# ZigBee based Wireless Sensor Networks

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*Abstract*— In recent years, Wireless sensor networks have achieved an attention on a world level. These consist of small sensors with limited power and limited resources. Wireless sensor standards developed with the special requirement for consuming low power. Some of these standards are WirelessHART, IETF 6LoWPAN, ISA100.11, IEEE 802.15.3, Wibree, IEEE 802.15.4 and ZigBee. IEEE 802.15.4 has been developed to focus on low cost of deployment, low complexity and low power consumption. IEEE devices are designed to support the physical and data link layer protocols and ZigBee defines the higher layer communication protocols built on IEEE 802.15.4 standards. This paper provides a review on ZigBee technology. Firstly it gives an introduction to the ZigBee technology then the characteristics of ZigBee. After that there is an introduction to ZigBee alliance. Then are the access methods, devices and topologies supported by ZigBee. The most important part of this paper consists of the protocol architecture of ZigBee and in the last section there is various application of ZigBee technology.

Keywords—Wireless sensor networks, IEEE 802.15.4, ZigBee Technology.

## I. INTRODUCTION

In March 1999, IEEE establishes the 802.15 working group as part of the IEEE Computer Society's 802 Local and Metropolitan Area Network Standards Committee. 802.15 working group was established with a specific goal of developing standards for short wireless networks, known as Wireless Personal Area Network-WPAN.
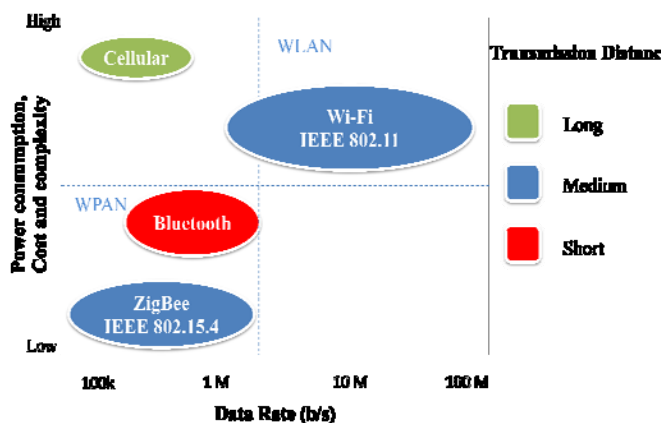


Fig. 1 Standards of Wireless Sensor Networks

A WPAN is a wireless personal area network for the interconnection of devices around a single person's workspace and connections among devices are wireless. WPAN uses the technology that allows communication in the distance of 10 meters which is very short distance. One of the short range technologies is Bluetooth.

There are four target groups within the 802.15-working group. Target group number one (802.15.1) standard defines the WPAN based on the Physical (PHY) and Medium Access Control (MAC) level of Bluetooth version 1.1. Target group number two (802.15.2) develops a model for coexistence of WLAN (801.11) and WPAN (802.15). The purpose of the target group three (802.15.3) is to develop standards for a data flow in WPAN (20Mbps and higher). The target group four (802.15.4) is responsible for developing standards of PHY and MAC level for a small flow of data, very complex solutions that will extend battery lifetime to years. This new standard 802.15.4 is also called ZigBee. The target group five is for mesh networking.

IEEE 802.15.4 is the proposed standard for low rate wireless personal area network (LR-WPAN). IEEE 802.15.4 focuses on low cost of deployment, low complexity and low power consumption. IEEE devices are designed to support the physical and data link layer protocols and ZigBee defines the higher layer communication protocols built on IEEE 802.15.4 standards. ZigBee specification has network layer and the application layer and some where it has the security services too. It is different from other approaches, like Wi-Fi that offers more bandwidth and consumes more power. The prominence is on low cost communication between the nearby devices having no infrastructure, aims to utilize this low power consumption.

## II. ZIGBEE TECHNOLOGY

There are various wireless control and monitoring applications in home environments and industries which needs lower data rates, longer battery life and lower complexity than the existing standards. For these type of wireless applications, a new standard has been developed by IEEE which is called IEEE 802.15.4. This new standard is also named as ZigBee. Moreover, to fulfil the demand of consuming low power and low speed in wireless communication devices, a new wireless technology ZigBee comes as per the requirement of time.

ZigBee is named for erratic zigzagging patterns of bees between flowers which symbolizes communication between nodes in a mesh network. Network components of ZigBee are analogous to queen bee, drones and worker bees. This communication dance (The ZigBee Principle) is what engineers are trying to emulate with this protocol a bunch of separate and simple organisms that join together to tackle complex tasks. [8]

## III. CHARACTERISTICS OF ZIGBEE

ZigBee is a low cost, low complexity and low power technology that exhibits the following characteristics which makes it more beneficial to use in the industry applications. Characteristics of ZigBee are given as:

- ZigBee is created by ZigBee alliance
- ZigBee offers full Wireless mesh networking
- ZigBee supports approximately 65,000 devices on one network
- Designed to connect the very large range of devices in an industry into a single network.
- ZigBee adds network layer, security layers and an application framework to enhance the IEEE 802.15.4 standard.
- ZigBee operates globally in 2.4 GHz band of frequency as per IEEE 802.15.4.
- It has regional operation in 915MHz (Americans) & 868 MHz (Europe) bands.
- ZigBee absorbs low power for all classes of devices.
- ZigBee has various transmission options like broadcast.
- It has security key generation mechanism and it uses the AES-128 security scheme.
- It supports alliance standards like public application profiles or manufacturer application profiles.

## IV. ZIGBEE ALLIANCE

ZigBee is organized under the control of the organization called ZigBee Alliance. ZigBee alliance is an organization of companies working together to define an open global standard for making low power wireless networks.[8] The intentional outcome of ZigBee alliance is to make a description that defines how to build altered network topologies with features of data security and interpretable application profiles. This organization has more than 150 members out of which seven are the promoter. A big challenge for the ZigBee alliance is to make the interoperability to work among different products. [8] For solving this problem, ZigBee Alliance has defined profiles which depends on the category of the product to which it belongs to. For e.g. there is a profile called the home lightning which defines how altered brands of home lightning-products should communicate to each other.

## V. ZIGBEE ACCESS METHODS

ZigBee provides two types of access methods that are:

- Beacon Enabled
- Non Beacon Enabled

In Non Beacon Enabled network, any node in the network may send the data whenever channel is free. But the method is different for the Beacon Enabled network. In beacon enabled, nodes can only send or recieve in preagreed time slots. Here PAN coordinator assigns the guaranteed time slots (GTS) to every device; so devices can transmit the data in their own time slot. Both, beacon enabled and non beacon enabled, access methods are shown in figure 2.
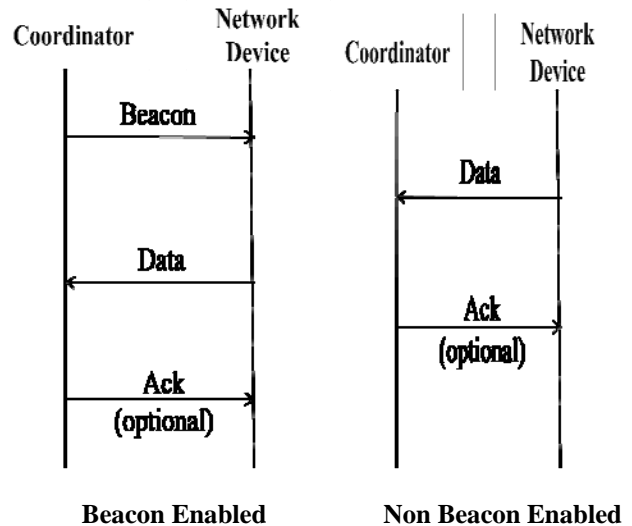


**Beacon Enabled**      **Non Beacon Enabled**

Fig. 2 ZigBee Access Methods

## VI. ZIGBEE DEVICES

ZigBee devices are the combination of application like light sensors for lightening control. There are three types of ZigBee devices. ZigBee Coordinator which is responsible for intelligent network, selecting suitable channel to create a network and adding child nodes to the network. ZigBee routers can be sensor devices and is routing capable device. ZigBee end devices have no routing capability. ZigBee devices increase battery life up to years using primary cells, which have low cost, without any chargers.



Fig 3 ZigBee Devices

## VII. TOPOLOGIES SUPPORTED BY ZIGBEE

ZigBee supports three types of network topologies that are star topology, tree topology and mesh topologies. Star topology is where a coordinator is surrounded by a group of end devices or routers. This topology is simple but it has some disadvantages. In the moment when the coordinator stop functioning the entire network is functionless because all traffic must travel through the centre of the star. For the same reason the coordinator will easily be bottleneck to traffic. Then is the Tree topology, a coordinator initializes the network and is the root of the tree. The coordinator can have routers or end devices connected to it and for every router; there is a possibility for connection of more child nodes to each router. Because the message can take only one path so this type of topology is not the most reliable topology. Mesh topology is the most flexible topology because message can take multiple paths from source to destination. If a particular router fails the ZigBee's self healing mechanism will allow the network to search for an alternative path for the message to be passed. Following are the topologies supported by ZigBee; Star topology, Tree topology and Mesh topology.
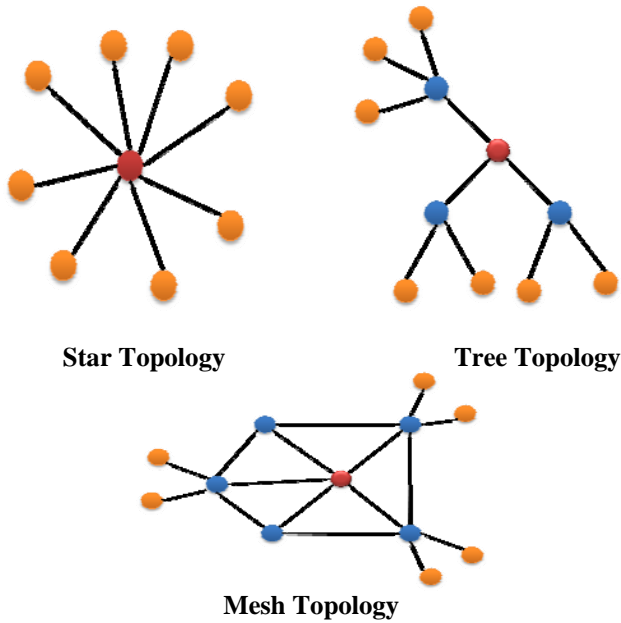
**Star Topology**                    **Tree Topology**

**Mesh Topology**

Fig 4: Topologies supported by ZigBee and ZigBee devices

## VIII.  PROTOCOL ARCHITECTURE OF ZIGBEE

The figure 5 shows the protocol architecture of ZigBee. The IEEE standard defines the characteristics of PHY and MAC layers. ZigBee builds upon IEEE 802.15.4 standard defines the network layer specifications and provides a framework for application programming at the application layer.

ZigBee follows the standard OSI (Open system Interconnection) reference model. Protocol stack of ZigBee has a layered structure. The first two layers, PHY (physical) and MAC (media access) are defined in the standard IEEE 802.15.4 as shown in the figure. The layers above to the physical and MAC are defined by the organization called ZigBee Alliance.

A. *Physical Layer:* The physical layer of the standard IEEE802.15.4 is the nearest to the hardware, that controls and communicates directly with the radio transceiver. It controls all tasks like access to the ZigBee hardware, initializing the hardware, selection of channel, energy detection measurement, link quality estimation and clear channel assessment to assist the channel selection. Next in the upward direction there is the Media access control that is MAC layer.

B. *Medium Access Control:* MAC layer is an interface between the physical and the network layer. The function of MAC layer is to generate beacons and synchronize the devices to the beacon signal, in a network which is beacon enabled. It also performs the connect and disconnect function. The IEEE 802.15.4 MAC has defined four types of frame structures: A beacon frame which is used by a coordinator to transfer beacons. The beacon frame awakes the client devices, which hear for their address and sleep again when they receive it. A data frame is used for all transmissions of data. The data frame provides up to 104 bytes of

payload. An acknowledgment frame is used to confirm successful reception of frame. It sends feedback from receiver to the sender and confirms that the packet has received without any error. A MAC command frame is used to handle all MAC peer operation control transfers. MAC command frame provides a method for remote control and layout of client nodes. MAC layer provides collision avoidance mechanism and is responsible for validating frames, frame delivery, network interface and secure services.
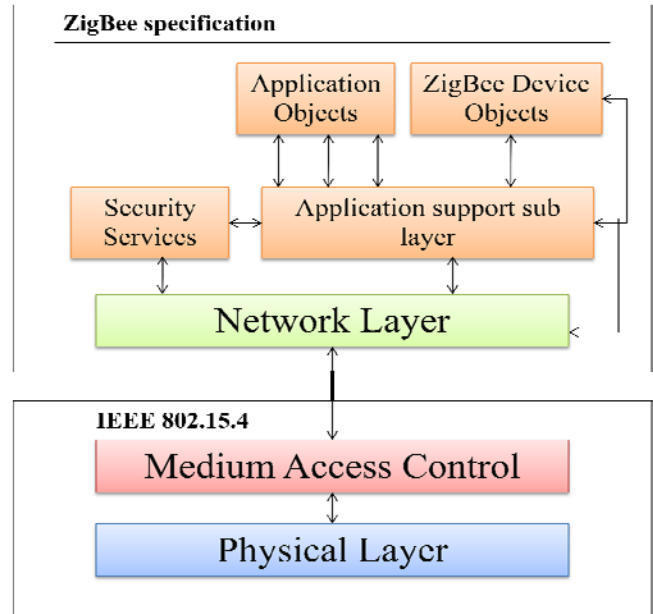


Fig 5: Protocol architecture of ZigBee

C. *Network Layer:* Network layer comes under the ZigBee specification. Network layer is an interface between the application layer and the MAC Layer. Functions of this Layer are formation of network and routing. This layer helps the low power devices to increase their battery life. The Network layer connects or disconnects devices by using the network coordinator that implements security and forward frames to their destination. Network layer of the coordinator starts a new network and assigns an address to newly connected devices. Multiple network topologies are supported by the network layer like star, tree, and mesh as shown in figure.

D. *Application Layer:* The application Layer is the upper most layer of the protocol stack and it holds the application objects. ZigBee specification divides the APL layer into three discrete sub layers:

* Application support sub layer
* ZigBee device objects, and
* Application framework which contains manufacturer defined objects.

1) *The application objects (APO):* Application objects are responsible to control and manage the layers in ZigBee devices. It is a type of software that controls the hardware. Each application objects allots a specific end point number that other APOs may use an addition to

the network device address for interaction. There could be approximately up to 240 application objects into one ZigBee device.

2) *ZigBee Device Object:* The key description of ZigBee is the ZigBee device object, that performs three main functions; security, service discovery & binding. The function of discovery is to find out nodes and ask about the MAC address of the coordinator or router by using the unicast messages. The discovery also facilitates the procedure for finding some services through their profile identifiers. The security services in the ZigBee device object are responsible to authenticate and derive the required keys for data encryption. The role of binding manager is to bind the nodes to recourses and applications also bind the devices to channels.

3) *Application support sub layer:* The APS sub layer is an interface between the Network layer and the APL layers. The APS sub layer processes incoming and outgoing frames to securely receive/transmit the frames and establish or manage the cryptographic keys.

4) *Security service provider:* ZigBee provides security methods for network layer and application layer, each of which is responsible for securing their frames. Security services have methods for key establishment, frame protection, key transport and device management.

## IX. APPLICATIONS OF ZIGBEE

Throughput of ZigBee is very low and the rate of data transfer is about 250 Kbps. Therefore ZigBee is useful for the applications which requires low data rate. Some useful applications of ZigBee are given as:

- Home automation and control.
- Automatic meter reading.
- Building automation.
- Personal health care.
- Fitness monitoring.
- Home gym.
- Hospital and industrial.
- Patient monitoring.
- Cable replacements.
- Status monitoring
- Telecom services.
- ZigBee based multilevel parking vacancy monitoring system. [2]
- Design of intelligent warehouse measure and control system based on ZigBee based wireless sensor networks. [2]
- Design of greenhouse monitoring and control system based on ZigBee based wireless sensor networks.
- Application of ZigBee based wireless sensor networks in environmental monitoring.
- Vehicle control; vehicular and entertainment.
- Residential and commercial utility system.

## X. CONCLUSION

The IEEE 802.15.4/ZigBee protocol stack gives a practical application solution for low data rate, low cost and low power dissipation characteristics of WSNs. This paper gives all over details of the ZigBee technology. ZigBee is a technology designed by ZigBee alliance which offers various characteristics like low power consumption, advanced security services, full mesh networking etc. ZigBee offers two types of access methods; beacon enabled and non beacon enabled and supports three types of ZigBee devices. It supports three network topologies. Protocol stack of ZigBee is given in this paper with sufficient details. ZigBee has its applications in various fields which require low data rate and low power consumption. The prominence of this technology is on low cost communication between the nearby devices having a little or no infrastructure, aims to utilize this low power consumption.

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