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Study on ZIGBEE Technology

Abhishek Kumar[*1], Sandeep Gupta[2]
[*1,2] Department Of ECE, Bharat Institute of Technology, Partapur, Meerut-250003, India
999electro.abhi@gmail.com

Abstract

ZIGBEE is one of the most widely used transceiver standard in wireless sensor networks. Zigbee over IEEE 802.15.4., defines specifications for low rate WPAN(LR-WPAN) to support lower monitoring and controlling devices. Zigbee is developed by Zigbee alliance ,which has hundreds of member companies. Zigbee alliance(software) defines the network, security and application layers. IEEE802.15.4(hardware) defines the physical and media access control layers for LR-WPAN. This paper presents a detailed study of Zigbee wireless standard, IEEE802.15.4 specification, Zigbee device types, the protocol stack architecture and its application.

Keywords: Zigbee, IEEE802.15.4. Standard, LR-WPAN.

Introduction

Wireless Technology is being developed rapidly nowadays. Advancement in micro electromechanical systems brings integration of sensing, signal processing and RF capability on very small devices. All kind of portable applications tend to be able to communicate without the use of any wires. Aim of wireless communication is to gather information or perform certain task in the environment. A typical sensor node contains three C's, are Collection, Computation and Communication units. Based on the request of sink, gathered information will be transmitted wirelessly. The collection unit has series of sensors. Computation unit contains microcontroller and memory. Finally the communication unit contains transceiver to transmit and receive data; various transceivers (such as RFM TR1000 family, Hardware accelerators, ChipconCC1000 and CC2420 family , Infineon TDA 525x family, IEEE802.15.4/Ember EM2420 RF transceiver, ConexantRDSSS9M) used for this purpose.

The reasons [1] for using Zigbee are,

- Reliable and self healing
- Supports large number of nodes.
- Easy to deploy
- Very long battery life
- Secure
- Low cost
- Can be used globally
- Vibrant industry support with thirty or more vendors supplying products and services
- Open Standards protocol with no or negligible licensing fees
- Chipsets available from multiple sources
- Remotely upgradeable firmware
- No new wires
- Low power (ability to operate on batteries measured in years)
- Low maintenance (meshing, self organizing)
- Standards based security [AES128]
- Ability to read gas meters

All of the technologies are young – Bluetooth being the oldest with developments started in 1997. ZigBee started its developments in 2001. Different companies developed other technologies within the last three or four years. Zigbee is one of the most widely utilized Wireless Sensor Network standards with low power, low data rate, low cost and short time delay characteristics, simple to develop and deploy and provides robust security and high data reliability. Name of the Zigbee came from zigzagging patterns of honey bees between flowers, represents the communication between nodes in a mesh network [1].

ZIGBEE and IEEE 802.15.4

ZigBee is developed by ZigBee alliance, which has hundreds of member companies (Ember, Freescale, Chipcon, Invensys, Mitsubishi, CompXs, AMI Semiconductors, ENQ Semi conductors), from semiconductor and software developers to original equipment manufacturers. ZigBee and 802.15.4 are not the same. ZigBee is a standard based network protocol supported solely by the ZigBee alliance that uses the transport services of the IEEE802.15.4 network

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specification. ZigBee alliance is responsible for ZigBee standard and IEEE is for IEEE802.15.4. It is like TCP/IP using IEEE 802.11b network specification [2]. ZigBee alliance (software) defines the network, security and application layers. IEEE802.15.4 (hardware) defines the physical and media access control layers for LR-WPAN in figure1. Power needed for ZigBee is very small. In most cases it uses 1mW (or less power). But still it provides range up to 150 meters in outdoor which is achieved by the technique called direct sequence spread spectrum (DSSS). Also DSSS consumes less power compared to Frequency Hopping Spread Spectrum (FHSS). It works in the 868 MHz (Europe),915 MHz (North America and Australia) and 2.4 GHz(available worldwide) ISM band with up to 20kbps, 40kbps and 250kbps data rate respectively .

Because these wave bands are different from the bands of current common wireless networks, Wireless Fidelity (Wi-Fi), Bluetooth, Wireless USB etc. Mutual interferences between them will not occur, therefore, this guarantees our system will not interfere other wireless networks and will not be affected as well.

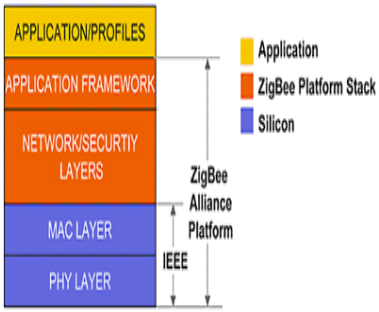

Figure 1: ZigBee adds network, security, and application-services layers to the PHY and MAC layers of the IEEE 811.15.4 radio.

The IEEE 802.15.4 standard employs 64-bit and 16-bit short addresses to support theoretically more than 65,000 nodes per network [7]. ZigBee network can have up to 653356 devices, the distance between ZigBee devices can be up to 50 meters, and each node can relay data to other nodes. This leads capability of making a very big network which covering significant distances.

ZIGBEE Standard

ZigBee device are the combination of application (such as light sensor, lighting control etc), ZigBee logical(coordinator, router, end device), and ZigBee physical device types (Full Function Device and Reduced Function Device)[1].

A,ZigBee physical device types: Based on data processing capabilities, two types of physical devices are provided in IEEE 802.15.4: Full Function Devices (FFD) and Reduced Function Devices(RFD). Full Function Devices can perform all available operations within the standard, including routing mechanism, coordination tasks and sensing task. The FFD plays role of coordinator or router or end devices (It can be either FFD or RFD depends on its intended application). A typical FFD in a ZigBee network will be powered from an AC-fed mains supply, as it must always be active and listening to the network. Reduced Function Devices, on the other hand,implements a limited version of the IEEE 802.15.4 protocol.

The RFDs do not route packets and must be associated with an FFD. These are end devices such as sensors actuators which only doing limited tasks like recording temperature data, monitoring lighting condition or controlling external devices. The current ZigBee standard requires FFDs to be always on, which in practice means that FFDs must be constantly powered. Battery-powered FFDs have a lifetime on the order of a few days.

B. ZigBee logical device types :There are three categories of nodes in a ZigBee system.They are Coordinator, Router and End devices.

1) Coordinator : Forms the root of the network tree and might bridge to other networks. There is exactly one coordinator in each network. It is responsible for initiating the network and selecting the network parameters such as radio frequency channel, unique network identifier and setting other operational parameters. It can also store the information about network, security keys.

2) Router: Router acts as intermediate nodes, relaying data from other devices. Router can connect to an already existent network, also able to accept connections from other devices and be some kind of re- transmitters to the network. Network may be extended through the use of ZigBee routers.

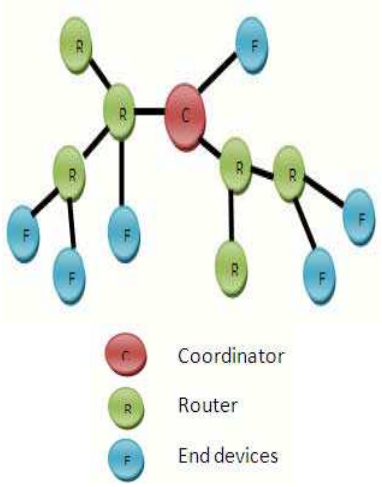

Figure 2: Zigbee Network

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3) End Devices : End Device can be low-power/ battery-powered devices. They can collect various information from sensors and switches. They have sufficient functionality to talk to their parents (either the coordinator or a router) and cannot relay data from other devices. This reduced functionality allows for the potential to reduce their cost. They support better low power models. These devices do not have to stay awake the whole time, while the devices belonging to the other two categories have to. Each end device can have up to 240 end nodes which are separate applications sharing the same radio.

C. Access Modes: Two ways of multi-access in ZigBee protocol, are Beacon and Non-beacon. In non beacon enabled network, every node in the network can send the data when the channel is free. In beacon enabled network, nodes can only transmit in predetermined time slots. Here PAN coordinator allocates guaranteed time slots (GTS) for each device; therefore devices will transmit their data during their own slot. All devices should be synchronized for this process. This will be achieved by sending beacon signal. The coordinator is responsible to transmit beacon signals to synchronize the devices attached to it [4]. Network in which the coordinator does not transmit beacon signal is known as non-beacon network. It cannot have GTS and contention free periods, because the devices are not synchronized. Battery life is better than beacon enabled network, because the devices are wake up less often.

ZIGBEE Protocols Stack

Protocol architecture is based on Open system interconnection (OSI). ZigBee builds on IEEE standard 802.15.4 which defines the physical and media access control (MAC) layers.

ZigBee alliance defines the network layer and application layer. Fig.2 shows protocol stack of ZigBee system.

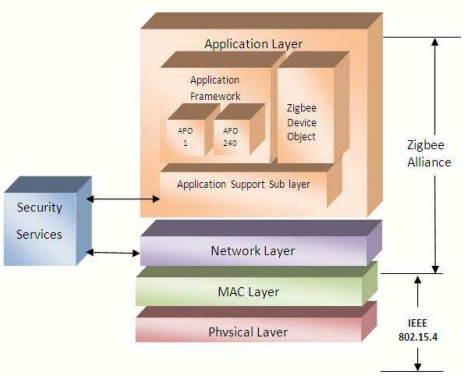

Figure 3. ZigBee Protocol Stack

A. Physical Layer: The physical layer of the IEEE802.15.4 standard is the closest layer to the hardware, which control and communicate with the radio transceiver directly. It handles all tasks involving the access to the ZigBee hardware ,including initialization of the hardware, channel selection ,link quality estimation, energy detection measurement and clear channel assessment to assist the channel selection.

Supports three frequency bands, 2.45GHz band which using 16 channels, 915MHz band which using 10 channels and 868MHz band using 1 channel. All three using Direct Spread Spectrum Sequencing (DSSS) access mode.

Parameters/frequency	868Mhz	915Mhz	2450Mhz
Channels	1	10	16
Data rate	20Kbps	40Kbps	250Kbps
Applicability	Europe	USA	World

B. MAC Layer: This layer provides interface between physical layer and network layer. This provides two services; MAC data services and MAC management service interfacing to the MAC sub Layer Management Entity (MLME) Service Access Point called (MLME-SAP). The MAC data service enables the transmission and reception of MAC Protocol Data Units (MPDUs) across the PHY data service. MAC layer is responsible for generating beacons and synchronizing devices to the beacon signal in a beacon enabled services. It is also performing association and dissociation function. It defines four frame structures, are Beacon frame, Data frame, Acknowledge frame, MAC command frame. Basically there are two types of topology; star and peer to peer. Peer to peer topology can take different shapes depends on its restrictions. Peer to peer is known as mesh, if there is no restriction. Another form is tree topology. Interoperability is one of the advantages of ZigBee protocol stack. ZigBee has wide range of applications, so different manufacturer provides ZigBee devices. ZigBee devices can interact with each other regardless of manufacturer (even if the message is encrypted).

C. Network Layer: Network layer interfaces between application layer and MAC Layer. This Layer is responsible for network formation and routing. Routing is the process of selection of path to relay the messages to the destination node. This forms the network involving joining and leaving of nodes, maintaining routing tables (coordinator/router), actual routing and address allocation. ZigBee coordinator or router will perform the route discovery. This layer Provides network wide security and allows low power devices to maximize their battery life. From the basic topologies, there are three

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network topologies are considered in IEEE802.15.4 are star, cluster tree and mesh.

D. Application Layer: The application Layer is the highest protocol layer and it hosts the application objects. ZigBee specification separates the APL layer into three different sub-layers: the Application Support Sub layer, the ZigBee Device Objects, and Application Framework having manufacturer defined Application Objects.

1) The application objects (APO) : Control and manages the protocol layers in ZigBee device. It is a piece of software which controls the hardware. Each application objects assigned unique end point number that other APO's can use an extension to the network device address to interact with it [6]. There can be up to 240 application objects in a single ZigBee device. A ZigBee application must conform to an existing application profile which is accepted ZigBee Alliance. An application profile defines message formats and protocols for interactions between application objects. The application profile framework allows different vendors to independently build and sell ZigBee devices that can interoperate with each other in a, given application profile.

2) ZigBee Device Object: The key definition of ZigBee is the ZigBee device object, which addresses three main operations; service discovery, security and binding. The role of discovery is to find nodes and ask about MAC address of coordinator/router by using uncast messages. The discovery is also facilitating the procedure for locating some services through their profile identifiers. So profile plays an important role. The security services in this ZigBee device object have the role to authenticate and derive the necessary keys for data encryption. The network manager is implemented in the coordinator and its role is to select an existing PAN to interconnect. It also supports the creation of new PANs. The role of binding manager is to binding nodes to recourses and applications also binding devices to channels [5].

3) Application support sub layer: The Application Support (APS) sub layer provides an interface between the NWK and the APL layers through a general set of services provided by APS data and management entities. The APS sub layer processes outgoing /incoming frames in order to securely transmit/receive the frames and establish/manage the cryptographic keys. The upper layers issue primitives to APS sub layer to use its services. APS Layer Security includes the following services: Establish Key, Transport Key, Update Device, Remove Device, Request Key, Switch Key, Entity Authentication, and Permissions Con□guration Table.

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

E. Topologies: There are following topologies

(1)*Star Topology:* Star topology consists of one coordinator and any number of end devices. In star topology a master slave network model is adopted where master is the ZigBee coordinator which is FFD and slave will be either FFD or RFD. ZigBee end devices are physically and electrically separated from each other end devices and pass information through coordinator. Devices can only communicate with the coordinator. This is does not provide multi-hop networking and mesh networking.

(2)Cluster Tree Topology: The cluster tree topology is similar to the star topology. The difference is that other nodes can communicate with each other so that more RFD/FFDs can be connected to non-coordinator FFDs. The advantage of this topology is the possible geographical expansion of network.

(3)Mesh Topology: In mesh topology, each node can communicate any other node within its range. Mesh topology is complex to maintain and beaconing is not allowed here. But it is more robust and tolerance to fault.

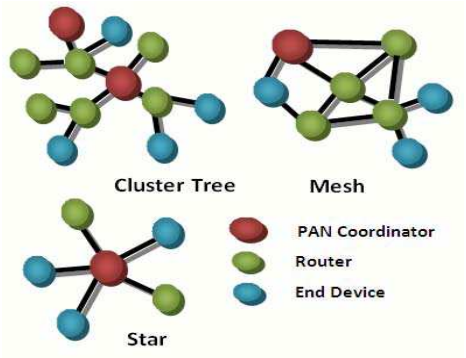

Figure 4: topologies

ZIGBEE Application

Zigbee Alliance targets applications "across consumer, commercial, industrial and government markets worldwide". Unwired applications are highly sought after in many networks that are characterized by numerous nodes consuming minimum power and enjoying long battery lives.

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Zigbee technology is designed to best suit these applications ,for the reason that it enables reduced costs of development, very fast market adoption, and rapid ROI.

Airbee Wireless Inc has tied up with Radio craft AS to deliver "Zigbee-ready solutions; the former supplying the software and the latter making the module platforms .With even light controls and thermostat producers and includes big OEM names like HP ,Philips,Motorola and Intel.With Zigbee designed to enable two-way communication , not only will the consumer be able to monitor and keep track of domestic utilities usage, but also feed it to a computer system for data analysis.Futurists are sure to hold Zigbee up and says," See I told you so". The Zigbee Alliance is nearly 200 strong and growing, with more OEM's signing up. This means that more and more products and even later, all devices and their controls will be based on this standard. Since Wireless personal Area Networking applies not only to household devices, but also to individualized office automation applications, Zigbee is here to stay .It is more than likely the basis of future home-networking solutions.

Table 1 Application of Zigbee

Market Name	ZigBee®	---	Wi-Fi™	Bluetooth™
Standard	802.15.4	GSM/GPRS CDMA/1xRTT	802.11b	802.15.1
Application Focus	Monitoring & Control	Wide Area Voice & Data	Web, Email, Video	Cable Replacement
System Resources	4KB - 32KB	16MB+	1MB+	250KB+
Battery Life (days)	100 - 1,000+	1-7	.5 - 5	1 - 7
Network Size	Unlimited (2^{64})	1	32	7
Bandwidth (KB/s)	20 - 250	64 - 128+	11,000+	720
Transmission Range (meters)	1 - 100+	1,000+	1 - 100	1 - 10+
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

Comparison to Blue Tooth

Zigbee was developed t serve very different applications than Bluetooth and leads to tremendous optimizations in power consumption. Some of the key differentiators are :

(a) Zigbee: It has very low duty cycle, very long primary battery life ,Static and Dynamic star and mesh networks ,>65,000 nodes, with low latency available, Ability to remain quiescent for long periods without communications, Direct Sequence Spread spectrum allows devices to sleep without the requirement for close synchronization.

(b) Bluetooth: It has Moderate duty cycle ,secondary battery lasts same as master, very high QoS and very low, guaranteed latency, Quasi –static star networks up to seven clients with ability to participate in more than one network, Frequency Hopping Spread Spectrum is extremely difficult to create extended networks without large synchronization cost.

Advantages of ZIGBEE

The main advantages include product interoperability, vendor independence, and accessibility to broader markets. Customers can expect increased product innovation as a result of the industry standardization of the physical radio and logical networking layers. Instead of having to invest resources to create a new proprietary solution from scratch every time, companies will now be able to leverage these industry standards to instead focus their energies on finding and serving customers. the United States. This specification maintains the same usage and architecture as wired USB devices with a high-speed host-to-device connection and connects to a maximum of 127 devices. WUSB is based on a hub and spoke topology.

Conclusion

The main conclusion of this Master's thesis project is that, yes, ZigBee is a suitable base for embedded wireless development. The main reason is that development is easy and fast. ZigBee also meets the promised technical requirements. The areas that ZigBee is likely to be used in is building automation and industrial networks. The chances seem highest in the industry since ZigBee is currently the only option for such standardized wireless networks. Even though there are some competition, due to better performance, price and compliance, ZigBee is likely to dominate the home automation market as well. PC peripherals and consumers electronics are two areas that ZigBee is very unlikely to be used in, because it offers very little over the competition.

"Just as the personal computer was a symbol of the '80s, and the symbol of the '90s is the World Wide Web, the next nonlinear shift, is going to be the advent of cheap sensors."

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