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LoRa technology-an overview

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***Abstract*— IoT is gaining high popularity in today's world. Embedded systems have become a major part of our lives. People are able to control, monitor, and do a lot more from remote distance. This is done by connecting various objects reducing physical distance. IoT is the connectivity of various objects with network connectivity. Many a times these systems are battery operated and need a high battery backup. These systems require a technology that consumes less power and also covers long distances. But many technologies such as Zig-Bee, Wi-Fi, Bluetooth popularly used at present consumes high power and is not suitable for battery operated systems. LoRa is a new found technology that is emerging rapidly. The LoRa technology addresses these needs of a battery operated embedded device. The LoRa technology is a long range low power technology. This paper discuses about the advantages of LoRa over the existing technologies used in IoT. It also discusses the features of LoRa. LoRaWAN (Long Range Wide Area Network) is an open grade secure standard for the IoT connectivity. The LoRa alliance is an open non profitable group that shares their experience to drive LoRa.**

Keywords*— IoT, LoRa, LoRaWAN, LoRa Alliance, Embedded Systems.

I. INTRODUCTION

Now is the era of connected objects. IoT (Internet of Things) is gaining much importance in almost every field such as business, industry, consumer electronics, automotive and much more. Every object in today's world is well connected to each other in one way or the other. We can control the lights and equipment in our homes sitting in our office. In industries and other fields activities are regulated and controlled from a remote location. Controlling street lights from a remote distance, smart food order system, etc., is no longer a dream. Gone are the days where the presence of the person on the spot was necessary for the monitoring and control. Technology has advanced to an extend where everything can be made possible sitting in your house or in your office cubicle. IoT plays a major role in this. IoT connects various objects such as sensors, actuators, electronics and network connectivity that enable the objects to exchange data between them and stay connected. It is a network of physical objects. According to Machina Research, connected objects will account for more than 25 billion connections by 2025 [3] [7]. At present 16 billion objects are connected by IoT with industries, smart cities and smart homes contributing the highest number. A large number of objects are connected by technologies such as GSM, ZigBee, Wi-Fi, and Bluetooth. But in all these power requirement and battery life is a major issue. Most of the applications in today's world are embedded systems. These systems have very high power constrains as most of this system are battery operated and not externally powered.

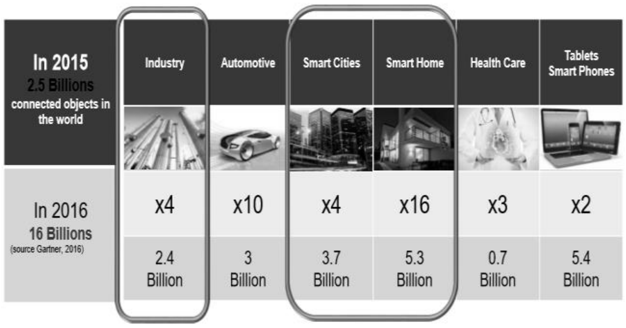

Fig 1. IoT market growth

LoRa (Long Range) is a new wireless IoT connectivity family that has recently evolved and is gaining popularity in low powered battery operated embedded systems that need to transfer small amount of data at short intervals over long range [1].

II. COMPARISION OF LoRa WITH VARIOUS EXSISTING TECHNOLOGIES

There are numerous technologies in today's world that is used in IoT applications. Every technology has its own features, merits and demerits. One technology cannot serve all the applications of IoT [4]. Different applications will have different requirements. No technology can be said as the best technology. Each technology differs from other in different aspects. Applications also differ from each other in their requirements and their usage. Based on the requirement we can only choose a technology that is best suited for the specific application from the existing technologies.

Wi-Fi is the most popular technology that has been recently evolved and is used in long distance communications. We have Bluetooth, ZigBee, etc., for short distance as well and these can and are being used in various IoT applications. But in all of this battery is a major concern. LoRa enables secure bi-directional, low cost and mobile communication for IoT, smart city, machine to machine (M2M) and industrial applications. LoRa or LPWA (Low Power Wide Area) is a generic term for a group of technology for wide area communication. LoRa is rapidly gaining high popularity and is a preferred technology for IoT embedded systems because of its Long Range, high capacity of nodes in network, long battery life, bi-directional, secured and efficient network, interference immunity.

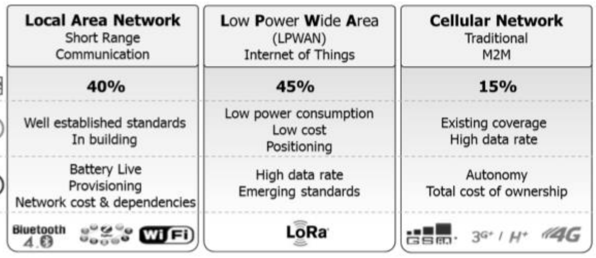

Fig 2. Comparison of LoRa with various other technologies

A. LoRa versus Cellular Network

The traditional cellular network consisting of GSM, 2G, 3G, 4G are very popular and widespread. These are one of the well-established networks. But these were traditionally built for high data throughput and so these do not optimise the power consumption [11] [12]. These technologies consume too much power and are not a good option when small amount of data is to be transmitted less frequently. The total cost of ownership is also very high. With the advent of the 5G technology many of the cellular providers are discontinuing 2G services orphaning the IoT devices running. The LoRa technology on the other hand comes with a lower power consumption rate and is very much suitable were small amount of data is to be transmitted over long distances.

B. LoRa versus LAN

LAN or Local Area Network is a widely adopted standard. It is used within a limited area such as in buildings, schools, office, laboratories etc. LAN can be wired or wireless. Ethernet and Wi-Fi is the commonly used technologies in LAN. The wireless technology used in LAN is the Wi-Fi. Wi-Fi stands for wireless fidelity. They provide a wireless link for communication. The Wi-Fi is usually confined within a small area such as a building, home office. It can span over a limited range that is 1 km in radius [8]. But Lora technology provides a long range. A single LoRa gateway can span an area of 100 km^2. The quality of service of Wi-Fi is poor. The Wi-Fi is always flooded with huge number of data and is difficult to distinguish between the data and many a time data is not received by the correct receiver. The LoRa technology in other hand has reasonable quality of service. Wi-Fi is wireless and so the security is low [9]. Anybody can interfere with the data during transmission. It was a very poor encryption and cannot be regarded as secure. On the other hand, the LoRa offers double AES encryption. The security of LoRa is very high. The LoRa is based on chirp spread spectrum (CSS) which is highly resistant to multipath and fading.

C. LoRa versus ZigBee

ZigBee is based on high level communication protocol used to create personal area networks. It consists of small low power digital radios. These are best suited for small scale projects that need to transfer data over small distances. Its range is 10 -100 meters. These are based on mesh networks that transmit data over long distances by transmitting data to many intermediate devices [10]. This consumes power and thus is not suitable for applications with low power requirements. LoRa on the other hand is based on star topology that eliminates the transmission of data to intermediate devices thus decreasing the power expenditure to a great extent. Also mesh networks are suitable for short to medium range communications and do not have the long-range capability of LoRa technology.

D. LoRa versus NB-IoT

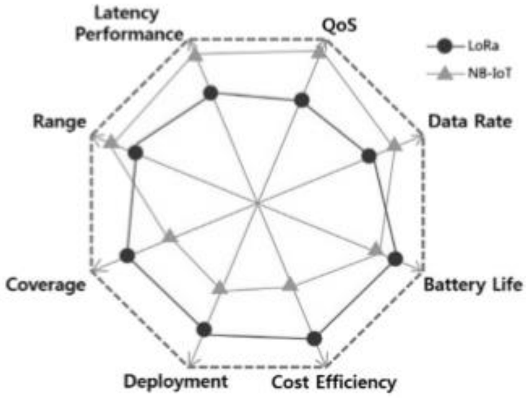

Fig 3. Comparison of LoRa and NB-IoT

NB-IoT stands for narrow band IoT. Both NB-IoT and LoRa are emerging technologies and are of great importance. As every technology both of them have their own advantage and disadvantage. Both of them are suited for different applications based on their features. The LoRa technology is based on ALOHA and is asynchronous while the NB-IoT is based on FDMA [3]. It needs infrequent synchronization which leads to higher battery consumption than the LoRa technology. But the latency and the data rate of NB-IoT is good contrary to LoRa [3]. So those applications that require high latency and need high data rate can use NB-IoT while the ones with lower data rate requirement can choose LoRa. LoRa technology is most suited for IoT industry while the NB-IoT is suited for IoT personal and IoT public.

III. NETWORK ARCHITECTURE

LoRa is a physical layer that provides a long-range communication link. This has been standardized and extended by adding a MAC layer LoRaWAN (Long Range Wide Area Network) to it. This defines the network architecture and communication protocol. LoRaWAN specification is standardized and open sourced by the LoRa alliance.

Most of the existing technologies are based on mesh network. In the mesh network the infrastructure node is connected to as many nodes as possible and cooperates with one another to route the data. In the mesh network each node receives and forward data from other node that might be irrelevant for it. This increases the range to a great deal but also adds complexity and decreases the battery life. On the other hand, in the star topology the bridge or switches are directly connected to a small subset of bridge or switches deceasing complexity of the network. These provide a hierarchical infrastructure. LoRaWAN is based on star topology. They decrease the power consumption and battery life to a great extend in comparison with the conventional mesh network.

The LoRa network consist of four basic elements

- The LoRa node or End Points
- The Gateway
- The Network Server
- Application Server

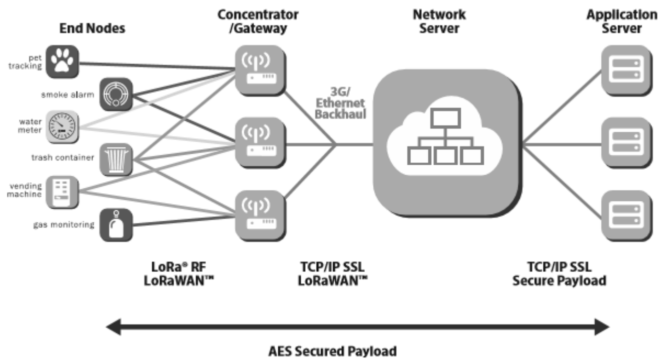

Fig 4. LoRaWAN network architecture

A. The LoRa Node or End Points

The end points or LoRa nodes comprises sensors or application where sensing and control takes place such as sensors, tracking devices, etc., [1] [4]. This is the heart of an embedded system. These include water meter, smoke alarm, gas monitoring and such applications.

B. The Gateway

The gateway comprises the net element of the LoRa network. There are a number of gateways [1] [4]. Each gateway is connected to every end node. The data transmitted by the node is sent to all the gateways and each gateway which receives a signal transmits it to a cloud based network server via cellular, Ethernet, satellite, or Wi-Fi. The gateway can be micro gateway or pico gateway. Micro gateways are used in public network to give city or nationwide coverage while the Pico gateway is used in hard to reach dense areas to improve the quality of service and network capacity. Micro gateway gives high coverage. Both Omni-directional and multi-sector antennas are used in LoRa base station.

C. The Network Server

The network server has all the intelligence. The data received from different gateways is filtered, security checks, adaptive data rates etc., are performed and acknowledgement is sent to the gateways [1] [4]. The network server is the one who identifies whether the data received is intended for any application server and is thus sent to the intended application server via some backhaul.

D. The Application Server

They receive the intended data from the network server.

III. LoRa FEATURES

A. Long Range of Lora

As the name implies LoRa is a long-range protocol. It is capable of transmitting data over long distances. A single gateway can cover hundred-kilometer square of area. The long range of the LoRa technology is due to its link budget and the chirp spread spectrum modulation that it employs.

1) Chirp spread spectrum: LoRa employs chirp spread spectrum modulation technique. This technique is being used in military and space communication for over decades due to its robust nature and long-range capacity. It is now being used commercially in LoRa communication. It also provides immunity to multipath and fading. The chirp spread spectrum has a low transmission power requirement. Chirp is a signal whose frequency increases or decreases over time. Thus, a chirp signal can be up-chirp and down-chip.

In the chirp spread spectrum modulation the wanted data signal is multiplied with the chirp signal [2]. This spreads the bandwidth beyond the bandwidth of the original data signal. At the receiver end the received signal is re-multiplies with the locally generated copy of the chirp signal. this compresses the modulated signal back to the original bandwidth. This reduces the noise and interference.

The LoRa modulation bit rate can be expressed as

$$R_b = SF * \frac{1}{\frac{2^{SF}}{BW}} \text{ bit/sec} \quad (1)$$

R_b: Bit Rate
SF: Spreading Factor
BW: Bandwidth

The increase in the signal bandwidth gives the error free data that is transmitted over long distance. This can be visualized by comparing the sensitivity of the LoRa modulated signal to the frequency shift key modulated signal. The sensitivity of the chirp spread spectrum modulated signal is much higher than that of frequency shift key modulation.

2) Link Budget: The LoRa technology has a link budget greater than any other existing technologies. Link budget accounts for its long range to a great extent.

Link budget is an accounting of all the gains and losses in a transmission system. The link budget of a network can be expressed as

$$P_{RX}(dBm) = P_{TX}(dBm) + G_{SYSTEM}(dB) - L_{SYSTEM}(dB) - L_{CHANNEL}(dB) - M(dB) \quad (2)$$

where,
P_{RX}(dBm): received power
P_{TX}(dBm): transmitted power
G_{SYSTEM}(dB): system gains such as those associated with directional antennas, etc.
L_{SYSTEM}: losses associated with the system such as feed-lines, antennas etc.
$L_{CHANNEL:}$ losses due to the propagation channel
M: fading margin

The link budget is the power that is received at the receiver side. The link budget of LoRa is high that in turn accounts for its high sensitivity. Most of the technologies used for connectivity in IoT uses frequency shift key (FSK) modulation. When the data rate of LoRa signal is equivalent to four times the data rate of the frequency shift key (FSK) signal the LoRa signal offers the similar or equal sensitivity. Thus, LoRa can cover more distance than any other technique.

B. Battery lifetime

The most important criteria of an embedded device is its battery lifetime. Most of the embedded devices need to communicate with other devices near or far. This consumes high power. The embedded devices are all mostly battery operated. Thus, the essential requirement of these embedded devices is its battery lifetime. Most of the protocols or techniques used to create IoT embedded device now-a-days consumes very high power thus reducing the battery lifetime. LoRa optimizes the battery consumption in a device and is most suited for battery operated embedded device. LoRa consumes the least power when compared to all the existing technologies.

The low battery consumption in a LoRa networks accounts to the asynchronous communication of the nodes in the network. In a LoRa network the nodes communicates only when they have any data to send whether energy driven or scheduled. They adopt the ALOHA method. In ALOHA method frame is send only when there is any data to send otherwise no transmission takes place. If the frame is received successfully another frame is sent or the same frame is retransmitted. The ALOHA method saves battery lifetime because the network is doing transmission when there is any data. It does not do any transmission otherwise. Also, most of the other technologies are of mesh network or adopt synchronous communication in which the nodes have to wake up and synchronize time to time. This consumes more energy. In a recent study it was shown that the LoRa technology is 4 to 5 times better than any other existing technology.

C. Network Capacity

Star network is used in Lora network. The LoRa network gateway receives data from large number of nodes. For this the gateway must have high capacity. This is achieved by adaptive data rate and multichannel multi-modem transceiver at the gateway.

Adaptive Data Rate (ADR) is a mechanism for optimizing data rates, airtime and energy consumption in the network. Static nodes use ADR (Adaptive Data Rate)[6]. Whether to use ADR or not is decided by the node itself. In ADR the data rates of the node are managed by the network. When the node decides that it wants to use ADR it sets the ADR bit to 1 in the uplink transmission. When the network gets the signal that the node wants to use ADR it collects the signal to noise ratio, data rate, number of gateways that receive the data and signal strength of the 20-recent transmission from the specific node. Based on this data the network decides how much it can increase the data rate of decrease the transmission power. This reduces the air time and optimizes the transmission power. We can also say that it helps in reduction of battery consumption. This whole thing is done using the ADR algorithm. A node that is static at one time and mobile at another. So, the ADR algorithm can also be used by a mobile node that is parked at a fixed spot at the given time [13].

The multichannel multi-modem transceiver enables messages to be simultaneously received from multiple gateways.

D. Security

AES encryption and IEEE 802.15.4/2006 Annex B is used in this technology for security and authentication. While most technologies incorporate single layer security, LoRa network incorporate two layers of security: network security and application security. The network security is used for authenticating the node in the network while the application security protects the end user application data from the network operator. The LoRa technology uses two keys for the security and authenticity: NwkSKey (Network Session Key) and AppSKey (Application Session Key).

For the end device to participate in a network it must be activated and authenticated. The technology has two methods of authentication and activation

1. Over the air activation (OAA)
2. Activation by personalisation (ABP)

1) *Over the air activation (OAA):* In this type of end device activation, the device is not personalized with any information. A join procedure is done for the end device to join any network. Before joining the network, the end device is loaded with the information. This then has to be repeated for every transmission over the network when the session context information is lost. This method ensures that the end devices is not confined to any particular service provider and can join any network service provider while in roaming.

2) *Activation by personalization (ABP):* In this type of activation, the end device will be already stored with the information needed for the activation. The device directly

joins the specific network defined in the information when the device is started.

This type of personalization is not used frequently and is used only under some specific cases. The commonly used personalization method is the Over the Air Activation method. In ABP method simply a join request and join accept message is sent between the end device and the network for the end device to activate. NetSKey and AppSKey must be specific to every end device. Apart from being an activation method both the methods also provide authenticity and security over the network.

E. Quality of Service (QoS)

Quality of service is the account of overall performance of a network. It is based on various parameters such as data rate, immunity, throughput, packet loss, etc. The LoRa technology which is based on chirp spread spectrum technology offers fairly good quality of service. It is immune to interference, multipath and fading.

In a wireless network, as the distance between the devices increases the signal strength decreases. These are usually avoided by installing repeaters or by having additional nodes as in mesh topology. But the cost of having more repeaters or nodes in between is very high. But for LoRa, those signal with different sequence will be treated as noise at the network coordinator. The nodes near the coordinator can transmit at a higher data rate and ones far away from the coordinator can reduce the bandwidth.

IV. MAC PROTOCOL

LoRa defines the physical link layer while LoRaWAN defines the communication protocol and the network architecture. The end nodes in a LoRa network are divided into three basic classes according to their battery lifetime and the downlink communication latency [5]. The end device in a LoRa network has different requirements and serves different applications. According to these the end devices are put in any of these classes.

The three-basic class of the end devices in LoRa network is

- Class A
- Class B
- Class C

A. Bi-Directional End Devices (Class A)

These are the lowest powered end device system. The devises under this class follows aloha method of communication. These devices have one uplink transmission slot and two downlink receive slots.

Fig 5. End device receive slot timings

Here first the end device transmits an uplink message and opens up two receive slots. The first receive slot is opened after a delay of +/- 20 microsecond. The downlink data rate and the downlink frequency are a function of uplink data rate and uplink frequency. Again, after a delay of +/- 20 microseconds the second downlink receives window is opened. The data rate and the frequency in this slot is configurable. They can be configured using the MAC command. Only at these two receive slots the server can sent data. If the server wants to send more data, it has to wait for the next uplink transmission from the end device this class can only be used by those applications that need to send small data and that has to send data only after the end device sent an uplink.

The duration of the receive window must be long enough for the end device to at least detect the preamble of the downlink message. Once the end device detects the preamble it stays active until it receives and demodulates the frame. Data can be received by the end device in any one of the two receive slots. If the data is received at first receive slot, the end device process the data, demodulates it and if the data is intended for that end device the end device does not open the second receive slot. If the network has to do downlink transmission it starts the transmission at the starting of any of the receive slot. The end device is not ready to receive next downlink message until and unless it has received a message in any of the two receive slot for the previous uplink transmission or till the receive slots expires.

B. Bi-directional end-devices with scheduled receive slots (Class B)

In class B addition to the random receive slots of class A there is additional scheduled receive slots. Therefore, there are more receive slots than class A which opens at scheduled times. The gateway sent scheduled beacon to the end device for the end device to open their additional receive slot at periodic times. The server then knows that the end device is listening. The additional times slots are called ping slots. This class is used when additional receive slots are needed at predictable time in addition to the slots of class A that is available after an uplink transmission from the end device to the server.

In this class all the gateways synchronously send the beacon to the end device. The end device opens up the receive slot called ping slot at the specified time. The network then sends the data to the end device at the specified slot. The downlink communication is called ping. The network selects the gateway for the downlink communication depending on the signal strength of the last update of uplink from the end device. If the end device moves and finds any change in the signal strength it should notify the network in the uplink transmission. The network then updates this in its database. While joining every device joins as class A and then shifts to class B.

C. Bi-directional end-devices with maximal receive slots (Class C)

Unlike class A and class B, the class C devices open their receive slots all the time. The receive slot is closed only when the end device is transmitting. Since the class C end devices have their receive slot open all the time they consume more power than the other two classes. But these classes provide lowest latency for communication. These can be used for only those devices that do not have any power constrains.

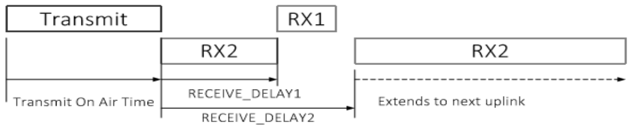

Fig 6. Class C end device receive slot timings

The class C end devices open a receive slot 2 in between the end device class A transmit and receive slot 1. When the receive slot 1 is closed the receive slot 2 is again opened until the next transmit or receive slot. Whenever there is no transmission or reception in the usual class A slots the receive slot 2 opens up indefinitely until next transmit or receive. The class C end device always have the receive slot 2 open and thus the end device can receive data from the server. These Class end devices have the most power requirement than class A or class B end devices.

V. APPLICATION

LoRa technology is developed for IoT applications. LoRa network can transfer small amount of data at intervals. So those applications that need to transfer small amount of data can use LoRa technology. They are mostly used in vehicular to infrastructure applications. They also find application in smart meters, sensors, smart cities, streetlight controls, hospital management, airport managements and a lot more provided these applications requires the transfer of small amount of data at intervals. Those applications where the data rate is high such as audio and video the LoRa technology cannot be used. But this technology can still be used in audio and video streaming where there is a need for instructing the video to capture data etc. The technology can be used for various applications.

A. LoRa for street light monitoring

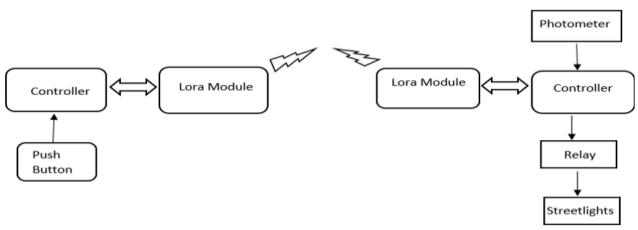

Fig 7. Block Diagram

LoRa technology can be used for street light automation [14]. The given block diagram can be implemented for the automation of streetlight using LoRa module.

The system consists of a push button and LoRa module integrated to controller at the operating section and a LoRa module, photometer, and relay with series of street lights integrated to the controller at the lighting section. Lights can be operated at the operating section using the push button. The on-off signal is transmitted to the lighting section through the LoRa module placed at both the sides. The on-off signal is received at the lighting section and accordingly the lights are switched on or off. The lighting section can also be operated automatically according to the surrounding. As it goes darker from evening to night the streetlight intensity can be slowly increased and can be slowly decreased and switched off at dawn. The intensity of light is measured by the photometer placed at the lighting section. Selection between manual and automatic control of light can be set at the operating side.

The whole system optimizes the power consumption and is very easy to install.

B. LoRa for smart parking

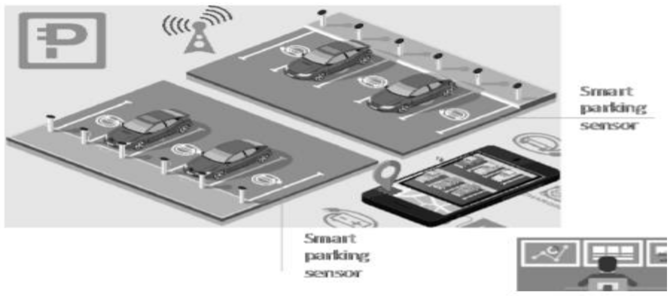

Fig 8. Smart Parking System

Parking is one of the main hurdles now. With the incasing vehicles on the road it is difficult to find a parking space and many a times we don't notice even a parking space that is available because of the tightly paced vehicles around the spot [1]. A number of smart parking systems are developed now to assist the drivers to find a correct parking spot using many available technologies. A more efficient smart parking can be implemented using the LoRa technology. Since this system is the one that need to transmit small data at specific intervals and also need to cover long distance such as a city LoRa can act as a boon.

The LoRa sensor can detect if the parking place is full and notify the driver who is looking for a parking spot. This can significantly reduce the time to search for a place because the driver can be notified beforehand about the availability of space. The system can also monitor all the parking space in real time. This type of system can reduce pollution due to vehicles that is looking for a parking spot.

VI. LIMITATIONS

LoRa like every technology has its own limitation too. The limitations of LoRa are listed below:

- Only those applications that require low data rate (upto 27 Kbps) can use this.
- Limitations with the Duty Cycles in LoRa networks effectively limits the number of "messages" that can be sent during a specific time frame.
- It is not suited for real time applications that require lower latency.

In LoRa network for all the classes the frame is always acknowledged. Following the acknowledgement of the frame by the end device in any of the receive window there is an off period to comply with the duty cycle regulations. Thus, to avoid capacity drain the end devices and the network must restrict the acknowledgement transmissions. Also in the LoRa network after the transmission of data in a sub-band, there is an off period where no data is to be sent to that particular channel. This time period in which data is send and when data is not sent accounts for the duty cycle. Thus in LoRa the network capacity is limited by the duty cycle.

VII. CONCLUSION

LoRa or LPWA is a very recent technology that has been evolved. In 2013 or before that, the term did not even exist. Now the technology has developed and is being promoted and used worldwide because of its various technical advantages. This technology compliments various other technologies such as cellular network. As recently as in 2013 nobody thought that such a technology would exist. The LoRa technology is preferred due to various advantages such as the battery lifetime, the long range, the security, robustness to interferences and more. The technology is a package in itself.

Various applications differ from each other in its requirement and capabilities. Every application thus, cannot use the same technology. The technology that an application uses depends on its requirement and other factors. And so LoRa as such cannot serve every application out there. But it is a preferred and most suited technology for the IoT applications that need to communicate a long distance and in which the battery lifetime and power consumption is a major limitation. LoRa technology also offers high security. It is expected that by 2024 3.6 billion LPWA connections will be established.

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