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IEEE 802.15.4 and ZigBee: A Conceptual Study

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Abstract— ***Networked Control Systems (NCSs) are distributed control systems where sensors, actuators, and controllers are interconnected by communication networks with its protocol followed by them. The general term used for these types of network is wireless sensor network. The use of Wireless sensor network infrastructure requires the ZigBee and IEEE 802.15.4 are standards-based protocols which defines the physical and MAC layers, network and application layers. For sensor network applications, the major criteria are the long life battery based nodes with the low cost and also that must support to the wireless mesh network concept for the compatibility of the different and multiple application environment. In this paper the conceptual study of IEEE 802.15.4 standard and ZigBee standard based wireless sensor network is discussed.***

Keywords— **IEEE 802.15.4, ZigBee, ZigBee Protocol Stack, ZigBee Topologies**

I. INTRODUCTION

The IEEE 802.15.4 standard and ZigBee protocol stack provides low cost, low data rate, and low energy consumption characteristics for Wireless Sensor Networks (WSN). Home Automation, Commercial Building, Security, Agriculture and Environmental Monitoring, Healthcare Medical Monitoring, Vehicle Monitoring are the major applications of the wireless ZigBee networks [1]. Fig. 1 shows the scenario of the ZigBee wireless standard application. The performance of the WSN can be affected by Energy consumption, latency and reliability. To improve the performance of the system it is mandatory to look out at these parameters which mostly decide the performance of WSN.

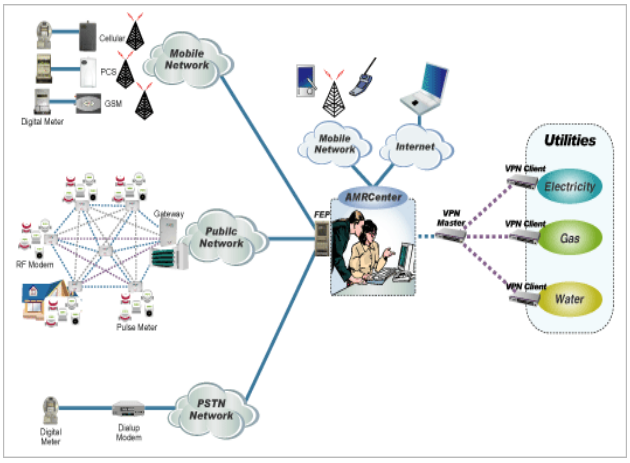

Fig 1: Application Scenario of ZigBee

ZigBee is a standard for wireless radio networks for the field of control which requires the necessity of Low cost, Ultra-low power consumption, Low data rate (less than 250 Kbps), Use of unlicensed radio bands, Cheap and easy installation, Flexible and easy installation, Integrated intelligence for network set-up and message routing to enhance the performance of the application. ZigBee standard works in the three different transmission bands [1]. ZigBee is a network which used CSMA/CA method with the preference of the network topology of star and mesh. The general ZigBee specifications are as shown in Table 1.

TABLE 1: GENERAL SPECIFICATION OF ZIGBEE

Parameter	Range
Transmission Range (meters)	1 – 100
Battery Life (days)	100 – 1,000
Network Size (# of nodes)	> 64,000
Throughput (kb/s)	20 - 250
Topology	Mesh
Maximum Child	254
Wakeup Delay	15 ms
Data rate	250 Kbps (at 2.4 GHz)

ZIGBEE PROTOCOL STACK

ZigBee protocol stack consist of the Application Layer, Application Framework, Network Layer, Mac Layer, Physical Layer as shown in Fig. 2.

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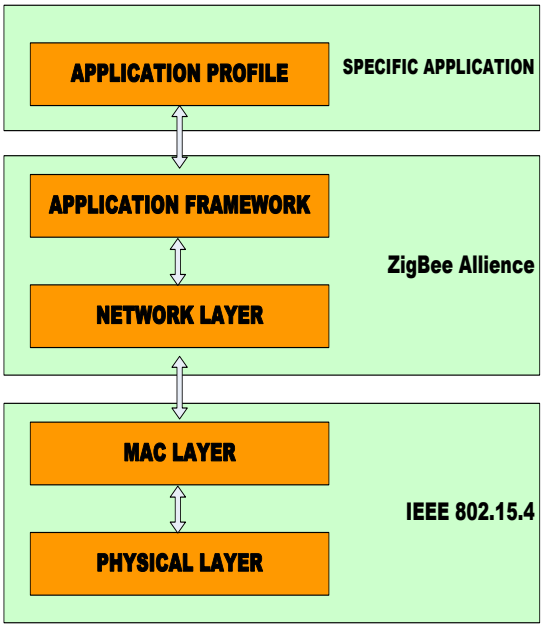

Fig 2: ZigBee Protocol Stack [2]

The application layer is the top layer in the ZigBee protocol stack consists of the specific application objects known as ZigBee Object Device, and Application Support (APS) Sub layer. The end device, routing and coordinator are the nodes that participate in the network are considered in the ZigBee Object Device. ZigBee alliance have an application framework and network layer which provides the range of standard data types, frame formats for transmission of data and the attribute based profiles [8]. The network layer handles the addresses of the network and provides the routing actions taken in the MAC layer. It also include the coordinator by assigning the network address, also manages the network nodes, its routing information, security and the route discovery phase. Frame counter, will determine the age of the message it receives, and detect the possibility that an old message was recorded and is played back to the device. The physical layer and MAC layer is under the IEEE 802.15.4 which providing the reliable and communication between the nodes of the network by avoiding the collisions to improve the efficiency [6]. It decides and assemble routing data packets and frames and also responsible for the defragmentation of it. The physical layer is concern with the physical transmission medium for the communication. The PHYSICAL layer can operate in two separate frequency ranges of 868MHz which is used in European band and 915 MHz band used in U.S and Australia, while higher frequency bad 2.4 GHz used in world wide. The Table 2 gives the frequency ranges used in ZigBee, IEEE 802.15.4 for different area of world.

TABLE 2: FREQUENCY BANDS USED IN ZIGBEE, 802.15.4

Frequency Bands	Region	Number of Channels
868- 868.6	European Country	1
902- 928	North America	10
2400- 2483.5	Worldwide	16

II. ZIGBEE DEVICES AND TOPOLOGIES

IEEE 802.15.4 network and ZigBee uses three types of devices viz.

- Full Function Device (FFD),
- Reduced Function Device (RFD),
- Network (ZigBee) Coordinator.

The Network coordinator has the information of the overall network. To maintain all the information regarding network it required much more memory and the processing, computing power. For every ZigBee network, there can be only one coordinator. This node is responsible for initializing the network, selecting the appropriate channel, and permitting other devices to connect to its network. It can also be responsible for routing traffic in a ZigBee network [8].

The FFD is the device which support the protocols of the wireless standard defined for WSN. It also can take the responsibility like a Network Coordinator. It also server the facility of the network router using the extra memory and the computing power and could be used at the edge of the network to works like a network edger devices [8]. This provides the facility to take the information from the real world. A router is able to pass on messages in a network, and is also able to have child nodes connect to it, whether it be another router, or an end device. Router functions are only used in a tree or mesh topology, because in a star topology, all traffic is routed through the center node, which is the coordinator. Routers can take place of end devices, but the routing functions would be useless in such cases. If the network supports beaconing, then a router can sleep when inactive, periodically waking up to notify the network of its presence.

The Reduced Function Device gives the function as per its name. It provides the limited functionality with the low cost and complexity. It generally used for the Network Edge Devices with very low power consumption. The power saving features of a ZigBee network can be mainly credited to the end devices [8]. Because these nodes are not used for routing traffic, they can be sleeping for the majority of the time, expanding battery life of such devices. These nodes carry just enough function to talk to parent nodes, which can be either a router or a coordinator. An end device does not have the ability to have other nodes connect to its network through the end device, as it must be connected to the network through either a router, or directly to the coordinator.

1) Star Topology: In this topology group of devices are connected to the single coordinator as shown in Fig 3. This type of topology is simple. Whenever the coordinator fails the whole network is stop to function because all the traffic was handled by the coordinator, so the coordinator becomes the major bottleneck of the star topology. This reduces the network efficiency when the number of nodes increased.

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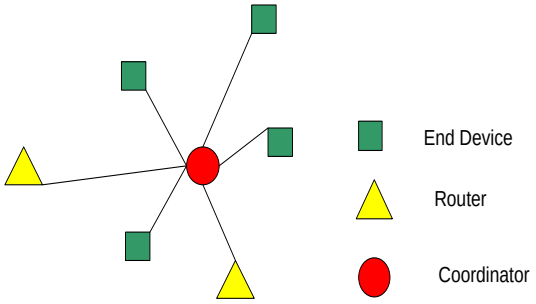

Fig 3: Star Topology

2) *Tree Topology:* In a tree topology of the network is shown in Figure 4, a coordinator initializes as the root of the tree. The routers or the end devices can be connected to the coordinator and can be expand like a tree. Child nodes cannot connect to an end device because it cannot relay the messages. This topology allows for the different levels of nodes. The messages are continuously relayed up by one level of the source node and it continues till it passed it reaches to the destination node. This type of topology is most reliable. If a router fails, then all of that router's children are cut off from communicating with the rest of the network [9].

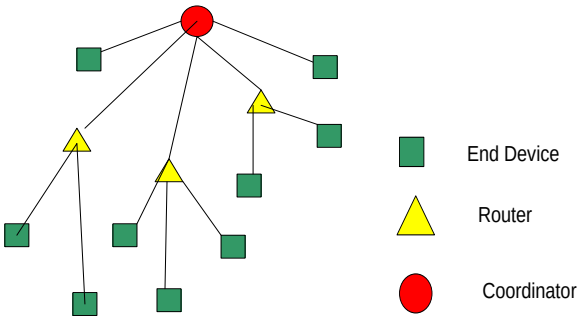

Figure 4: Tree Topology

3) *Mesh Topology:* A mesh topology shown in Figure 5 is the most flexible and widely used topology of the three. Message can take multiple paths from source to destination. If a particular router fails, then ZigBee's self healing mechanism will allow the network to search for an alternate path for the message to take.

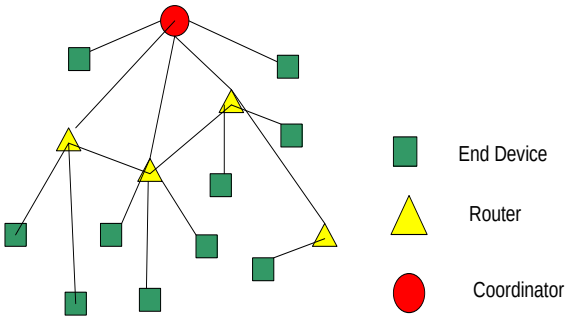

Figure 5: Tree Topology

III. ZIGBEE: STATE OF ART

ZigBee Network is applied to the many application used now a days and researchers are much interested in the performance optimization of the application using it.[10] has described the fundamental of ZigBee network it structure and its architecture. In the paper [8] evaluate the potential of an 802.15.4 radio for use in an ultra low power sensor node operating in a dense network. Jin-Shyan Lee et.al [7] compared the ZigBee protocols with the Bluetooth, ultra wideband and with Wi-Fi. E.S.Nadimi et.al [2] has applied the ZigBee network to monitoring the animals' behaviour. Potorti [4] compared their main features and behaviours in terms of various metrics, including capacity, network topology, security, quality of service support, and power consumption. Baker [5] studied their strengths and weaknesses for industrial applications, and claimed that ZigBee over 802.15.4 protocol can meet a wider variety of real industrial needs than Bluetooth due to its long-term battery operation, greater useful range, flexibility in a number of Dimensions, and reliability of the mesh networking architecture.

IV. CONCLUSION

ZigBee and 802.15.4 communications standard could give the base of future wireless sensors, offering data reliability, long battery life, lower system costs, and good range through flexible networking. This paper presents the overview of ZigBee protocol in terms of its network topologies, architecture in terms of protocol stack. This paper has presented a structural concept of the IEEE 802.15.4 and ZigBee standard and its wide variety of applications. The protocol stack and its layers fundamental is also given briefly. The topological study and working of network components explained. This paper is not to draw any conclusion regarding which is superior in the topology since the suitability of network application and the protocols is greatly influenced by practical applications, in which many other factors can affect to the performance to be considered in the future.

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Biography

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