Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

Zigbee, It's Applications and Comparison with Other Short Range Network Technologies

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***Abstract* – When we talk about wireless short-range communication protocols we often speak about Wi-Fi and Bluetooth. There is another such short-range communication protocol called the ZigBee. When it comes to Internet of Things applications, there are those that have low power requirements and prefer to be cost-effective. ZigBee was formulated on the IEEE 802.15.4 radio standard and was developed to support low-cost, low-power IoT applications [1]. The reason for ZigBee's popularity is its support of multiple network topologies, scalability and it enables us to connect to local networks without having to give up on reliability. This paper covers the basic concepts of ZigBee technology, two important applications of ZigBee – Home Automation and Smart Irrigation Systems, and a comparative study of ZigBee with other short-range protocols such, i.e., Wi-Fi and Bluetooth.**

Keywords - ZigBee, Wireless Networks, ZigBee Devices, ZigBee Standards, ZigBee Protocol Suite, ZigBee Topologies, Applications.

I. INTRODUCTION

In the present world, there is a huge demand for wireless devices and wireless communication. ZigBee is one such technology that contributes to wireless communication. ZigBee devices that can create a wireless network can create a large network area, the devices are small, low power consumption, the cost is low and there is a very short time of delay in communication when compared to other devices. [7]. It provides a global open standard for wireless radio networks in controlling and monitoring the fields which include a lot of network devices. ZigBee is mainly used in devices that do not require very high bandwidth and is taken as an alternative to Wi-Fi and Bluetooth and used widely in low-powered devices. Devices such as Amazon Echo, Philips Hue, Bosch Security Systems use ZigBee as the communication medium as it uses very less power and mainly suitable for small areas or so called the personal area. It supports most of the topologies such a star topology, mesh topology, and tree topology. It has become one of the most used devices for communication in a wireless personal area network (WPAN) and has been acting as one of the most important elements of the "Internet of things" (IoT).

ZigBee is known for its security and reliability, it supports 128Bit Advanced Encryption Standard (AES) encryption. The importance of ZigBee has been increased since it follows and uses IEEE 802.15.4 standards and other industry standards. It provides low power connectivity for devices that run daily and needs long-lasting battery life. The IEEE standards, the Physical layer and the MAC layer in the Zigbee Protocol Suite allows networks to handle n number of devices simultaneously. As it uses IEEE 802.15.4, it provides the concept of low power usage, adaptability to the environment that we are using it in, and connect to local networks for better communication among the devices.

II. LITERATURE SURVEY

The history of ZigBee dates to the 1990s. The ZigBee Alliance, the group of companies that preserve and maintain the ZigBee Standard, was formed in the year 2002 to address this concern. The ZigBee Alliance is responsible for the development of open, global standards, certify products and promote the usage of the standards. ZigBee Alliance is over 500 companies, which includes companies such as Amazon, Apple, Legrand, Ikea, Comcast. The ZigBee Alliance is in relation to the IEEE 802.15.4. Looking back at the history, in December 2004, ZigBee v.1.0 was ratified and released in the year 2005 as the ZigBee 2004 specification, later in the year 2006, ZigBee Alliance launched the ZigBee 2006 specification which held modification to the earlier ZigBee 2004. In 2007 ZigBee Alliance released ZigBee pro. On November 2nd, 2002, ZigBee's first application profile - Home Automation was announced. Following that, other Application profiles were released. Smart Energy, Personal Home and Hospital Care, Telecom Applications, and many others are among them. Many applications have been developed using ZigBee technology, and many applications have profited from its use.

ZigBee is a low-power, low-cost, wireless network technology targeted to support those applications that have low power, cost-efficient and low data rate requirements. The reasons for using ZigBee as a communication protocol for IoT applications are – Support to a large number of nodes, security, low cost, low power consumption, low maintenance high security, global usage, reliable and self-healing [1]. ZigBee networks can contain up to 653356 devices, and these devices can be separated by 50m. This sums up to a significantly large area [2]. A typical sensor node comprises the following components – a sensing element, a battery, processor, memory, and a communication element [3]. The resulting network of the ZigBee applications would use a very small amount of power so that the individual applications can operate for a year or two using the originally installed battery [4]. The ZigBee Structure consists of three types of devices – ZigBee Coordinator, routers and end devices. Every network must contain exactly one Coordinator who is responsible for storing and handling data and perform operations such as

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

receiving and transmitting data. Routers are responsible to act as an intermediary device and to and fro the passage of the data [4].

Looking into certain related works. Sujan Shrestha et Al, have indicated in their work on analysis of the ZigBee wireless communication, that use of ZigBee standard communication gives Physical as well as Media Access Control layers at very low data rates and also handles more devices [5].

Salim Jibrin Danbatta and colleagues compared the use of Zigbee, Z-Wave, Wi-Fi, and Bluetooth Wireless Technologies for home automation. They concluded that when the question is to pick devices from the same manufacturer at a cheap cost and low power consumption, ZigBee is the best fit [6].

Jin-Shyan Lee et Al evaluated the ZigBee-based wireless networks in an indoor environment. They conducted an experiment to evaluate the practical performance of the ZigBee Network with the multihop transmission in indoor environments over a long operation duration. ZigBee can operate in three frequency bands – 868 MHz in Europe, MHz in the United States of America and Australia, and 2.4 GHz worldwide. They have a data transmission rate of up to 250kbps. From their experiment, they obtained results on Node Connectivity, Packet Loss Rate, and Transmission Throughput. During this experiment, they achieved a transmission of 25kbps which is substantially less than the 250kbps nominal value. They conclude that these observed results are due to the transmission overhead and the CSMA-CA random backoffs [7].

ZigBee also has applications in the medical field. Maocheng Cao et al performed a study on the usage of the ZigBee WSN system that was based on a digital filter mathematical model in post-chemotherapy monitoring and diagnostic value of average fluorescence intensity of peripheral blood neutrophil CD64 for bacterial Infections. They performed this study on 128 blood tumour patients who are undergoing chemotherapy. The result of their study was that the filter had suppressed the baseline shift and heightened the detection accuracy [8].

Concluding on the anterior work we understand a substantial amount of progress and research has been done in the field of ZigBee technology and its applications. ZigBee has a wide range of applications such as home automation, medical application, smart agriculture, etc. We could keep counting and the list would still go on. ZigBee is ideal for all those applications that look forward to being cost-efficient and have low requirements on data transfer rate and power consumption. What we pick up from the literature review is the potential behind this technology. Further in this paper, we have reviewed 2 important applications of ZigBee – Hotel intelligent guidance system and Smart Irrigation, for which we picked up the certain kinds of literature that motivated us and which we felt were more efficient.

III. ZIGBEE PROTOCOL SUITE

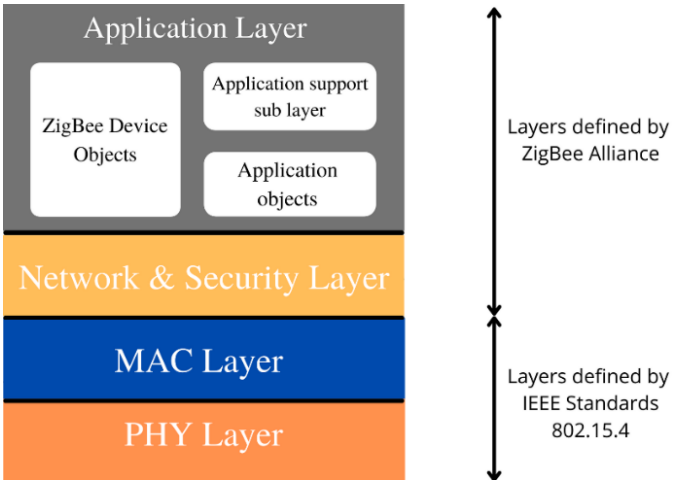

Fig 3.1 ZigBee Protocol Stack

Zigbee Protocol stack also knows as network layers of Zigbee contains four layers namely Application layer, Network, and Security layer which is governed by the Zigbee Alliance, and the other two layers namely the Mac layer and Physical layer which are governed by IEEE Zigbee Standards 802.15.4. The Zigbee protocol stack is based on OSI (Open System Interconnection) model. The configuration of Zigbee modules is done through X- CTU software [2].

Physical Layer: The physical layer of the Zigbee protocol stack interprets the physical and electrical attribution of the network. The simple and one of the basic tasks of the physical layer in the protocol suite is data transmission and network reception. Some techniques, such as modulation and some spreading techniques, are used to convert the data. Another work of the physical layer is it helps in enabling and disabling the trans receiver. It also helps in assessing the quality of the channels that are between various Zigbee devices. It is also used to assess the quality of the received packets through the channels.

MAC Layer: As we know that there can be multiple Zigbee devices in an area coordinating together for a particular task and the MAC layer is defined under IEEE 802.15.4 which explains how the devices share the same radio waves for sharing information among the devices. The Mac layer is responsible for the generation of a beacon if the device transmitting signal is a Zigbee coordinator. Since the devices are placed in a small area there may be chances of collision. The MAC layer is responsible for collision avoidance, and it acts as a medium for transferring the data to its upper layers.

Network and Security Layer: This layer is responsible for taking up tasks such as setting up a network, end-to-end device connection, routing, configuring different devices in the same network. Zigbee supports 128Bit AES encryption for security. This layer contributes to providing network-wide security and helps the Zigbee devices to suppress

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

battery usage and extend their battery life to the maximum. It follows mainly three network topologies that are star topology, mesh topology, cluster tree topology which are considered under IEEE 802.15.4. The Zigbee router is a device that helps in network routing and address allocation for the various devices participating in the topology.

Application Layer: It is the topmost layer in the protocol suite. This is a layer defined by Zigbee Alliance. This layer consists of three more layers inside an application layer namely Zigbee device objects, Application support sublayer, and Application objects.

a) Zigbee Device object: The main objective of this layer is it provides service discovery, binding, and security. The main work of service discovery is to find the nodes and that are available for communication. As we all know, the security is 128-bit AES encryption, which aids in data encryption during transmission as well as decryption at the receiving end. The binding service helps in binding several nodes together and recourse it to a specific node and channel.

b) Application support sublayer: This sublayer helps in decoding the incoming and outgoing frames from a node. It also plays a major role in managing the cryptographic keys that are used to encrypt and decrypt the data at the nodes.

c) Application objects: It is a sublayer that helps in controlling and maintaining all the protocols that are necessary to run a Zigbee device. A Zigbee device can have a maximum of 240 Application objects. In a Zigbee topology, the application objects are given a unique end point number those other devices can use to communicate with them. In short, it can be called a sublayer which keeps the network address of the Zigbee devices.

IV. ZIGBEE STANDARDS

Zigbee was initially developed by Zigbee Alliance (this means many companies were included in the development). When we talk about Zigbee main thing that comes to light is IEEE 802.15.4. Zigbee uses protocols of IEEE 802.15.4 and hence the application and network layer of Zigbee is based on these standards. The ZigBee Alliance makes use of security, network, and application layer protocols. The physical layer for LR-WPAN is defined by IEEE802.15.4, which is hardware. Zigbee operates on an extremely low power level, as low as 1 mW. Under the IEEE 802.15.4, it used a technology called direct sequence spread spectrum (DSSS) which helps in increasing the range of a Zigbee device up to 150metres. And by using this technology it consumes very little power and hence the power consumption is very low. It provides an 868Mhz bandwidth which works effectively in Europe, and it provides a 915Mhz bandwidth which works effectively in North America and Australia and it provides a 2.4Ghz bandwidth that works effectively worldwide. In regredience with IEEE 802.15.4 standards, the ZigBee device adopts 64-bit and 16-bit addresses. Zigbee network can include a maximum of 653356 devices. Based on the IEEE standards for Zigbee the maximum distance between any two devices is set to 50meters.

V. ZIGBEE TOPOLOGIES

Zigbee stack is responsible for the formation of the network, which is in the Zigbee network layer. There are three Zigbee network topologies- Star, Mesh, Cluster tree. Zigbee uses IEEE 802.15.4 2003 specification for the physical layer and MAC layer. IEEE 802.15 offers topologies-star, a cluster tree, and mesh.

A. STAR TOPOLOGY

It is made up of coordinates as well as end devices (nodes). All the end devices are connected to coordinates and are both physically and electrically separated. The coordinator must handle all packet exchanges between the devices. The benefit of a star topology is that it is straightforward, and packets must pass through two hops to reach their destination. The downside is that all packets must pass via the coordinator, which may cause bottleneck; also, there is no other path from source to destination.

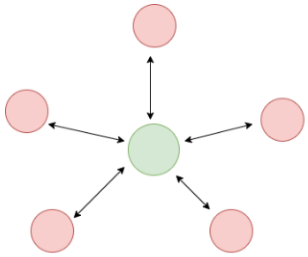

Fig 5.1 Star topology

B. MESH TOPOLOGY

Peer-to-peer networks are another name for mesh topology. It is made up of a coordinator, as well as many routers and end devices. It is a cluster tree topology extension. A mesh topology is a multi-hop network in which packets go through numerous hoops before arriving at their destination. If one of the paths fails, the packet attempts to reach the target through another route. In a mesh topology, adding or deleting devices is simple. Any device in the network can communicate with any other device.

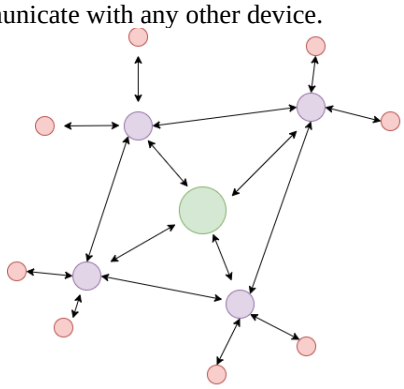

Fig 5.2 Mesh topology

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

C. CLUSTER TREE TOPOLOGY

A peer-to-peer topology, which is a subset of the tree topology, is referred to as a cluster tree topology. A cluster is made up of a parent and its child, each of which is recognized by a cluster id. The cluster tress topology is supported by IEEE 802.15.4 but not by Zigbee. The routers increase the network's range, so the end devices do not have to be inside the coordinator's range. End devices are unable to interact directly with one another, however, routers can connect with other routers and the coordinator.

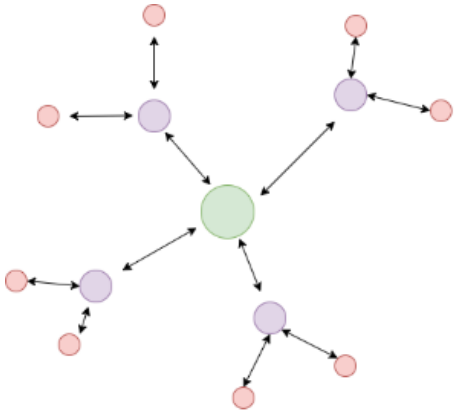

Fig 5.3 Cluster tree topology.

VI. ZIGBEE DEVICES.

Zigbee devices are a combination of Zigbee logical and physical device types.

A. ZIGBEE PHYSCIAL DEVICES.

In IEEE 802.15.4, Based on data processing capabilities Physical devices are of two types - FULL FUNCTION DEVICES (FFD) and REDUCED FUNCTION DEVICES(FRD).

Full Function Devices (FFD): This type of device can do all the standard's functions, including routing, coordination, and sensing. It can function as a coordinator, router, or end device. An AC-fed mains supply will power the FFD in a Zigbee network since it must always be operational and listening to the network.

Reduced Function Devices (FRD): It implements a limited version of the IEEE 802.15.4 protocol. It has the least computing capability. They do not route packets and they should be associated with an FFD. RFD's main goal is to find an available network to transfer data to check whether there is any awaiting data and make a request for the data to the network coordinator. These are end devices like sensors and actuators that have a limited set of operations, such as reading temperature data, monitoring light, or regulating other equipment.

B. ZIGBEE LOGICAL DEVICES

There are 3 ZigBee logical devices – Coordinators, Routers and End Devices.

Coordinators: It forms the root of the network tree and tries to build a bridge for other networks. Each network has exactly one coordinator. It oversees selecting the network as well as its specifications, such as the radio frequency channel, network identity, and others. It also keeps network and security key information.

Router: Zigbee router is an intermediate device in a network. It routes the data from source to destination. A router can join a network that already exists. With the help of Zigbee routers, a network may be expanded. It may also accept connections from other devices and function as a network re-transmitter.

End Devices: An FFD or an RFD can be used as an end device. Sensors and switches provide them with a wealth of data. The end devices depend on a coordinator or router to send the data and it cannot relay data from other devices. These devices can be low-power, or battery-powered devices and have limited computer capabilities. The end devices are not needed to stay awake the entire time, although the devices of the other two must. Each of these devices has 240 end nodes, each of which is a separate application with the same ratio.

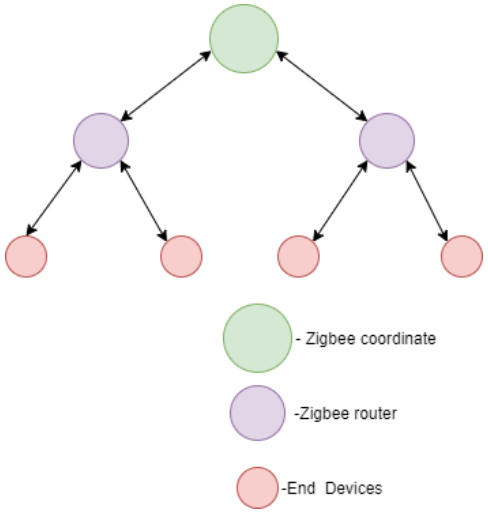

Fig: 6.1: ZigBee Devices.

VII. ZIGBEE APPPLICATIONS

We have reviewed two applications in the perspective of the usage of the ZigBee technology – Hotel Intelligent Guidance System based on ZigBee Technology [9] and Automated Irrigation System Using WSN and GPRS Module [10].

A. HOTEL INTELLIGENT GUIDANCE SYSTEM BASED ON ZIGBEE TECHNOLOGY

Xiaoyan Shen, et Al put forward an intelligent guidance system that helps people to navigate through the guestroom corridors. Hotels and guest rooms are of large sizes. They are internally divided into multiple sections. These include the entertainment area, food stalls, rooms, and accommodation places, and many more sections. This makes is it not so convenient for the people who are not

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

familiar with the hotel plan. Most of them use ushers or guides to navigate to their rooms or to their destinations. The purpose was to design an intelligent system that could provide the customers with a more expedient method to navigate. This system made use of the ZigBee technology to connect the handheld devices, the guidance modules, and the control modules. This system uses the ZigBee communication network on the one hand, and the ZigBee ad hoc network capabilities on the other, to achieve the proximity guidance effect. ZigBee 3.0 IP is compliant in every way [11]. This lets several devices interact over the same network, system compatibility and extension for new devices.

The room's guidance data, which is kept in a guidance module, is updated, and sent over the ZigBee network. When a handheld device approaches the guiding module, it picks up a significant signal strength from the module due to the ad hoc network protocol. The guiding module will connect to the network after switching to the parent module. The portable module would then send a request to the parent node, and the guidance module would respond by displaying the guidance information on the screen, assisting the client in finding their way out to their rooms. This technology also displays a way to exit in the event of an emergency, improving the customer check-in experience and the hotel's competitiveness. Because of these factors, the authors believe it has a promising market application.

B. AUTOMATED IRRIGATION SYSTEM USING A WIRELESS SENSOR NETWORK AND GPRS MODULE
Joaquín Gutiérrez et Al have worked on an automated irrigation system that optimizes the water usage for agricultural crops. This system comprises of two components. One is a Wireless Sensor Unit(WSU) and another is a Wireless Information System (WIS). This allowed the transfer of data such as temperature and soil moisture, implementing a Wireless Sensor Network using the ZigBee Technology.

Several WSU's can be implanted in the field to constitute the Wireless Sensor Network for the automated irrigation system. Each of these WSUs are based on the PIC24FJ64GB004 that controls the XBee Pro S2. These WSUs are configured. For example, the end devices were required to deploy a networking topology point to point based on a coordinator which was implemented using an XBee radio modem of the WIU. The end device's job was to join a ZigBee Personal Area Network (PAN) before it could send or receive data, not to allow other devices to join the network, to always receive and transmit radio frequency through its parent, to adopt low power modes to save power, and to be battery powered.

These WSUs pick up the data such as the soil moisture and the soil temperature from analog digital ports. The data so collected is packed along with the corresponding identifier, date and time, and transmitted via XBee radio modem using an RS-232 protocol through 2 digital ports that are configured as the Transmitter (TX) and the Receiver (RX). After sending the data, the WSU goes to sleep mode, this enables power saving. The first time the WSU is launched it inquiries the WIU for the date and time to program the RTCC and periodically synchronizes.

The data received from each WSU is recognized, recorded, evaluated, and processed at the WSI. The WIS is a PIC24FJ64GB004 microcontroller with an XBee radio modem. In addition, we have a separate GPRS module. The WIS is now ready to provide the date and time back to the WSU when the query has been completed. Finally, the WIU delivers the data to the server over HTTP via the GPRS Module once it has been processed.

VIII. COMPARISION BETWEEN SHORT RANGE COMMUNICATION METHODS LIKE ZIGBEE, WIFI AND BLUETOOTH.

Zigbee is a wireless technology, which holds a suite of IEEE 802.15.4-based specifications for communication protocols. This communication protocol is less expensive and similar to the other proprietary short-range wireless sensor networks, it supports different network configurations. Wi-Fi stands for Wireless Fidelity, which holds a suite of IEEE 802.11 for local wireless networks. WIFI is an alternative network to wired network which is commonly used for connecting devices in wireless mode. It connects the computer one another and mutually, to the internet and wired networks. Bluetooth is a wireless technology that allows the exchange of data between different devices. It uses wavelength to transmit information, which works within a short distance for the devices to stay connected.

BASIS	ZIGBEE	WIFI	BLUETOOTH
Standard	Zigbee has a technology based on IEEE 802.15.4 standard.	WIFI has a technology based on IEEE 802.11 standards.	Bluetooth has a technology based on IEEE 802.15.1 standards.
Frequency Range	Frequency range is 2.4 GHz worldwide.	Frequency range is 2.4 GHz and 5GHz radio frequency.	Bluetooth's frequency range may vary from 2.4GHz to 2.483 GHz.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 06, June-2021

Phase Shift Key	It uses binary phase shift key (BSPK) and quadrature phase shift key (QPSK).	It uses binary phase shift key (BSPK), quadrature phase shift key (sQPSK) , complementary code keying(CCK) and coded orthogonal Frequency division multiplexing(COFDM).	It uses Gaussian Frequency Shift Keying modulation technique.
Power Consumption	Best quality of Zigbee is the rate of power utilization as well as battery life of it.	WIFI is high power consumption.	Bluetooth is low power consumption.
Bandwidth	The bandwidth requirement is low but greater than Bluetooth's bandwidth most of the time.	WIFI requires high bandwidth.	Bluetooth needs low bandwidth.
Radio Signal Range	Radio signal range is ten to hundred meters	The range of WIFI's radio signal is 100 meters.	radio signal range of 10 meters.
	A Zigbee has more than 65000 node cells and sixteen RF channels.	WIFI has 2007 node cells and 14RF channels.	Bluetooth's maximum of 8 cell nodes and 79RF channels.
Range	Zigbee range is 291 meters.	WIFI range is 50meters.	A range for Bluetooth is 77 meters.

Table 1: Comparison between ZigBee, Wi-fi and Bluetooth

The user's choice of wireless technology is entirely dependent on the requirements of the chosen wireless solution. When it comes to cheap cost and power consumption, Zigbee is the finest option. If simplicity of use and range is important, Wi-Fi is recommended; however, if cost is a problem, Bluetooth is a better option.

IX. ADVANTAGES AND DISADVANTAGES OF ZIGBEE

The reason for ZigBee emerging in its prime are the advantages that it has provided to the user. We have listed the advantages below:

- The Zigbee network can be set up very easily.
- It is easy to control and monitor.
- It is a low power device; the resulting network will use significantly less power. Each end device will have a battery life of approximately two years.
- It is scalable, i.e., it is very simple and easy to add or remove "Zigbee End Devices" to the network
- The number of nodes that ZigBee supports is large which is approximately equal to 6500.
- Zigbee can be used as an alternative to Bluetooth and Wi-Fi technologies for home automation and smart systems.
- Zigbee is compatible with products manufactured by different companies.
- Zigbee offers mesh topology unlike Bluetooth and Radio Frequency which operate on the basis of point-to-point communication.
- Setting up cost is less than a Wi-Fi network as routers are not required, which reduces the cost of implementation. Hence it is more suitable for connecting devices across larger areas.
- No data is transferred between ZigBee devices without encryption. It utilizes AES (Advanced Encryption Standard) encryption with a key length of 128 bits (16 Bytes). The AES algorithm is used to not only encrypt but also to verify the data that is delivered.

There are certain disadvantages also, that have to be taken into account. The disadvantages are:

- Zigbee has lower transmission rates in comparison with Wi-Fi.
- Although ZigBee offers encryption it is not as secure as Wi-Fi based systems.
- Another major disadvantage is that it is not compatible with consumer electronics such as smartphones, laptops, tablet, computers etc.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 10 Issue 06, June-2021

- It is susceptible to network interferences as it uses the 2.6GHz band which is also used by Wi-Fi, cordless phones, and microwave ovens.

X. FUTURE SCOPE OF ZIGBEE

Although ZigBee seems flawless, and has so many outstanding features, there is still room for further improvement. Zigbee provides a basic level of security using encryption of data with the help of a network key, it is still vulnerable to a potential data breach. User data can be stolen and used for unethical purposes. The Encryption keys will give access to the node and network. Therefore, security keys that are used must be protected. There are high chances that a node can be removed from the current network and moved to another network where the hacker can control and gain access to your entire network. Loss of network service- by jamming the channel or the entire bandwidth by means of interference, can bring down the node. Hacker records the signal transmitted by any one of the nodes. Later the command is sent to a node by the hacker to achieve subversive control. This can be tackled by regularly changing the network key, which is tedious. These are a few areas where ZigBee can improvise in the upcoming days.

XII. CONCLUSION

In this paper, we have discussed in detail, the various topologies that can be achieved with ZigBee namely, mesh, tree and star topology. The mesh topology is used in most of the applications. The three types of devices that form a ZigBee network - The Co-Ordinator, the Router and end devices. We have also discussed the advantages and disadvantages of using ZigBee technology and a detailed comparison between ZigBee, Wi-Fi, and Bluetooth technology. We also discussed the different types of layers that ZigBee technology is built on: the physical, Medium Access Control (MAC), the network, and the application layers. ZigBee has a huge list of applications. In the Zigbee applications we have considered two applications from the perspective of ZigBee network technology utilization - Hotel Intelligent guidance system based on ZigBee and the second one being, automated irrigation system using a wireless sensor network and GPRS module. We see that ZigBee plays a prominent role in each application, in both ways – ad hoc networks and the communication facility.

Zigbee is the most preferable networking option considering the parameters such as power consumption, range, bandwidth, cost of implementation and data transfer speeds. Zigbee also provides a pretty good level of security for the users. The type of networking technology to be used depends mainly on the project you are working on and the user's expectancy. We can conclude that ZigBee is an ideal technology for use in home automation and industrial automation.

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