International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

An Overview of ZigBee Specifications and its Industrial Applications

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Abstract: ***This paper combines the characteristics of the IEEE 802.15.4 standard with the ZigBee specification. The capabilities of both can result in the availability of a technology tailored specifically for the low power, low cost, and low complexity applications in the industrial, residential, and home sensor networks. In this paper, we review the properties of ZigBee, its position in the networking architecture, the functioning and exchange of data in its wireless sensor networks. We also discuss some practical applications of ZigBee.***

Keywords: ZigBee, Wireless Sensor Networks (WSN), IEEE 802.15.4, ZigBee Applications

1. Introduction

ZigBee is an established set of specifications for wireless personal area networking (WPAN), i.e. digital radio connections between computers and related devices. The great potential of Wireless Sensor Networks (WSN) is being seen in industrial, consumer and commercial applications. This paper focuses on the most widely used transceiver standard in Wireless Sensor Networks- ZigBee technology. ZigBee over IEEE 802.15.4 defines specifications for low data rate WPAN (LR-WPAN) to support low power monitoring and controlling devices [1]. This is a wireless protocol that also operates in the 2.4GHz band, like Wi-Fi and Bluetooth, but it operates at much lower data rates. The main advantages of ZigBee wireless are:

- Less channel bandwidth of only 0.3-2Mhz compared to 22MHZ taken by Wi-Fi
- Low power consumption
- Very robust network
- Up to 65,645 nodes
- Very easy to add or remove nodes from the network

2. IEEE and ZigBee Alliance

As seen in Figure 1, the IEEE 802.15.4 standard develops the MAC layer and the Physical layer, which address things like the frequency and data rate specifications. The Physical layer also allows for two types of devices- full function devices (FFDs) and reduced function devices (RFDs). ZigBee Alliance meanwhile develops the Network Layer and Application layer, which includes the API and Security services. The Network layer and Application layer are more specific than the other layers and involve things like how a ZigBee network has to be set up and how the devices in the network connect to one another.

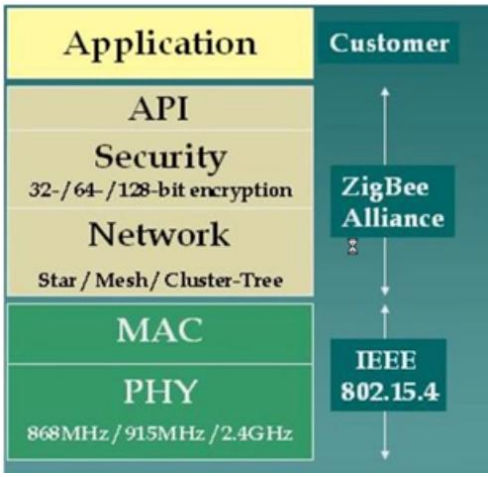

Figure 1: ZigBee position in Networking Layers

Thus, ZigBee is a low-cost, low-power, wireless mesh networking standard. The ZigBee standard provides network, security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard [2]. It employs a suite of technologies to enable scalable, self-organizing, self-healing networks that can manage various data traffic patterns.

3. ZigBee Network Topologies

ZigBee devices can transmit data over long distances by passing data through a mesh network of intermediate devices to reach more distant ones. ZigBee modules can be used to create networks with various topologies. Figure 2 indicates the three main topologies in a ZigBee WSN.

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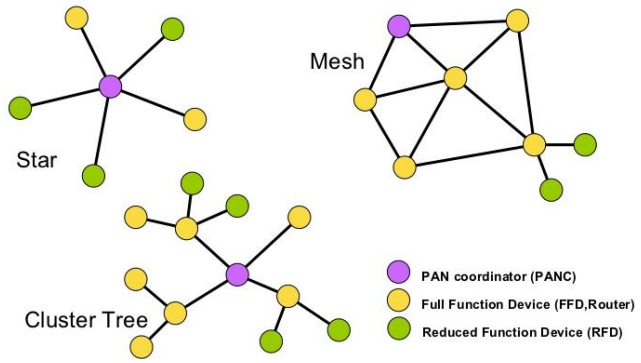

Figure 2: ZigBee Network Topology Models

ZigBee's network layer supports three networking topologies; star, mesh, and cluster tree. Star networks are common and provide for very long battery life operation. Mesh, or peer-to-peer, networks enable high levels of reliability and scalability by providing more than one path through the network. Cluster-tree networks utilize a hybrid star/mesh topology that combines the benefits of both for high levels of reliability and support for battery-powered nodes.

The devices in such networks are classified into the following three types:

1) ZigBee coordinator (ZC):
   Being the most capable device, the coordinator forms the root. It stores information about the network, including acting as the Trust Center & repository for security keys.
2) ZigBee Router (ZR):
   Along with running an application function, a ZR can act as an intermediate router, passing on data from other devices.
3) ZigBee End Device (ZED):
   Contains just enough functionality to talk to the parent node and it cannot relay data from other devices. A ZED requires the least amount of memory.

4. Distinguishing Devices and Routing within a Network

In ZigBee, a device is said to join a network successfully if it can obtain a 16-bit network address from the coordinator or a router. ZigBee specifies a distributed address assignment scheme, which allows a parent device to locally compute addresses for child devices. To assign addresses to nodes, nodes are grouped into clusters [3]. Each node belongs to one cluster and each cluster has a unique **cluster ID**. All nodes in a cluster have the same cluster ID, but different **node ID**s. The structure of a ZigBee network address is divided into two parts: one is cluster ID and the other is node ID.

In a ZigBee network, the coordinator and routers can directly transmit packets along the tree without using any route discovery. When a router receives a packet, it first checks if it itself is the destination or whether one of its child end devices is the destination. If so, this router will accept the packet or in the latter case, forward this packet to the designated child end device.

5. Data Exchanged between the Devices

ZigBee networks consist of multiple traffic types with their own unique characteristics, including periodic data, intermittent data, and repetitive low latency data. The characteristics of each are as follows:

1) Periodic data –
   It is usually defined by the application such as a wireless sensor or meter. Data typically is handled using a beaconing system whereby the sensor wakes up at a set time and checks for the beacon, exchanges data, and goes to sleep.
2) Intermittent data –
   It is either application or external stimulus defined such as a wireless light switch. Data can be handled in a beaconless system or disconnected. In disconnected operation, the device will only attach to the network when communications is required, saving significant energy.
3) Repetitive low latency data –
   It uses time slot allocations such as a security system. These applications may use the guaranteed time slot (GTS) capability [4]. GTS is a method of QoS that allows each device a specific duration of time as defined by the PAN coordinator in the super frame to do whatever it requires without contention or latency.

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.

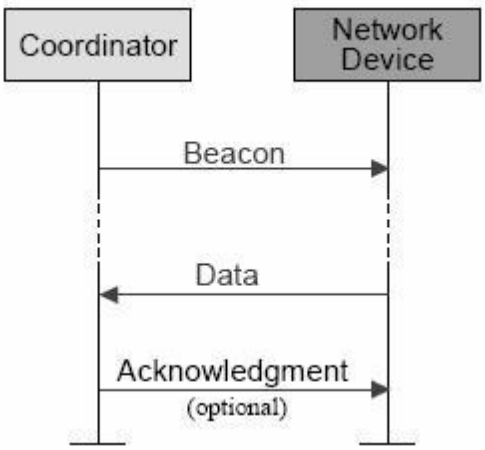

Figure 3: Beacon Network Communication

While using the **beacon mode**, all the devices in a mesh network know when to communicate with each other. In this mode, necessarily, the timing circuits have to be quite accurate, or wake up sooner to be sure not to miss the beacon. This in turn means an increase in power consumption by the coordinator's receiver, entailing an optimal increase in costs.

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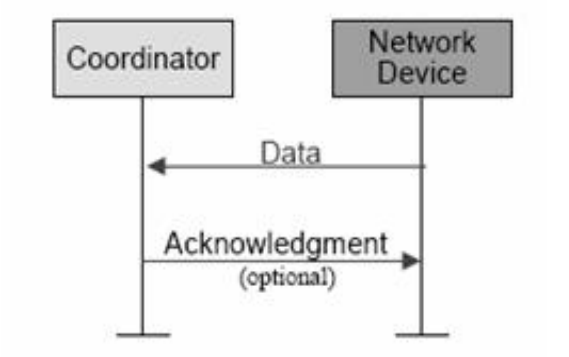

Figure 4: Non-Beacon Network Communication

The **non-beacon mode** will be included in a system where devices are 'asleep' nearly always, as in smoke detectors and burglar alarms. The devices wake up and confirm their continued presence in the network at random intervals [5]. On detection of activity, the sensors spring to attention, and transmit to the ever waiting coordinator's receiver. However, there is the remotest of chances that a sensor finds the channel busy, in which case the receiver unfortunately would miss a call.

6. Structure of the Data Frame

The four basic frame types defined in 802.15.4- Data, ACK, MAC command, and beacon.

a) Data:
The data frame provides a payload of up to 104 bytes. The frame is numbered to ensure that all packets are tracked.

b) Acknowledgment (ACK) frame:
It provides feedback from the receiver to the sender confirming that the packet was received without error.

c) MAC command frame:
The MAC command provides the mechanism for remote control and configuration of client nodes.

d) Beacon frame:
It wakes up client devices, which listen for their address and go back to sleep if they don't receive it. Beacons are important for mesh and cluster-tree networks to keep all the nodes synchronized without requiring those nodes to consume precious battery energy by listening for long periods of time.

7. Implementing Security in Data Exchange

ZigBee uses 128-bit keys to implement its security mechanisms. There are three kinds of keys: master, link and network keys [6]. A secure network will designate one special device which other devices trust for the distribution of security keys: the trust center. Devices will only accept communications originating from a key provided by the trust center, except for the initial master key.

- **Master Keys:**
  They are pre-installed in each node [7]. Their function is to keep confidential the Link Key exchange between two nodes in the Key Establishment Procedure (SKKE).
- **Link Keys:**
  They are unique between each pair of nodes. These keys are managed by the Application level. They are used to encrypt all the information between each two devices. For this reason, more memory resources are needed in each device.
- **Network Key:**
  It is a unique 128b key shared among all the devices in the network. It is generated by the Trust Center (the coordinator). Each node has to get the Network Key in order to join the network.

8. Applications of ZigBee Technology

8.1 Health Monitoring System

Wireless Sensor Network (WSN) can be used for monitoring patient's physiological conditions continuously using ZigBee. A ZigBee node can be connected to every patient monitor system that consumes very low power and is extremely small in size. These are specifically designed for low power consumption, with minimal circuit components intended for small packet, long distance range applications and typically consist of a low power processor with minimal resources and interface capabilities [8]. They also have a conservative transceiver that is capable of transmitting 8 bytes of data at a time and has a moderate transmitting range of about 130 m. Therefore, WPANs seem to be a perfect fit for remote patient monitoring.

In the aforementioned Health Monitoring System, wireless sensors are used to measure a patient's heart rate, temperature and saline level in the bottle using sensors. These physiological conditions of the patient are monitored by sensors and the output of these sensors is wirelessly transmitted via ZigBee and the same is sent to the remote wireless monitor for observing the patient's physiological signals.

8.2 Monitoring and Maintaining Artifacts

ZigBee sensor networks can be deployed in cultural buildings or museums which store artifacts such as ancient sculptures and paintings. These items need to be monitored for timely reparation and maintenance. Sensor modules, i.e., end devices in the network can be placed at the monitoring locations [9]. For each sensor module, both temperature and humidity sensors can be mounted. The sensor module senses and transmits collected data via the ZigBee network. The data is received by the ZigBee coordinator that communicates with a computer via the serial port. At the receiving end, one can monitor the conditions such as temperature and humidity which are likely to damage the artifacts in the WSN.

8.3 Greenhouse Monitoring System

In order to achieve maximum productivity in terms of plant growth in a field or greenhouse, environmental variables such as the air temperature and the soil humidity need to be kept within predefined limits [10]. Thus, a WSN using ZigBee can be employed. Parameters such as the moistness of the soil and ambient temperature can be measured using sensors. The base station, which is a personal computer will gather all the measurements from the wireless sensor network and can take action if necessary, to alter conditions

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(temperature, humidity, etc) around the sensors.

9. Conclusion

Smart energy/smart grid, AMR (Automatic Meter Reading), lighting controls, building automation systems, tank monitoring, and medical applications are just some of the many spaces where ZigBee technology is making significant advancements. ZigBee enables broad-based deployment of wireless networks with low-cost, low-power solutions. It provides the ability to run for **years** on inexpensive batteries for a host of monitoring and control applications. Its architecture, protocol structure and efficiency have therefore proved ZigBee to be the future of wireless networking.

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