An Overview of Zigbee Technology and its Industrial Applications

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ABSTRACT

Wireless technologies have been rapidly developed during recent years. Starting from military and industrial controls, it is now being widely applied in environmental monitoring and agriculture. Its advantages include the liability, simplicity, and low cost. However, there are many wireless monitoring and control applications for industrial and home environments which require longer battery life, lower data rates and less complexity than those from existing standards. For such wireless applications a new standard called ZigBee has been developed by the ZigBee Alliance. ZigBee is a technological standard created for control and sensor networks. It is one of the most popularly deployed wireless technologies in recent years because ZigBee is an open standard lightweight, low-cost, low-speed, low-power protocol that allows true operability between systems. The IEEE 802.15.4 standard specifies the PHY Layer and MAC Layer for low data rate wireless PANs. Although the ZigBee design specification includes security features to protect data communication confidentiality and integrity, however, when simplicity and low-cost are the major goals, security suffers. This paper gives an overview of the ZigBee technology including needs, device types, network topology, advantages, disadvantages and its applications.

Keyword: - ZigBee, WSN, IEEE 802.15.4.

1. INTRODUCTION

Wireless sensor networking is one of the most popular and active research areas in networking and communication field in recent years, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. It consists of low power, low cost smart devices which have limited computing resources. Rapidly increasing demand and interest in wireless sensor networks can be interpreted by knowing about what exactly they essentially are and how these can be utilized in different areas of real-life applications. Wireless Sensor Network (WSN) consists of large number of tiny sensor nodes which gather information from physical processes/events and communicate the processed data (information) cooperatively and wirelessly to the base station. The network is formed when the same or different types or group of sensors jointly monitor (and/or control) one or more physical environments. The wireless technology deployed for a particular sensor network depends on the type of application. Common wireless technologies include Infrared, Bluetooth, WiFi, WiMax, ZigBee etc.

The question arises why ZigBee, when there is Bluetooth. The reason is bandwidth of Bluetooth is 1 mbps; ZigBee's is one fourth of this value. Strength of ZigBee lies in low cost and long battery life.

ZigBee is a specification that defines a set of high level protocols for low cost and low power Wireless Personal Area Networks (WPANs). It does not require infrastructure (no need for access point) or when it does, it is usually pretty simple. It is employed principally for monitoring or control tasks which require low cost, reliability, security and low power consumption (long battery life) where high range or high rate communication is not needed. ZigBee is specified by a consortium of manufacturers, distributors and users called ZigBee Alliance (consisting of over 270 companies).

ZigBee has a transmission range of 10 - 100metres. Comparing ZigBee with WiFi and Bluetooth, ZigBee stack is lighter weighted (about 120 KB). It has a maximum throughput of 250Kbps while Bluetooth (except 802.11n)

and Wi-Fi transmit at 3Mbps and 54Mbps respectively. While WiFi devices (e.g. WiFi VoIP phones) are reported to have 8 – 12hours of battery lives and Bluetooth devices with a battery life of a few days, many ZigBee devices can boast of a battery life of up to 5years. The huge power saving resulted from relatively short-range of transmission, low data transfer rates and simple protocol stack of ZigBee.

ZigBee is based upon the IEEE Std 802.15.4 which, in turn, is a standard that defines the low level protocols that intends to guarantee connectivity among portable, low cost, low complexity and low power devices. The IEEE 802.15.4 defines the Physical and the Media Access Control (MAC) layers. ZigBee adds over IEEE 802.15.4 the definition of protocols for the Network and the Application layers.

2. WHY ZIGBEE IS NEEDED

a) There are a multitude of standards that address mid to high data rates for voice, PC LANs, video, etc. However, up till now there hasn't been a wireless network standard that meets the unique needs of sensors and control devices. Sensors and controls don't need high bandwidth but they do need low latency and very low energy consumption for long battery lives and for large device arrays.
b) There are a multitude of proprietary wireless systems manufactured today to solve a multitude of problems that also don't require high data rates but do require low cost and very low current drain.
c) These proprietary systems were designed because there were no standards that met their requirements. These legacy systems are creating significant interoperability problems with each other and with newer technologies.

3. ZIGBEE DEVICES TYPES

The operation of a ZigBee node depends on whether it is a full-function device (FFD) or reduce-function device (RFD). The FFD performs all the tasks defined by ZigBee standard while the function performed by the RFD is limited. An FFD can form any type of network (such as star, tree or mesh) while a RFD can only connect to an FFD. With respect to these functionalities, ZigBee devices are classified as Coordinator, Router and End Devices.

2.1 ZigBee Cordinator (ZC)

It is an FFD and a network must contain only one. It starts the network and is responsible for the overall management of the network. In star topology, it is the central node while in tree or mesh topology, it is the root node. Its other functions include address allocation, granting permission to nodes to join or leave network, transfer application packets and keeping list of neighbours table. Because of it functions in the network, it must always be powered on.

2.2 ZigBee Router (ZR)

It is also an FFD and can be absent in a network, a network can also contain just one or more depending on the size and topology of the network. It is not required in star topology. It is often used to expand ZigBee network (in tree and mesh). Basically, it performs all the functions of the coordinator except network establishment (start-up). Constant power source must also be provided for a ZR.

2.3 ZigBee End Devices (ZEDs)

They are RFDs and are usually located at the extremities of a network. Their main task is in sending and receiving packets. Other devices cannot connect to the network through a ZED and it cannot relay messages. ZEDs often sleep when they are not transmitting or receiving in order to conserve power. At this point in time, they are said to be in sleep mode. Therefore they can be battery powered for ease of mobility.

2.4 ZigBee Trust Centre (ZTC)

It is a dedicated device (node) in the network whose function is to provide security management, device authentication and key distribution. Where this is not available in the network, the coordinator performs these roles.

2.5 ZigBee Gateway

The main function of the gateway is to connect the ZigBee network to external network e.g. LAN using protocol conversion.

4. ZIGBEE NETWORK TOPOLOGIES

Three network topologies are specified for ZigBee network:-star, tree and mesh. The depth of a network depends on the network topology and is determined by the number of routers (hops) in the network from the coordinator to the farthest node.

4.1 Star Topology

This topology consists of a coordinator and several end devices as shown in Fig 1. It has no router and therefore a star network has a depth of one (1). End devices communicate with each other in the network only through the coordinator. Instead of end devices (in Fig 2), routers can be used. However, router message relay functions will not be used, only its application functions will be used. The end devices or routers now become children to the coordinator.

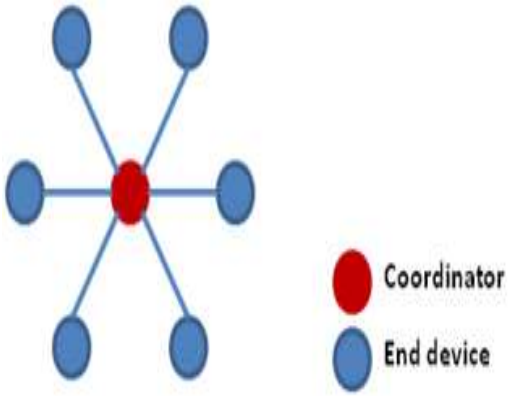

Fig -1: ZigBee Star Topology

The major advantage of a ZigBee star network is its simplicity. The main disadvantage is that it does not provide alternative route for packet transmission and reception. All transmission and reception go through the coordinator. This may increase the burden on the coordinator and hence cause congestion in the network.

4.2 Tree Topology

In the tree topology, the coordinator (at the top) is connected to several routers and end devices. In this case, the routers and the end devices are coordinator's children. The router is used to extend the network; a router can therefore connect to several other routers and/or end devices to form the router's children as shown in Fig 2. Only the coordinator and the routers can have children and hence can become parents in a tree topology. The end devices cannot have children and therefore cannot become parents.

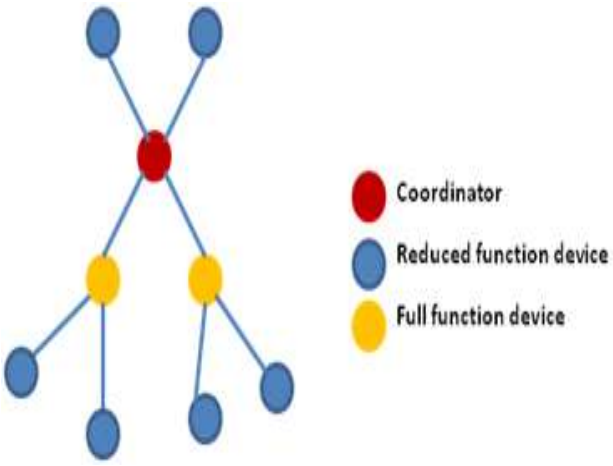

Fig -2: ZigBee Tree Topology

A child is only permitted to communicate directly with its parent and not with any other nodes. Parents can communicate directly with their parents and children.
Like in star, there are no alternative paths to destinations. If a parent is down, its children cannot communicate with other nodes in the network. And even if two nodes in the network are geographically close, their direct communication is not guarantee.

4.3 Mesh Topology

In mesh, the coordinator is also at the top like that of tree. It consists of a coordinator, several routers and end devices connected as shown in Fig 3. Routers are used to extend network range like in tree. As shown, packets pass through multiple hops to reach destinations and communication between any source and destination in the network is realistic. Hence it is also called a peer-to-peer multi-hop network.

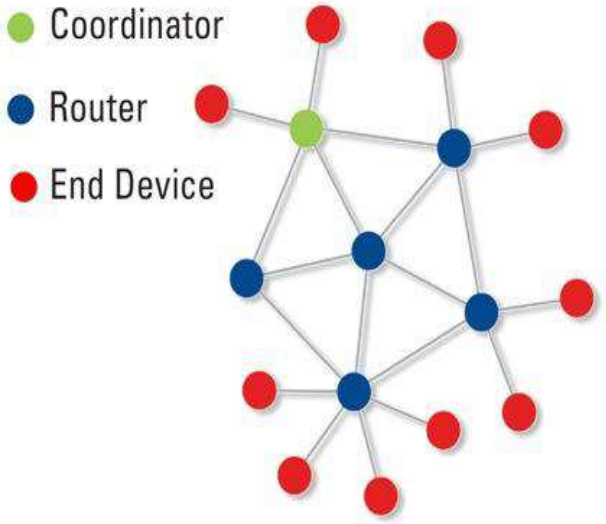

Fig -3: ZigBee Mesh Topology

Moreover, a mesh network provides alternative paths for packet to reach its destination if a path fails. With reference to this, mesh network is usually also being described as a "self-healing" network. Thus adding or removing a node is made easier.

Compared to star and tree ZigBee network configurations, mesh network is more complex and therefore requires more overhead and uses more complex routing protocols.

5. ZIGBEE PROTOCOL STACK ARCHITECTURE

ZigBee follows the standard OSI (Open system Interconnection) reference model. Protocol stack of ZigBee has a layered structure.

The IEEE 802.15.4 defines the physical layer and the medium access layer. The specification for the physical layer defines low-power spread spectrum radio operating at frequency bands such as 2.4GHz, 915 MHz, and 868 MHz. The specification for the MAC layer defines how multiple802.15.4 radios operating in the same area can share the airwaves.

MAC layer also defines different network topologies. The upper layers network layer and application layer are defined by the organization called ZigBee Alliance. Figure - 4 shows protocol stack architecture of ZigBee.

5.1 Physical layer

Physical layer of the IEEE802.15.4 standard controls and communicates with the radio transceiver directly. It handles all tasks involving the access to the ZigBee hardware, including initialization of the hardware, link quality estimation, channel selection, energy detection measurement and clear channel assessment to assist the channel selection. It supports three frequency bands, 2.45GHz band which using16 channels, 915MHz band which using 10 channels and 868MHz band using 1 channel.

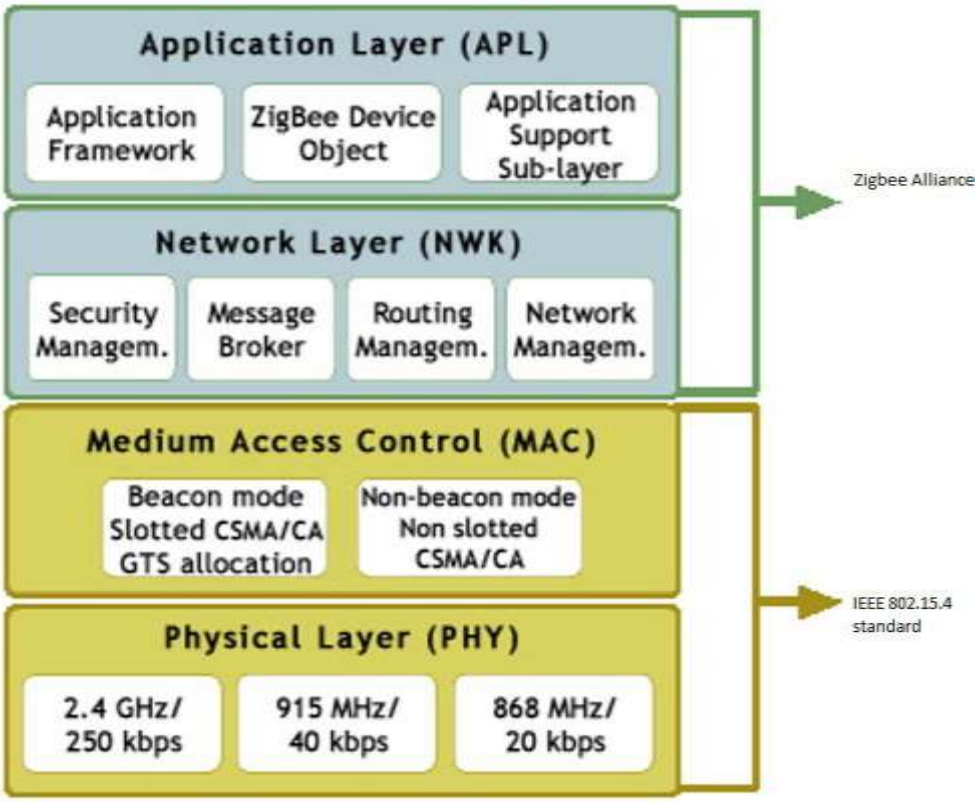

Fig -4: Protocol stack architecture of ZigBee

5.2 MAC layer

This layer is an interface between the physical and the network layer. It performs 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. Main function of MAC layer is to generate beacons and synchronize the devices to the beacon signal, in a network which is beacon enabled. 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.

5.3 Network layer

It 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. Route discovery is performed by ZigBee coordinator or router. This layer Provides network wide security and allows low power devices to maximize their battery life. It defines the basic topologies, star, tree Network and mesh.

5.4 Application Layer

It is the uppermost 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. 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: It performs three main functions; security, service discovery & binding. The security services in the ZigBee device object are responsible to authenticate and derive the required keys for data encryption. 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 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 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, Switch Key, Request Key, Entity Authentication, and Permissions Configuration Table.

6. ZIGBEE ADVANTAGES

The ZigBee protocol is designed to communicate data through hostile RF environments that are common in commercial and industrial applications.
ZigBee protocol features include:

1. ZigBee provides support for multiple network topologies such as point-to-point, point-to-multipoint and mesh networks.
2. It has low duty cycle which provides long battery life.
3. ZigBee has Low latency.
4. Direct Sequence Spread Spectrum (DSSS) is used in ZigBee technology.
5. ZigBee has ability to use upto 65,000 nodes per network.
6. 128-bit AES (Advanced Encryption Standard) encryption for secure data connections are used in it.
7. Collision avoidance retries and acknowledgements are one of the most efficient features of ZigBee.

7. DISADVANTAGES OF ZIGBEE

1. It is costlier to replace with ZigBee compliant appliances in some applications. As non-ZigBee radios are not supported in ZigBee infrastructure.
2. It cannot be predicted as more secure than a typical 802.11wireless network.
3. For ZigBee compatible appliance manufacturers, it is mandatory to use lithium battery.
4. ZigBee compliant manufacturers are still very slow to develop the standards as per market demand.

8. ZIGBEE APPLICATIONS

There are many applications that are having redundant, self-configuring and self-healing capabilities of ZigBee wireless mesh networks. These applications include:

8.7.1 Building Automation

It provides security; HVAC (Heating, Ventilation, and Air conditioning) refers to technology of indoor or automotive environmental comfort. Now HVAC is widely used in the buses and cabs. It is also used in lighting control, access control and Adaptive Multi-Rate (AMR or AMR-NB) audio codec is a patented audio data compression scheme optimized for speech coding.

8.7.2 Energy Management and Efficiency

To provide greater information and control of energy usage, provide customers with better service and more choice, better manage resources, and help to reduce environmental impact.

8.7.3 Consumer Electronics

To provide more flexible management of lighting, heating, cooling, security and home entertainment systems such as TV, DVD's, home theatre.

8.7.4 PC and Peripherals

To integrate the system to perform different types of tasks, we have input/output devices as well as high speed processors, storage media and many other devices such as joystick, OMR.

8.7.5 Home Control

To integrate the lighting, heating, cooling and security or we can say that it is responsible for controlling the home.

8.7.6 Telecommunication Services

It covers information services, Mobile Commerce, also known as M-Commerce or mCommerce, is the ability to conduct commerce using a mobile device, such as a mobile phone, Personal Digital Assistant (PDA), smartphone, or other emerging mobile equipment such as dash top mobile devices.

8.7.7 Industrial Automation

To extend existing manufacturing and process control systems reliability. The interoperable nature of ZigBee means that these applications can work together, providing even greater benefits.

8.7.8 Personal Health Care

ZigBee Alliance provided many devices which helps for the fitness of patients such as personal wellness monitoring, Electrocardiograph (ECG), chronic disease monitoring, glucose meter and pulse oximeter.

9. CONCLUSIONS

ZigBee technology is the most promising wireless sensor and control network in recent times. This technology has the attractive features, such as, open standard lightweight, low-cost, low-speed, low-power, interoperability protocol, among others. ZigBee networks are reliable and self-healing. These networks are easy to deploy which is cheaper as compared to other technologies. It is based on existing IEEE 802.15.4 standard. This paper has provided a general overview of the ZigBee sensor networking technology in which its needs, devices type, topology, and applications have been presented.

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