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ZigBee : A Promising Wireless Technology

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Abstract

As a result of high cost of laying the wired networks and increasing demand for mobility, the wireless network has gained popularity in recent times in residential, commercial and industrial applications. Several wireless technologies have emerged ranging from short, medium and long distances. Presently, Bluetooth, Infrared and Wireless Local Area Network (WLAN) are some of the most widely used wireless communication technologies. These technologies had some limitations like short battery life, high power dissipation, high data rate, complex, etc. ZigBee emerges as a powerful wireless network technology which overcomes these shortcomings of other wireless technologies. The paper reviews different aspects of ZigBee network: ZigBee architecture, Devices, Routing Protocol, Forming and Joining a ZigBee Network.

Keywords: *AODV, IEEE 802.15, WPAN, ZigBee*

1. Introduction

ZigBee is a specification based on an IEEE 802.15 standard for wireless personal area networks(WPAN). The ZigBee specification is defined by ZigBee Alliance, which is a group of companies that works on creating wireless network standards for low-powered digital radios.[7] ZigBee is a low-cost, low-power, wireless mesh network standard. The low cost allows the technology to be widely deployed in wireless control and monitoring applications. Low power-usage allows longer life with smaller batteries [2]

ZigBee sensor networks are potentially suitable for a wide range of applications such as medical care applications, fire emergency applications, smoke and heat sensors, security, commercial and residential control, traffic management systems, various monitoring and tracking applications, and many others.

2. ZigBee Standard Device Types

ZigBee devices are the combination of [1] :

- Application (such as light sensor, lighting control etc),
- ZigBee Logical Devices (coordinator, router, end device), and
- ZigBee Physical Device Types (Full Function Device and Reduced Function Device)

2.1 ZigBee Logical Devices

ZigBee logical devices include:

2.1.1 ZigBee coordinator (ZC):

The coordinator initiates the network and is the root of the network. Each Network has just one ZigBee coordinator. It is also responsible for 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. [1]

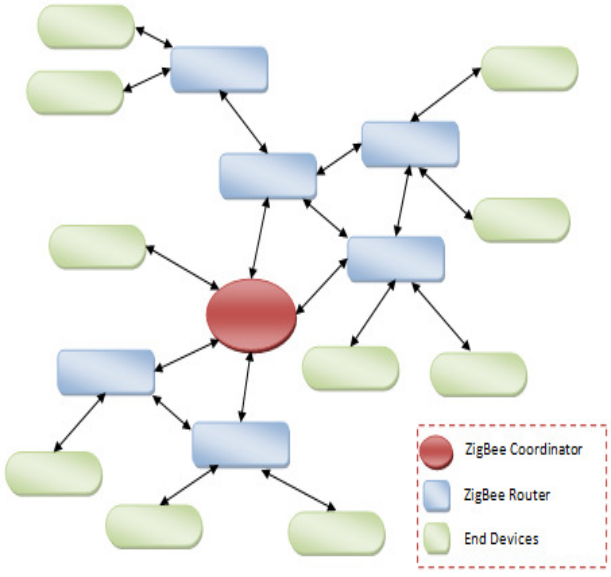

Fig. 1 ZigBee Mesh Network

2.1.2 ZigBee Router (ZR):

ZigBee router acts as an intermediate router that helps in transmitting data from one device to another.

2.1.3 ZigBee End Device (ZED):

It is a low-power device which interacts with the parent node which could be either the coordinator or a router. It cannot transmit data from other devices. This allows the end device to sleep thus providing a long battery life.

2.2 ZigBee Physical Device Types

2.2.1 Full Function Devices (FFD):

These devices perform routing mechanism, coordination tasks and sensing task. The FFD can operate in three modes serving as a PAN coordinator, a coordinator, or a device. An FFD can talk to RFDs or other FFDs [6].

2.2.2 Reduced Function Devices (RFD):

These devices do not route packets and can only be associated with a single FFD at a time. The RFD can communicate with only an FFD.

3. ZigBee Architecture

The ZigBee stack architecture consists of various layers which performs set of functions for the layers above them. ZigBee is built on top of the IEEE 802.15.4 standard which defines two layers - the physical (PHY) layer and the medium access control (MAC) sub-layer. ZigBee Alliance includes the network (NWK) layer and the application layer. Application Layer further consists of application support sub-layer (APS), the ZigBee device objects (ZDO) and the manufacturer-defined application objects.

Physical Layer

Physical Layer is defined by IEEE 802.15.4 standard which is responsible for data transmission and reception. It interfaces with the physical transmission media to transmit data bits and also exchanges data bits with the MAC layer which is placed above it in the ZigBee Stack.

MAC Layer

IEEE 802.15.4 MAC is placed above the physical layer and is responsible for addressing for outgoing data it determines where the data is going, for incoming data it determines where the data has come from. It is also responsible for assembling data packets or frames to be transmitted for a decomposing received frames. [9]

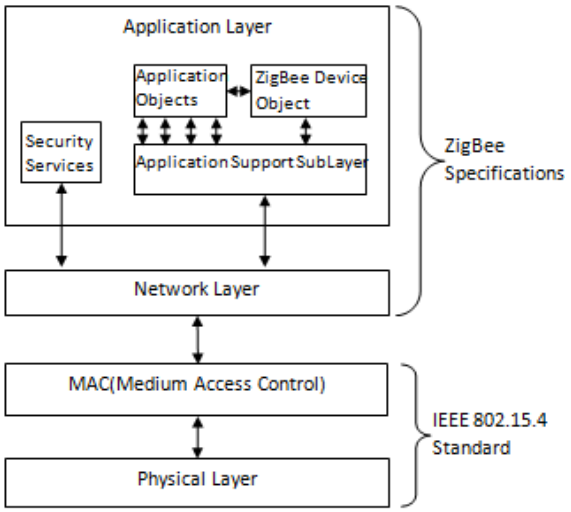

Fig. 2 ZigBee Architecture

Network layer

Network layer is the lowest layer of ZigBee and acts as an interface between application layer and MAC Layer. This Layer is responsible for network formation and routing. The responsibilities of the ZigBee network layer includes [5]:

- mechanisms used to join and leave a network,
- to apply security to frames,
- to route frames to their intended destinations,
- discovery and maintenance of routes between devices,
- storing of pertinent neighbor information

Application Layer

Application Layer is the highest layer of the ZigBee stack. ZigBee specification divides the APL layer into three different sub-layers: Application Support Sub layer, ZigBee Device Objects, and manufacturer defined Application Objects.

The *Application Support sub layer* is responsible for:

- Maintaining tables for binding and forwarding messages between devices,
- Address mapping from 64-bit IEEE addresses to and from 16-bit NWK addresses,

- Grouping address definitions.
- Fragmentation and reassembly of packets
- Reliable data transport
- Establish and Manage the cryptographic keys for security

The *ZDO (ZigBee Device Object)* performs different functions like Device Discovery, Service Discovery, Security services and Binding. The endpoint number for ZigBee Device Object is 0.

Application objects are developed by the manufacturer to customize a device for various applications. A device can support up to 240 application objects.

4. Forming And Joining ZigBee Network

4.1 Forming the ZigBee Network

Coordinator is responsible for forming the network. The following are the steps for forming the ZigBee network[10]:

- Search for a Radio Channel:

  The first step for formation of a ZigBee network is that the Coordinator searches for suitable Radio Frequency channel.

- Assignment of PAN ID:

  Once the Radio Channel is search, Coordinator starts the network by assigning a PAN ID to the network. This PAN ID assignment can be done in two ways - Manually by using the pre configured ID or dynamically by checking other PAN IDs of the networks. The Coordinator also assigns network address to itself i.e. 0x0000.

- Start the Network:

  Coordinator completes its configuration. With these steps, the coordinator is prepared to accept network joining request from routers and end devices.

4.2 Joining the ZigBee Network

Once the Network has been started by the Coordinator, Routers and Coordinator can all allow other nodes to join the network. The following process is followed for joining the ZigBee network[9]:

- Search for Network:

  New node which wish to join the network searches for the network which it should join among the multiple networks which are available in the same channel.

- Select the Parent:

  The node then selects the Parent (Router or Coordinator) from the network to which it should connect to.

- Send the Join Request:

  The node then sends the message to join the network to the Parent.

- Acceptance/Rejection of Join Request:

  Coordinator/Router then decides whether the node is a permitted device or not, whether they are currently allowing devices to join the network based on the configured Join Time Period and whether they have enough address space. If these conditions are satisfied then the join request is approved and an address is allocated to the requestor node.

5. ZigBee Addressing

ZigBee Specification offers two address types which are provided by IEEE 802.15.4 protocol:

5.1 The 16-bit Network Addresses

When a node joins a network, a unique 16-bit network address is assigned to it by the parent node (i.e. the router or Coordinator) which is local to that particular network. Two nodes on different networks can have the same network address. It is also called the **short address**. The ZigBee coordinator has a special 16-bit network address of 0x0000 [8].

5.2 The 64-bit Addresses

Each node contains a unique 64-bit permanent address which is allocated by the IEEE. It is also called the **MAC address** or the **extended address**. No two devices can have the same MAC address.

6. ZigBee Data Transmission

The following data transmission mechanisms are available in ZigBee:

6.1 Broadcast Transmission

In a Broadcast transmissions, the data packet is transmitted to all other devices in a personal area network (PAN). When a device receives the data packet, it will further transmit the packet three times. Each node that transmits the broadcast will also create an entry in a local broadcast transmission table. This entry is used to keep track of each received broadcast packet to ensure the packets are not endlessly transmitted. Each entry persists for 8 seconds. The broadcast transmission table holds eight entries. [5] When a node sends the data packet, it listens to check if all of its neighbor nodes have retransmitted the message or not. This is known as Passive acknowledgment scheme.

6.2 Multicast Transmissions

Multicast transmissions broadcasts the data packets only to those devices which are part of multicast group. All other functions are similar to the broadcast transmissions.

6.3 Unicast Transmissions

In Unicast Transmissions, a message is transmitted from a single source to one dedicated destination which is identified by a unique 16-bit network address. Since the 16-bit network address can change, ZigBee devices uses the address discovery mechanism to identify the 16-bit address corresponding to a particular 64-bit MAC address which is permanent. When the 16-bit address has been identified, a route discovery is performed to unicastly transmit the message to the intended destination using the Ad-hoc On-demand Distance Vector routing (AODV) protocol.

7. Data Routing In ZigBee

ZigBee devices route the packet using the *Ad-hoc On-Demand Distance Vectoring (AODV)* algorithm. The AODV protocol uses the routing table which stores the information about the next node to reach the intended destination. If the next node information is not available in the routing table, then route discovery is performed in order to find the path from source to destination.

Routing tables

Each routing table entry contains the following information:

- Destination
- Next hop
- Number of hops
- Destination sequence number
- Active neighbors for this route
- Expiration time for this route table entry

Expiration time, also called lifetime, is reset each time the route has been used. The new expiration time is the sum of the current time and active route timeout. This parameter, also called route caching timeout, is the time after which the route is considered as invalid, and so the nodes not lying on the route determined by RREPs delete their reverse entries. If active route timeout is big enough route repairs will maintain routes.

Route Discovery

In Route Discovery, a *Route Request* RREQ packet is transmitted and the routers send the *Route Reply* RREP to source node if the route to destination is available. Once a node receives data packet, it must send an acknowledgement to the source node. If an acknowledgement is not received, the router sends a Route Error RERR packet back to the source node and this procedure is repeated until a new route to the destination is found.[7]

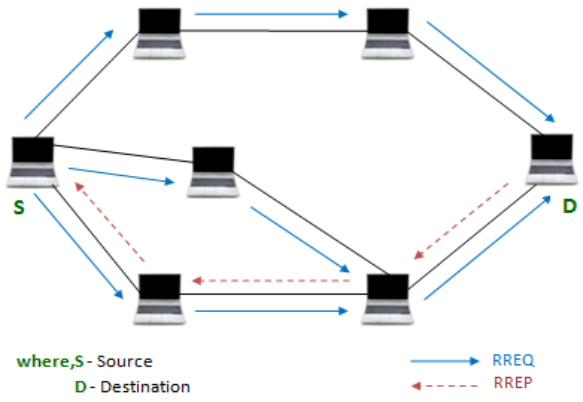

Fig. 3 Ad-hoc On-demand Distance Vector (AODV) Protocol

The RREQ contains the following fields:

Source Address	Request ID	Source Sequence Number	Destination Sequence Number	Hop Count

The RREP message has the following format:

Source Address	Destination Address	Destination Sequence Number	Hop Count	Lifetime

8. Reliable Communication Measures

To ensure the reliable data communication, ZigBee provides the following techniques [9] :

8.1 Listen Before Send

Before initiating a data transfer, a node listens on the channel to see if the channel is free or is busy performing some other activity. If channel is found busy then the node waits for some time and then listens again to check the channel availability. If the channel is free, the node will begin the transmission, otherwise the delay-and-listen cycle is repeated. This is known as Carrier Sense, Multiple Access with Collision Avoidance (CSMA-CA).

8.2 Acknowledgement

When the destination node receives the message, it sends an acknowledgement to the source node indicating that the message has been delivered. If the source node does not receive an acknowledgement within a defined interval of time, it resends the original message till the message has been acknowledged.

8.3 Route Discovery for Alternative

In this approach, if the default destination route is unavailable due to failure of link or unavailability of node then an alternate route is discovered and implemented to deliver the message.

8.4 Data Coding

In this technique, a coding mechanism is applied to the radio transmissions which ensures that the message will be delivered to its intended recipients even if there are interfering transmissions.

9. Conclusion And Future Work

The key focus of our study is to explore different aspects of ZigBee Wireless Technology. In the recent times, ZigBee has gained popularity in the field of Wireless Technologies. The IEEE 802.15.4 based ZigBee offers an ideal specification for low data rate and low power consumption applications providing a reliable and cost-effective network. These features ensure ZigBee application for various sensing and monitoring purposes like Health Care, Fire Emergency, Traffic Management, Smoke Detectors, flood detection, military applications and home automation.

The implementation of ZigBee Specification can be extended using the current or emerging network technologies and protocols. Further, the network security aspects can be addressed to provide a secure communication network.

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