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

Overview of ZigBee based WSN

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Abstract: ***Wireless Sensor Network is the best solution for quick capturing, processing and transmission of critical data. Sensor nodes can be deployed in hostile environment but nodes suffer from low battery power. So, energy efficiency and network lifetime are main concerns in WSN. In order to improve these factors ZigBee plays an important role. Low cost, low data rate features of ZigBee results in low power consumption and makes it useful in wireless sensor networks, increasing life of small batteries of nodes in the network. In this paper, we are dealing with ZigBee based wireless sensor networks.***

Keywords: ZigBee, WSN, IEEE 802.15.4(Keywords)

1. Introduction

Wireless Sensor Network (WSN) consists of large number of tiny sensor nodes. In WSN all the sensor nodes are deployed randomly in hostile environment that’s why it is not possible to recharge their batteries or repair them. As a result, WSN suffers from many limitations like high energy consumption, packet loss, high end to end delay, deployment and coverage of nodes.To make WSN nodes more energy efficient and to increase lifetime of network different protocols are used. WSN form an ad-hoc network that operate with nominal or no infrastructure. In this paper we are considering ZigBee based wireless sensor networks.

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 [5].

ZigBee is a specification that defines a set of high level protocols for low cost and low power wireless personal area networks. ZigBee is based upon IEEE 802.15.4 standard. It defines physical and media access control (MAC) layers [1], [9], [10].ZigBee alliance adds network and application layers.

ZigBee can operate at data rates of 250kbits/s at 2.4 GHz, 40kbit/s at 915MHz, and 20kbit/s at 868MHz. While the data rate is much lower than Bluetooth, the energy consumption is at least one order of magnitude lower and can be used for low duty cycle (<0.01) sensor applications [7].

ZigBee supports three kinds of networks, namely star, tree, and mesh networks. A ZigBee coordinator is responsible for initializing, maintaining and controlling the network [3], [4]. A star network has a coordinator with devices directly connecting to the coordinator. For tree and mesh networks devices can communicate with each other in a multihop fashion. The network is formed by ZigBee coordinator and multiple ZigBee routers. A device can join a network as an end device by associating with the coordinator or a router.

There are two types of ZigBee devices, FFD (full function device, RFD (reduced function device).

A FFD accept any role in the network and is capable of performing all duties described in IEEE standard. RFD has limited capabilities. For e.g., FFD can communicate with any other device in a network, but RFD can talk only with FFD device. In an IEEE 802.15.4 network FFD can take three different roles, coordinator, PAN coordinator and device [7]. A coordinator is FFD device that is capable of relaying messages. If the coordinator is also principal controller of a personal area network then it is PAN coordinator. If a device is not acting as a coordinator it is simply called a device.

ZigBeestandard use slightly different terminology [5].A ZigBee coordinator is an IEEE 802.15.4 PAN coordinator. A ZigBee end device has least memory size and fewest processing capabilities and features. An end device is least expensive device in the network.

ZigBee coordinator-There is exactly one ZigBee coordinator in each network. It is the most capable device, it forms root of the network tree and might bridge to other networks [9]. It is able to store information about the network.

ZigBee router- It runs an application function, a router can act as an intermediate router, passing on data from other devices.

ZigBee end device-It requires least energy, memory capabilities and it is cheaper than other two devices [9], [10]. It has long battery life and cannot relay the data to other devices.

2. Topologies Supported by ZigBee

ZigBee supports three types of network topologies tree topology, star topology and mesh topology.In the Tree topology, a coordinator initializes the network and it is the root of the tree. The coordinator can have routers or end devices connected to it and for every router; there is a possibility for connection of more child nodes to each router. As the message can take only one path, this type of topology is not the most reliable topology. Startopology is where a coordinator is surrounded by a group of end devices or routers. This is simpletopology but it has some disadvantages. In the moment when the coordinator stop functioning the entire network is functionless because all traffic must travel through the centre of the star. For the same reason the coordinator will easily be bottleneck to traffic. Mesh topology is the most flexible topology [8]because message can take multiple paths from source to destination. If a particular router fails the ZigBee's self-healing mechanism will allow the network to search for an alternative path for the message to be passed. Following are the topologies supported by ZigBee; Star topology, Tree topology and Mesh topology.

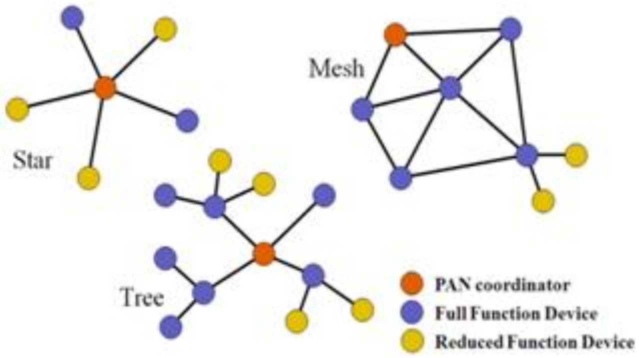

Figure 1: Network topologies supported by ZigBee

3. ZigBee protocol stack architecture

ZigBee follows the standard OSI (Open systemInterconnection) 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 MHzThe 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.

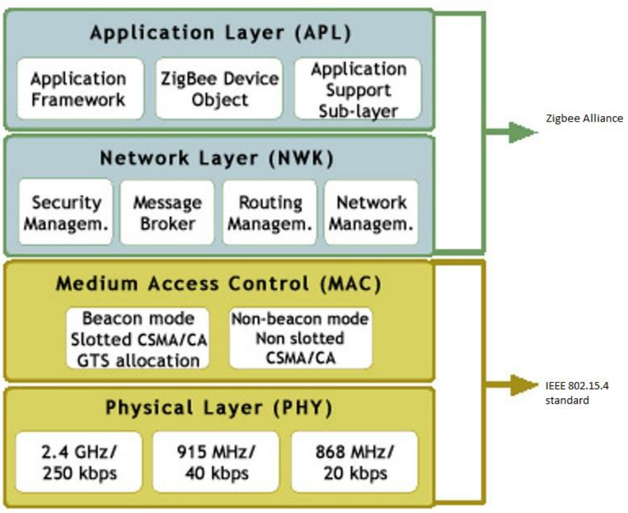

Figure 2: Protocol stack architecture of ZigBee

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.

MAC layer: This layer is an interfacebetween 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.

Network layer: It interfaces between application layer and MAC Layer. This Layer is responsible fornetwork 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 discoveryis performed by ZigBee coordinator or router. This layer Provides network wide security and allows low power devices to maximize their battery life. It definesthe basic topologies, star, tree Network and mesh.

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.

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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 interfacebetween 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.

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.

4. Network Model

The functions of the coordinator which usually remains in receptive mode encompass network set-up, beacon transmission, node management, storage of node information and message routing between nodes.

The network node is meant to save energy and its function includes searching for the network availability, data transfer, checks for pending data and queries for data from the coordinator. For the sake of simplicity this IEEE standard defines quarter frame structure and super frame structure used optionally only by coordinator.
The four frame structures are-
i) Beacon frame for transmission of beacons
ii) Data frame for all data transfers
iii) Acknowledgement frame for successful frame receipt confirmation
iv) MAC command frames

These frame structures and coordinators super frame structure play critical roles in security of data and integrity in transmission. The coordinator lays down the format for sending beacons after every 15.38 ms or and thereof up to 252s. This interval is determined a priori and the coordinator thus enables sixteen time slots of identical width between beacons so that channel access is contention less. Within each time slot access is contention based. The coordinator provides as many as 7 GTS for every beacon interval to ensure better quality.

5. Data Transfer Models

1. Data transmission to a coordinator: In a beacon-enabled network, the slotted CSMA/CA mechanism is used by the device which sends data to contend for channels after receiving beacons. In a non-beacon-enabled network, devices contend for channels using the unslotted CSMA/CA mechanism. After successfully obtaining a channel, a device can send data to its coordinator directly,in both kinds of networks. A coordinator that receives a data frame from a device may reply an acknowledgement (optional). Fig. shows the procedures of data transfer to a coordinator.

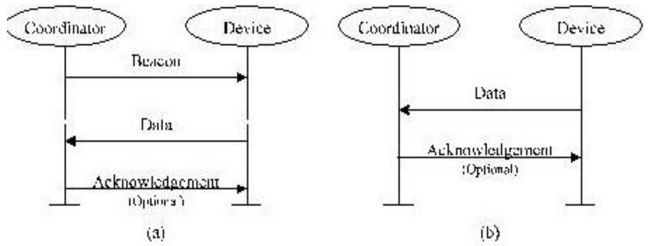

Figure 3: a) Data transmission to a coordinator in a beacon-enabled network. (b) Data transmission to a coordinator in a non-beacon-enable network.

2. Data transmission from a coordinator: Data transmission from a coordinator is based on requests from devices. In a beacon-enabled network, instead of directly sending data frames to devices, a coordinator should notify devices that it has buffered packets by its beacons. A device that receives a beacon first check whether it's ID appears in the pending datafieldsin the beacon. If so, this device sends a data request command to the coordinator. The coordinator, after receiving the data request, will reply an acknowledgement and forward the data frame to that device. On the other hand, in a non-beacon-enabled network, a device should periodically send data request frames to query the coordinator if there are buffered packets for itself. The coordinator, on receipt of a data request frame, should check if there are frames for the sender. If so, the coordinator will reply an acknowledgement and then send a data frame to the corresponding device.

The procedures of data transmission from a coordinator are shown in Fig.

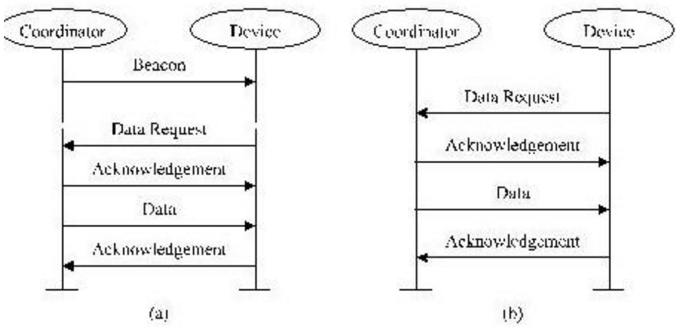

Figure 4: a) Data transmission from a coordinator in a beacon-enabled network. (b) Data transmission from a coordinator in a non-beacon-enable network.

3. Data transmission between peers: In a beacon-enabled network, peers cannot senddata to each other directly. However, peers can directly transmit data to each other in a non-beacon-enabled network. The unslotted CSMA/CA mechanism is used to contend for channels.

6. Applications

As the costs for sensor nodes and communication networks have been reduced, many other potential applications including those for civilian purposes have emerged. The following are a few examples.

- Automatic meter reading
- Building automation
- Health care monitoring
- Home automation and control
- Patient monitoring

7. Conclusion

Wireless sensor network has many applications but because of node cost and low battery life its applications are limited to scientific research and laboratory purpose. IEEE 802.15.4 /ZigBee's low cost, low data rate features solved these questions. Combination of these two, ZigBee based WSN used in almost every application like medical field, environmental monitoring, home automation and control. This paper gives details of ZigBee technology including ZigBee devices, topology models, protocol stack architecture, and data transfer models.

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