ZIGBEE TECHNOLOGY: A COMPREHENSIVE REVIEW OF PROTOCOL, APPLICATIONS, AND ADVANCEMENTS

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Submitted Date : 15 Jan, 2015
Accepted Date: 17 Feb, 2015

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Abstract:

Wireless Sensor Networks are constantly stepping out for different applications. Among the most well-known transceiver protocols for networks of wireless sensors is ZigBee. ZigBee defines the low power monitoring and controlling devices in the Low data rate WPAN (LR-WPAN) specifications over IEEE 802.15.4. Being different from various existing technologies for wireless sensor networks, ZigBee protocol standard is noticed due to its exceptional features and short range. Besides encouraging the growth of wireless personal area networks, this technology is becoming increasingly vital in daily life. Zigbee is an ad hoc wireless network technology that is low-power, low-data-rate, and short-distance (also known as personal area networks) according to the authors of this research. It was developed as an open global standard to serve the special needs of inexpensive and low-power wireless IoT networks. It is based on the IEEE 802.15.4 specification for a suite of high level communication protocols.

Keywords*: ZigBee, WAPAN, PAN, XBee, Wireless Network, NDN, Network Topologies, IEEE802.15.4*

I. INTRODUCTION

Wireless communication technology is given priority when it comes to R&D for applications that enhance human life. One interesting technology in the ZigBee technology arena becomes named due to the figure-eight dance of bees. Bees use this mode of group communication as they go about flying and zig-zagging their wings to inform friends about the location of pollen. The following characteristics are possessed by the Zigbee technology: it organizes itself, is cheap, consumes less power, and is short-range. Hence, interested people adopt this technology with more areas of application to benefit their living. Naturally, the application of ZigBee technology is also affected by these characteristics [1]. To establish a home network, Zigbee is a communication protocol used to link smart devices such as plugs, lights, and smart locks. Just like the Internet of Things works, it is an enabling standard for network sensors and control actions. The packet radio protocol specification is to be used in low-cost battery-powered devices. Due to this protocol's sheer power, devices will be able to communicate in different network architectures and have several years of battery life.

A. ZigBee technology's guiding principles

ZigBee technology's fundamentals IEE802.15.4 protocol has a synonym called ZigBee. ZigBee is a wireless communication system that operates by this protocol, having a short range and using little power. Low data transfer rate technology is yet another term for it. The device is the simplest component of a wireless personal domain network. Network devices can be classified as coordinator nodes, router nodes, or terminal nodes, depending upon their various roles. The sole constraints on the possible applications of this two-way wireless data communication technology are its limited range, low complexity, low power, and low expense. Periodic, intermittent, and low response data are some of the kinds of data that are commonly conveyed over limited ranges using low power and low rates of transmission. As the major core of the entire network, the ZigBee network coordinator might be referred to as the network's "brain." Its tasks include setting up, running, and administering the network, as well as allocating network addresses. The key duties of the ZigBee network router are routing discovery, message transmission, and granting access to other nodes in the network. The ZigBee network coordinator or ZigBee router connects the ZigBee terminal node to the network. The primary role of a ZigBee terminal node is data collecting or control, but other nodes cannot connect to the network through it.

B. System for ZigBee Networks

In descending order, these layers make up the ZigBee network layer: physical layer, media access control layer (MAC), network layer, and application layer. They are four layers in all, each with its own set of tasks for the layers above it. The physical and MAC layers are defined by the IEE802.15.4 standard; the communication layer is also defined by IEE802.15.4. The ZigBee alliance had defined the network layer and application layer. Each layer gives its top layer data and management functions.

Physical layer: Allocates channel and working frequency band, provides data services, and controls the MAC layer. At this level, there is direct control over and communication with the radio transceiver hardware. The operations of the hardware are fully supported. This functionality includes hardware initialization, channel selection, connection quality estimate, energy detection measurement, clear channel assessment to aid in channel selection. Supported by three frequency bands: 2.45GHz (16 channels), 915MHz (10 channels), and 868MHz (1 channel). All three use the direct sequence spread spectrum access mode.

MAC layer This layer serves as a bridge between the network and physical layers. This offers two services: Mac data services and MAC managements, and it interfaces to the MAC sub Layer Management Entity (MLME) Service Access Point.

II. LITERATURE SURVEY

Amar Abane et al. [1] explain Named Data Networking (NDN), a new architecture that allows communications using native data namespaces, names rather than logical host addresses. Over the last decade, various research efforts have shown how NDN can enable new IoT applications such as home automation, smart cities, and smart farming. For better service of IoT applications that are said to need wireless sensing and actuation capabilities, mobility support, and low power consumption, this work tries to hybridize NDN with ZigBee. JiasongMuLiangHan et al. [2] ZigBee networks have lately received much attention because of their low price and simplicity and widely used. However, because the application is not fulfilled thoroughly, the power consumption issue further needs an enhancement. With the emerging communication technology 5G, smarter gadgets and native support to M2M communication become possible. Accordingly, 5G terminals can integrate with existing ZigBee and perhaps further promote the data transmission level. This paper examines the flexibility of ZigBee networks under various 5G environment situations. Based on JiasongMu [3], the revised AODV Junior routing protocol needs to be incorporated within ZigBee routing strategy networks. But the routing overhead caused by routing discovery and routing table maintenance needs to be reduced further. Based on the deployment environment, upcoming 5G technology is highly likely to be broadly deployed in the near future. 5G terminals can be used as gateways for ZigBee networks to make the current routing method more efficient because they natively support smart devices and M2M communication. Chenget Chia-Hsin, etc. [4] A multichannel ZigBee Wireless Sensor Network (WSN) is recommended for effective data transportation. Improving the Packet Delivery Ratio (PDR) by using multi-channel technology was the objective of this research. We created a multi-channel time division multiple-access strategy with hardware elements according to a cluster-tree construction procedure. Furthermore, the unlicensed 2.4 GHz industrial, scientific, and medical (ISM) frequency band is the place where ZigBee and Wireless LAN (WLAN) operate. The results of our experiments demonstrate that the PDR of ZigBee has greatly enhanced transmission in the presence of WLAN interference. JacekStępień et.al. [5] An implementation to track mobile nodes using wireless ZigBee and Wi-Fi networks

is being discussed; a basic yet universal system has been designed, based on recognized algorithmic and circuit solutions that have been prototyped in an application for the localization of people within a museum area. covers applications and principles linked with wireless data communication. The review first goes through the fundamental ideas: the electromagnetic spectrum, radio transceivers, protocols, and antennae. Rob Toulson et.al. [6,7] Bluetooth is introduced and tested using the RN-41 Bluetooth module. Fundamental Bluetooth concepts are applied on the RN-41. Implementation of simple Bluetooth connections between modem and PC. Introduction to the Zigbee protocol, common networks, and applications. Simple Zigbee connections are demonstrated through XBee radio modules in transparent mode, and then the use of XBee in its more flexible API mode is presented-once again opening the path to more complex Zigbee applications. Jia[7]etal. According to the description, at the physical layer, the ZigBee communication system is established by IEEE 802.15.4, and because of its spread spectrum characteristic and error correction of the baseband coding process, it is highly resistant to external white noise. JacekStępień et.al. [5] An implementation to track mobile nodes using wireless ZigBee and Wi-Fi networks is being discussed; a basic yet universal system has been designed, based on recognized algorithmic and circuit solutions that have been prototyped in an application for the localization of people within a museum area. covers applications and principles linked with wireless data communication. The review first goes through the fundamental ideas: the electromagnetic spectrum, radio transceivers, protocols, and antennae. Rob Toulson [6,7,] et.al. Bluetooth is introduced and tested using the RN-41 Bluetooth module. Fundamental Bluetooth concepts are applied on the RN-41. Implementation of simple Bluetooth connections between modem and PC. Introduction to the Zigbee protocol, common networks, and applications. Simple Zigbee connections are demonstrated through XBee radio modules in transparent mode, and then the use of XBee in its more flexible API mode is presented-once again opening the path to more complex Zigbee applications. Jiaet al al [7]. According to the description, at the physical layer, the ZigBee communication system is established by IEEE 802.15.4, and because of its spread spectrum characteristic and error correction of the baseband coding process, it is highly resistant to external white noise. Indeed, ZigBee in dealing with impulsive noise suffers from a drawback in its performance as revealed in previous studies. In this sense, an upgrade in the ZigBee receiver is needed to improve the decoding procedure. To lessen the effect of impulsive noise before symbol detection and thereby improve the Bit Error Rate (BER) performance of the demodulation process of ZigBee, a new Error-Balanced Wavelet filtering approach through multiresolution is being offered. L.K. Wadhwa et.al. [8] mentioned that energy efficiency and network maximization are the twin aims in WSN. ZigBee influences these two factors and works to improve them. With the added advantage of being inexpensive and having a very low rate of transmission, ZigBee turns out to be a power-conservation technique for wireless sensor networks, which in turn prolongs the life of small batteries used by network nodes. Since tree routing in essence rarely stops the transportation of packets to their destinations through routing tables, it is well suited for ZigBee end devices with very limited resources. Different performance measurements (End to end delay, Routing overhead, Throughput, and Packet delivery ratio) are used in the performance evaluation of the routing systems AODV (Ad-hoc On-Demand Distance Vector routing), ZTR (ZigBee Tree Routing), and STR (Shortcut Tree Routing). Shashwat Pathak et al. [9,10,11] offer a ZigBee scenario for an energy-efficient wireless telemonitoring system for cardiac patients based on various duty cycles being delivered to sensors. In an intra-hospital telemedicine scenario, patient Electro Cardio Gram (ECG) data captured by ECG sensor nodes with transmission capacity is sent to a Personal Digital Assistant (PDA) at a nursing station over the ZigBee network. There is more ECG signal transfer.

III. WIRELESS NETWORK TOPOLOGIES

The topologies supported by the IEEE 802.15.4 and ZigBee standards are discussed in this part. The NDN of a network defines the physical or logical connections among the nodes of the network. Zigbee Technology Overview is illustrated in the figure below, the physical topology is a geometric form derived from the physical connections between the nodes Shown in figure 1. The data flow among the nodes is represented by the logical topology.

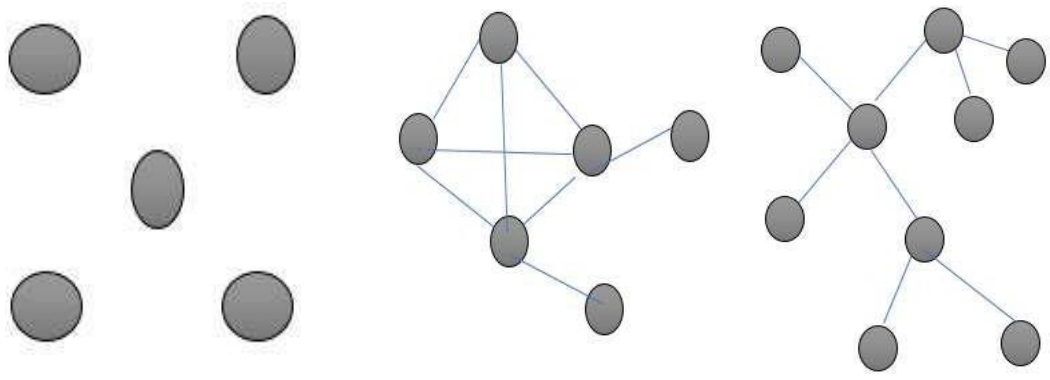


Fig. 1. ZigBee Network Topology

Peer-to-peer and star topologies are supported by IEEE 802.15.4. Both star and mesh and cluster tree peer-to-peer topologies are supported by the ZigBee specification. It is occasionally stated that devices that implement ZigBee can handle both point-to-point and point-to-multipoint topologies.

Wireless Standards

New standards have emerged in response to the growing need for wireless solutions, while some established standards have improved their standing in the market. Three widely used wireless standards are compared in this section, along with several design factors that set them apart.

Table 1. shows comparsion of wireless standards

Comparsion of wireless standards			
Wireless Parameter	Bluetooth	Wi-Fi	ZigBee
Frequency band [12,13]	2.4 GHz	2.4 GHz	2.4 GHz
Physical/MAC layers [14]	IEEE 802.15.1	IEEE 802.15.11b	IEEE 802.15.4
Range [15,16]	9m	75 to 90 m	Indoors: up to 30 m Outdoors (line of sight): up to 100 m
Current consumption [17]	60 mA (Tx mode)	400 mA (Tx mode) 20 mA (Standby mode)	25-35 mA (Tx mode) 3 µA (Standby mode)
Raw data rate [18]	1 Mbps	11 Mbps	250 Kbps
Protocol stack size[19]	250 KB	1 MB	32 KB 4 KB (for limited function end devices)
Max. no. of nodes/ network [20]	7	32 per access point	64 K
No. of channels [21]	19	13	16

A distinct market segment's needs are met by each wireless standard. Any wireless application's successful deployment depends on selecting the best-fitting wireless standard. The wireless standard you select will depend on the needs of your application.

IV. ZIGBEE NETWORK DEVICES & OPERATING MODES

Both the full function device (FFD) and the reduced function device (RFD) are involved in the LR-WPANs. Routing is not possible for an RFD. End nodes alone can be configured for the RFDs. The node which gave permission to the RFD to join the network will be the one with whom they will communicate. An FFD may be configured as the PAN coordinator while also possessing routing functions. Whether or not a node is an RFD or an FFD does not matter in a star network because all nodes communicate with the PAN coordinator only. There is only one PAN coordinator in a peer-to-peer network, and there are other FFDs that talk to the PAN coordinator as well as to other FFDs and RFDs. Three operation modes are indicated in IEEE 802.15.4: coordinator, end device, and PAN coordinator. Any of the operation modes may be configured for FFDs. In ZigBee parlance, the PAN coordinator simply is "coordinator." "Router" is the ZigBee term for "coordinator," the IEEE term for it.

How Zigbee Works

Digital radios offer communication between devices in this manner. A common ZigBee network consists of many types of devices. A network coordinator essentially forms the network; it controls information about each node, has knowledge of all the nodes in the network, and is aware of all the information that is communicated and received within the network. Thus, a network coordinator is necessary for each ZigBee network. There could be other FFDs in the network which are fully functional; they are capable of all of the operations of 802.15.4 and can be network coordinators, network routers, or simply devices that talk to the outside world. The Reduced Function Devices (RFDs), the last ones on these networks, usually act simply as physical world interfaces. ZigBee provides a variety of topologies, including mesh, star, and cluster tree, as aforementioned. A star topology is also effective when there are a large number of end devices that are near each other and share a common router node, such as you might find in figure 3 above. The node then can extend to link up to the larger mesh network, which itself connects up to the network coordinator. Mesh networking provides redundancy in the connectivity of nodes, enabling devices to select a standby route for communication in case one node fails.

Zigbee Devices

1. The most powerful device is the ZigBee Coordinator (ZC), which is the root of the network tree and can be connected to other networks. Because it is the initiating device of the network, every network has a single ZigBee coordinator. It is the Trust Center and key repository besides holding network data.
2. The ZR (ZigBee Router): It acts as an intermediate router that passes data from other devices along with providing application capability.
3. The ZigBee End Device (ZED) cannot forward data from other devices, but can communicate with the parent node (router or coordinator). Long battery life is facilitated by this relationship, which allows the node to be sleeping most of the day. It will almost always cost less to produce than the ZR or due to having the least amount of memory.

V. IEEE 802.15.4 OVERVIEW

802.15.4 Scope: It is packet-based radio technology and may be utilized for wireless communication with very low power usage and data rates. It is the basis of ZigBee. Figure 2's reduced portability stack only supports the two layers—the MAC and PHY—defined under 802.15.4.

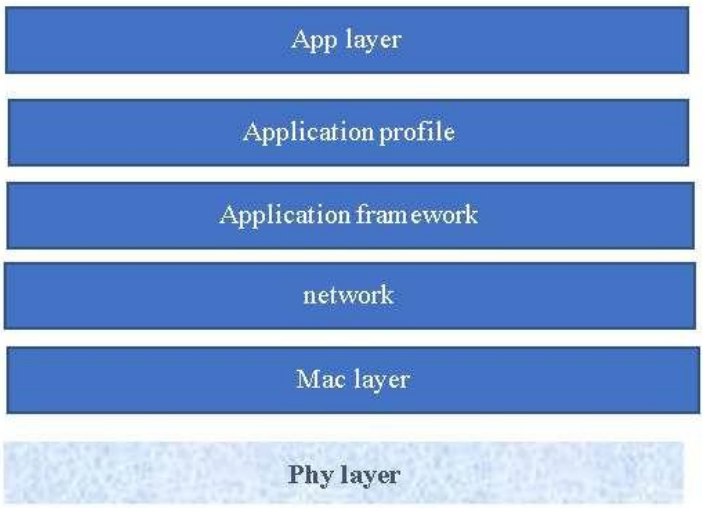


Fig 2. Zigbee stack

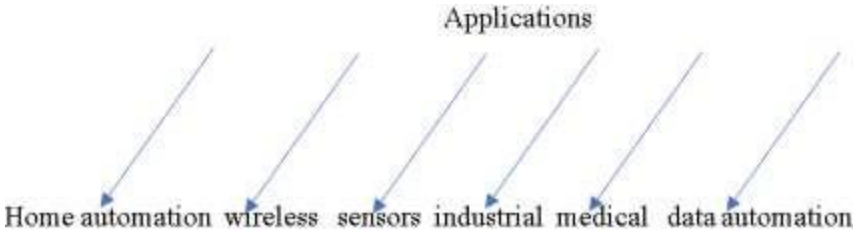
Physical Layer :
The network's electrical and physical properties are specified by the PHY layer.Data transmission and receiving are the PHY layer's primary functions. This entails modulation and spreading techniques at the physical/electrical level, which map bits of information so that they can move through the atmosphere. The PHY layer contains specifications for transmit output power and receiver sensitivity. Additionally, the PHY layer is in charge of the following duties: Turn on or off the radio transceiver's link quality indication (LQI) for energy detection (ED) of received packets in the clear channel assessment (CCA) mode.

MAC Layer :
How several 802.15.4 radios operating in the same vicinity will share the airwaves is determined by the MAC layer. This involves scheduling and routing data frames as well as coordinating transceiver access to the shared radio link.The MAC layer has built-in network affiliation and disassociation features. These capabilities facilitate a ZigBee network's peer-to-peer communication and self-configuration. The following duties fall under the purview of the MAC layer: beacon creation in the event that the device is a coordinator handling the guaranteed time slot (GTS) mechanism, carrier sense multiple access with collision avoidance (CSMA-CA), and data transfer services for higher layers.

Zigbee in security— how secure is Zigbee
According to Zigbee, it offers one of the safest wireless IoT devices. One of Zigbee's advantages is security. Symmetric-key cryptography, on which two parties must exchange keys in order to communicate, is the foundation of the security. The extremely secure 128-bit Advanced Encryption Standard (AES) encryption technique is used by Zigbee. Zigbee is a low-cost protocol with a "open trust" concept in which the layers of the protocol stack have mutual trust. Therefore, cryptographic protection only works between devices; it does not work between a device's layers. This enables the keys to be reused throughout the same device's layers. Zigbee employs the same security level for all devices on a network and for all device levels in order to simplify device interoperability. Additionally, a frame counter built into Zigbee commands prevents replay attacks, which allow an attacker to record and play back a command message. Duplicate messages are ignored and the frame counter is always guaranteed by the receiving endpoint. Due to Zigbee's capability for frequency agility, its network is moved in the event of a jamming attack.

Advantages
Low cost, standards based Suitable for use worldwide,dependable and self-correcting,has a high number of node support,incredibly extended battery life Secure,large capacity of the network

Applications
Zigbee has been used in household, business, and industrial settings, which has resulted in the creation of distinct service standards.



• **Zigbee in Home Automation**—Within a 10- to 100-meter radius of one another, Zigbee operates as a mesh network. It is ideal for a domestic setting. Approximately 400 home automation products are currently listed on the Zigbee Alliance website. You can purchase a brand-new Zigbee device for home automation that will connect to the current meh network. Common IoT home devices include lightbulbs, locks, switches, motion sensors, and thermostats. These devices are also known as Zigbee home automation devices. Amazon, Texas Instruments, Honeywell, Samsung, and Bosch are the main businesses that employ Zigbee devices. To control Zigbee devices, the Amazon Echo Plus has a built-in Zigbee hub. Additionally, Samsung's SmartThings devices support Z-wave and connect via Zigbee.

• Zigbee in Medicine Another application of Zigbee Technology is its application medicine. It is used in the in-home patient monitoring, in which the patient will have to wear a Zigbee device which will periodically collect the information like heart rate and blood pressure.

• **Zigbee in Wireless Sensor Networks (WSN)**— Despite its numerous uses in home automation and the military, Zigbee technology has primarily concentrated on wireless sensor networks. It is also employed in the structural health monitoring of the building. In regions that are prone to earthquakes, this application is particularly beneficial. Throughout the construction, a number of Zigbee-based wireless sensors, such as accelerometers, are deployed. These wireless sensors gather data that can be utilized to identify damage and determine whether the structure is safe for occupants.

• **Zigbee in Industrial Automation**— Zigbee Mesh Technology is supported by one of IoT's industrial devices in eModGATE from TECHBASE. Economical, ESP32-based solution serves as an end-point in any installation or works well as a gateway, gathering data from scattered sensor mesh across the installation. Research Method: Research was done by collecting data from primary and secondary resources. Primary research – Data about awareness of Zigbee Technology was collected through random sampling. The questionnaire was designed and circulated to various potential respondents. The sample size was 67 and the respondents were of different age groups, occupations and educational level. The tool used was Google Forms. Secondary research— The data regarding Zigbee Technology and its application in various fields were collected from secondary resources like published research papers and google search engine

VI. CONCLUSION

In this paper, the capabilities of ZigBee technology are studied. Zigbee is suitable for both household and business uses. It is an effective way to improve communication routing. Zigbee protocol improves the performance of wireless communication. Zigbee is although not very popular for now but soon it has a chance to become one of the best applications of Internet of Things. This review's primary finding is that ZigBee is a good foundation for embedded wireless development. The primary cause is because development is quick and simple. Additionally, ZigBee satisfies the stated technical specifications. ZigBee is more likely to be utilized in industrial networks and building automation. Since ZigBee is now the sole choice for such standardized wireless networks, the industry's chances appear to be the highest. Despite some competition, ZigBee is probably going to dominate the home automation market as well because of its superior performance, affordability, and compliance. ZigBee is unlikely to be employed in consumer electronics and PC peripherals because it provides very little advantage over the competitors.

VII. FUTURE SCOPE

Using zigbees to monitor trains for collision prevention,Border protection and structural well-being Floods and earthquakestraffic management. Devices based on the zigbee standard facilitate a variety of fields, including defense, national security, surveillance, and control, among others. The placement of the nodes in a zigbee network must be carefully examined in order to achieve the highest throughput possible. When considering a zigbee network's throughput and efficiency, the nodes' movements have been crucial.

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