with inbuilt security. As it is a technology working based on TCP/IP, it is prone to security attacks.

f. LoRaWAN

As discussed earlier, wireless technologies like Bluetooth Low Energy, ZigBee IP, SigFox, Wi-Fi, NB-IoT furnish low power provisions for multiple IoT applications. But the major constraints which limits these technologies is the coverage. These flaws don't make these technologies ideal to be established in smart city solutions and distant IoT applications. Various IoT devices powered by battery sends and receives the data over wide stretches. To solve the short distance drawback of these wireless technologies, LoRaWAN is been developed.

LoRa technology is a patented wireless technology for the data communication. It was developed by Cycleo of France. In the year 2012, Semtech acquired it. It is distinctly designed for low power and wide coverage communication. The public or multi-tenant networks will have the access to connect and share data with multiple applications which are running on the same network. It is popular in battery operated systems which sends small chunks of data at longer distances in a regional, national or global network. The complete city can be covered by a single gateway of LoRa, like the cellular network [14]. The difference between the cellular and LoRa is that, the cellular network technology provides higher value of throughput, while LoRa is specifically developed for IoT devices that transmits small chunks of data over large extents.

The network architecture of LoRaWAN consists of the end nodes, the gateway, the application server and network server. The nodes are the one that does the sensing and information collections. It consists of sensors, actuators, meters etc. The information from the end nodes are broadcasted to all the gateways present. The gateway is a transparent bridge between the network server and the end nodes. The network server has all the intelligence. It collects the information or data from the gateway does the security check, filter the receive packets, does adaptive data rate, send acknowledgement to the gateway etc. Then the data is passed on to the application server.

LoRaWAN uses star topology as it increases battery lifetime and provide long range connectivity. The data communication is generally bi-directional in the LoRa technology. The uplink path will have a higher traffic when compared to the downlink. For the successful implementation of star topology, the capacity of the gateway must be very high since these have to receive data from high volume of nodes. This is achieved by adaptive data rate. The adaptive data rate enables the reception of different data rate at the same time on same channel. The nodes with a good link and closer to the gateway can use higher data rate and free the spectrum faster. There is no need for these nodes to use lower data rate. This also reduces the time on sir and thus more nodes can then transmit on the channel. The multichannel multi-modem transceiver enables the reception of messages simultaneously on multiple channels. The advantages and disadvantages of the LoRaWAN for the IoT are discussed in Table 2.6.

Based on the application the end devices have different requirements. To serve those requirement efficiently LoRa has three classes [14]:

Class-A: Class A devices allows the communication in both the directions. The uplink transmission of each end device is trailed by two short downlinks receive slots. When end device wants to transmit, it schedules the transmission slot following the Medium Access Control Aloha. The power consumption is lowest in class A when compared to other classes. The server communication with the end device will be halted till the next uplink that is scheduled is completed. This class, supported by all devices, is intended for battery powered end-devices or actuators with no latency constraint. It can be useful for transmissions mainly in the uplink sense such as sensors for control temperature, traffic, metering, monitoring, mobile asset tracking.

Class-B: The class-B end devices provide extra slots for the receive window. In addendum to receive windows of class-A, class B end-devices opens additional slots for the receive at organized times. The gateway generates a beacon that is synchronized in time domain, which opens an extra receive slot. This will help to notify the server about the timings at which the end-device is listening. This class can be handy for battery powered devices where bidirectional sensors links are applicable, such as, reading a sensor with periodic control/configuration, alarm sensors with ensured alarm delivery.

Class-C: Class C devices have receive-windows which are continuously open. The receive windows are closed when transmitting data. The power consumption by Class C end devices is greater than other classes. The advantage is that the dormancy for the communication between the server and end device is lower when compared class A and class B. This class can prove beneficial in cases where the necessity of downlink communication may arise at any moment, such as: industrial control, real time control of pumps/valves, residential gateways, lighting control, car engine status, car tracking.

Table 2.6: Advantages and disadvantages of LoRaWAN applied to IoT

Pros	Cons
Highly Robust: LoRa has high resistance to the following interferences, such as in-band and out-of-band. Also, it is fully asynchronous in nature of operation. Multipath/fading Resistant: The chirp pulse used for the modulation process has a higher bandwidth and thus offering immunity to the fading phenomenon. This advantage makes LoRa suitable to be applied in the in urban scenarios. Capacity to have a coverage of long distance: This is because of the comparatively higher value of link budget for a fixed throughput and output power. Enhanced Network Capacity: Orthogonal spreading factors provides for the multiple transmissions at the same time and on the same channel. Localization: It is a dominant characteristic which provides the potential to the LoRa technology to discriminate between the time errors and the frequency	Data Rates: The utmost rate of data transfer which can be achieved is 50kpbs. Latency: Although it has modulation technique with low latency, it is not enough to service real time applications requiring very rapid response time. The network size of the LoRaWAN is restricted by duty cycle. It is not an absolute prospect to be utilized in implementations demanding low latency along with bounded jitter necessity.

III. COMPARISON OF SOME OF THE CURRENT LPWAN TECHNOLOGIES

In this section, the current LPWAN technologies are compared with respect to the IoT applications. The attributes considered for the comparison are range, battery lifetime, band, channel width, modulation technique used, power, sensitivity, topology, mobility, data rate etc as shown in table 2.7.

Table 2.6: Comparison tables for various technologies

ATTRIBUTES	GPRS	NB-IoT	Wi-Fi	SigFox	LoRa
Range	5 km	2-5 km in rural areas	1km in rural areas	5-10 km in urban and 100km in rural areas	5km in urban, 15km in rural areas
Battery lifetime	1 week	5 years	1 week	10 years	10 years
Frequency	8-900 MHz	7-900 MHz	2.4 GHz	865-868 MHz/ 902-928 MHz	433/868(Europe), 780/915(USA), 902 MHz (Asia)
Band	Licensed	License-d or shared	Unlicensed under 1GHz	ISM license free band	ISM license free band
Channel width	200 kHz	200 kHz	1/2/4/8/16 MHz	100 Hz	≥125 kHz
Modulation technique	Time division multiple access	Frequency division multiple access(uplink), Orthogonal frequency division multiplex(downlink)	Time division multiplexing/ Orthogonal frequency division multiplexing	Binary phase shift keying	Chirp spread spectrum
Power Transmitted	Up to 43 dBm	20 dBm	0 dBm to 30 dBm, depending on region	Up to 20 dBm	EU: 14 dBm, US: 27 dBm
Sensitivity	-114 dBm	-123.4 dBm	-92 dBm	-142 dBm	-137 dBm
Topology	Star	Star	Star, tree(2-hop)	Star	Star
Mobility	Yes	Yes	No	No	No
Uplink Data rate	10 kb/s	150 kb/s (NB) < 1 Mb/s	150 kb/s, up to 300 Mb/s	100 b/s	EU: 30 b/s-50 kb/s US: 100-900 kb/s
Downlink data rate	10 kb/s	150 kb/s (NB) < 1Mb/s	150 kb/s, up to 300 Mb/s	4x8b/day	EU: 30 b/s-50 kb/s US: 100-900 kb/s
IPv6 support	No	Yes	Likely	Unlikely	Likely
Duplex mode at gateway	Full	Full	Full	Half	Half
Commanding body	3GPP	3GPP	Wi-Fi alliance, IEE standards	SigFox	LoRa alliance
Deployment status	Deployed for several decades	Planned	Planned	Deployed since 2009	Planned

Number of nodes per gateway	5000	50000	8191	1000000	250000

We have concluded from the comparison that the LoRa technology has the longest range, low power consumption and highest battery lifetime up to 10 years. Along with these, the additional benefit is that it uses the license free ISM band. The sensitivity is highest in LoRa technology, making it most suitable for IoT applications. Hence LoRa technology can be deployed for the battery-operated embedded applications requiring low power consumption, which sends small chunks of data over long distances.

IV. Conclusion

To empower the foresight of IoT for expanding communication to almost everything and everywhere, the internet must assist linking things by utilizing various mobile and wireless technologies. In this paper we have reviewed few wireless technologies in the field of IoT specifically, Wi-Fi, Bluetooth Low Energy, ZigBee IP, SigFox, LoRa and Narrow band IoT. We have discussed about each technology in brief and evaluated their capabilities and limitation with respect to diverse attributes. A comparison of some of the widely used and commercial technologies is done by taking several factors such as, data rate, frequency, band of communication, power consumed etc. each technology has its own advantage in its field of application. It is very difficult to uphold any one of the technologies for the applications and services in the field of IoT. It should be taken in to account that the low cost and low power features of these technologies and their association in IoT requires advances security, management and privacy protection mechanisms. There is a necessity to organize exceptional tally of things bridged to the internet creating a huge volume of traffic across different network, specifically low power networks. Hence, the challenge lies in providing support to the interoperable and secure communications in between these multiple technologies. The excellent and outstanding solutions to the IoT applications can be provided by designing an ecosystem of concurring devices instead of making islands of networks.

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