Investigating the Impact of Topologies on the Performance of 802.15.4 ZIGBEE Wireless Sensor Networks

D. Deepika[1] and Prof. S. Pallam Setty[2]

[1]*M.tech, Department of Computer Science and Systems Engineering, Andhra University, College of Engineering, Visakhapatnam, AP, India*

[2]*Professor, Department of Computer Science and Systems Engineering, Andhra University, College of Engineering, Visakhapatnam, AP, India*

[1]*(Email : dsaideepika@gmail.com)*

[2]*(Email: drspsetty@yahoo.com)*

Abstract: *Wireless Sensor Network is emerging technology, which can be used for different applications ranging from industrial control and monitoring, home automation and consumer electronics, security and military sensing, supply chain management and health monitoring. The Zigbee is mainly based on the IEEE 802.15.4 standard in the wireless sensor networks, which is more advantages than other wireless communication standards with respect to parameters like battery usage and low power consumption, providing high performance with short range sensors. In this paper, we tested the topological characteristics and performance of the IEEE 802.15.4 standard in terms of throughput, node to node delay, and Load using OPNET Modeler 14.5 simulator. Simulation is performed with the increased number of nodes from 5,10,20,30,40 and 50 nodes for the three different topologies with different simulation time. From the analysis, ETD for tree topologies for 50 nodes is of 58.8 seconds and for star, mesh topologies has least ETD of 0.03seconds. Thus ETD is high for the increased number of nodes compared to the other topologies. The throughput is 130000bits/sec for mesh topology is better performance compared to star and tree topologies. it is concluded that mesh topology is highly suited and gives better performance compared to the other topologies because of its flexible network configuration.*

Keywords*: Zigbee, QoS, node to node delay, Throughput, WSN topologies, OPNET*

1. INTRODUCTION

Wireless sensor networks are distributed networks structures in which many sensors connect wirelessly to communicate with one another. Wireless communication is transmission between a transmitter and a receiver without any cable connection, example light or electromagnetic waves. The components in electronic applications that handle detection are called sensors, also known as detectors or probes. Sensors have the ability to identify many physical units, such as length, area, volume, mass air flow, strength, temperature, heat transfer, voltage, electric current, resistance, flux density, magnetic torque, condensation, content, and oxidation/reduction. The main components of a sensor node are the microcontroller, memory, receiver-transmitter, power supply and other components that may number one or more. There exist a different types of sensor nodes on the market, such as micaZ, mica2, TelosA, TelosB, Sensennode, eMote and IMote2 to be able to create wireless sensor networks.

ZigBee is the new generation technology and its an application in the Bluetooth technology. In this paper we discuss about the evolution of the technology, existence of the technology, compatibility with other technologies namely Bluetooth, WiFi, GPRS and the areas of applications of the ZiBbee technology. To overcome the disadvantages of recent wireless communications technologies which are widely spreading into many new areas, we are using the ZigBee technology. The existing technology has wide applications in the areas home automation, data acquisition, building control, monitoring systems and industrial automation. The compatibility of this technology with other technologies namely Bluetooth, WiFi, GPRS are discussed in the application areas. ZigBee technology is based on an industry standard; it supplies interoperability, allowing communication amongst devices from different manufacturers, and offers system integrators and consumers flexible purchasing options. ZigBee technology also offers simplicity and a cost effective approach to building construction and remodelling with wireless technology.

Zigbee is a low rate wireless personal area network (LR- WPAN) standard. Wireless personal area networks (WPANs) are used to convey information over relatively short distances. Unlike wireless local area networks, connections effected via WPANs involve little or no infrastructure. This feature allows small, power efficient, inexpensive solutions to be implemented for a wide range of devices. The ever decreasing cost and increase in performance of silicon radio frequency integrated circuits makes it practical to manufacture wireless communication capabilities into every day goods. Now with the introduction of the Zigbee wireless networking standard embedded system designers are integrating complete wireless systems on a chips on semiconductors smaller than a postal stamp, enabling product manufacturers to embedded very low cost, low power sensor and control capabilities to every day devices. At its most basic level, Zigbee simply ensures interoperability with other standard compliant products.

In this paper, performance analysis of wireless sensor network topologies was conducted by a simulator using the IEEE 802.15.4/ZigBee standard. We are analysing three different topologies star mesh and tree with respect to quality service parameters like end-to-end delay, throughput and Mac load. The novelty of the work is in the performance of the parameters can be measured by different simulations. These results will be helpful to configure the ZigBee and to select a suitable topology according to situation.

This paper is organized as follows. First section describes wireless sensor networks. Section 2 provides a brief summary of the Zigbee/IEEE 802.15.4 standard which includes the physical and MAC layer specifications. Section 3 discusses the Simulation Models and Implementation, while the results of simulation to the two scenarios will be in section 4 and Section 5 concludes the paper giving the results.

2. ZIGBEE OVERVIEW

Zigbee is used in many devices which implement in communication systems that need very low power such as wireless network standard aimed at spacious development of long life battery devices in wireless applications of controlling and monitoring. Zigbee is employed due to it has low-cost, low-power.

Transmission band	868,915,2459MHZ
Transmission range(meters)	100
Network Size(# no of nodes)	764000
Maximum children(# number of children)	20 to 250
Throughput(kbps)	254

Table1.Zigbee specifications

2.1 ZigBee Layers

Zigbee consists of four layers. The top two (Application and network) layers specifications are provided by the Zigbee Alliance to provide manufacturing standards. The bottom two (Medium Access Control and Physical) layers specifications are provided by the IEEE 802.15.4.2006 standard to ensure coexistence without interference with other wireless protocols such as wi-fi.

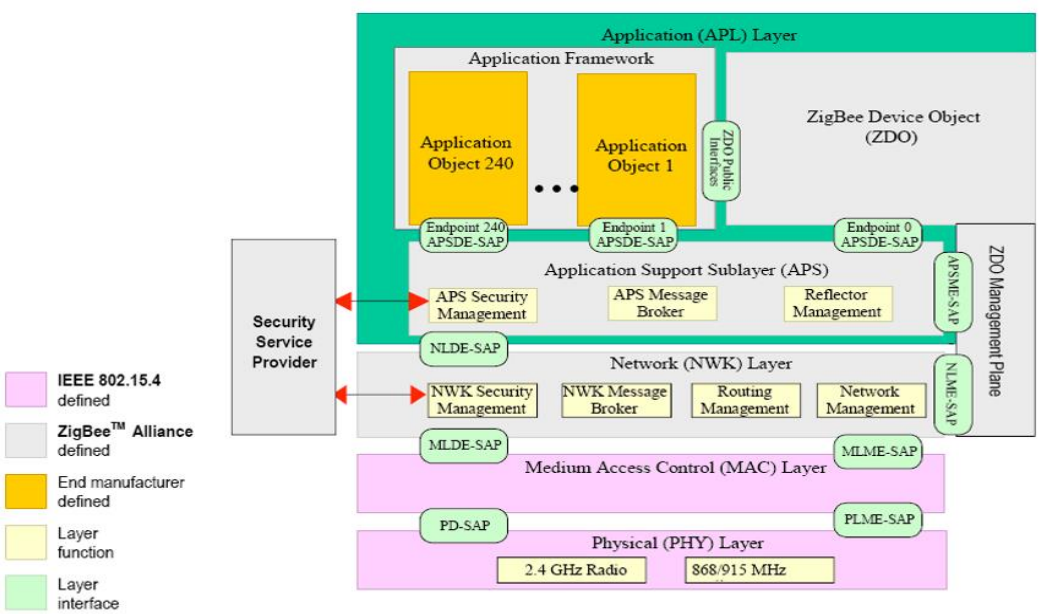

Figure1: Zigbee protocol layer in wireless personal area networks.

2.2 Network Devices

There are three different types of ZigBee Devices:

- ZigBee coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network .
- ZigBee Router (ZR): As well as running an application function a router can act as an intermediate router, passing data from other devices.
- ZigBee End Device (ZED): The power saving features of a Zigbee network can be mainly credited to the end devices. It contains just enough functionality to talk to the parent node (either the coordinator or a router) it cannot relay data from other devices.

2.3. ZigBee Topologies

The Zigbee is mainly configured in three topologies such as star, tree and mesh toplogies.

- Star Topology: Star topology is a communication topology, where each node connects directly to a gateway. A single gateway can send or receive a message to a number of remote nodes.
- Tree Toplogy: In tree topologies, each node connects to a node that is placed higher in the tree, and then to the gateway.
- Mesh Topology: The Mesh topologies allow transmission of data from one node to another, which is within its radio transmission range. If a node wants to send a message to another node, which is out of radio communication range, it needs an intermediate node to forward the message to the desired node.

3. SIMULATION MODELS AND IMPLEMENTATION

Simulation and modeling are important approaches in the development and evaluation of the systems in terms of time and costs. The simulation shows the expected behaviour of the system based on its simulation model under different conditions. Hence, the purpose of this system. For the simulation model is to determine the exact model and predict the behaviour of the real purpose of simulation, we will use OPNET Modeler 14.5, which is a leading environment for modeling and simulations. This simulation tool provides a comprehensive development environment to support modeling of communication networks and distributed systems, also to better understand the use of OPNET simulation tools to model the protocol of interest, Zigbee.

For the simulation of the Zigbee Wireless Sensor Networks with the OPNET 14.5 simulator, the star, tree, and mesh topologies were compared with each other based on parameters like end to end delay, throughput, and mac load. Figure 5.a,

Figure 5.b, Figure 5.c Figure 5.d show the analysis results of 3 topologies according to the end-to-end delay, throughput, and Mac load parameters, respectively.

Fig 2.Sample Node 5 Zigbee OPNET Modeler

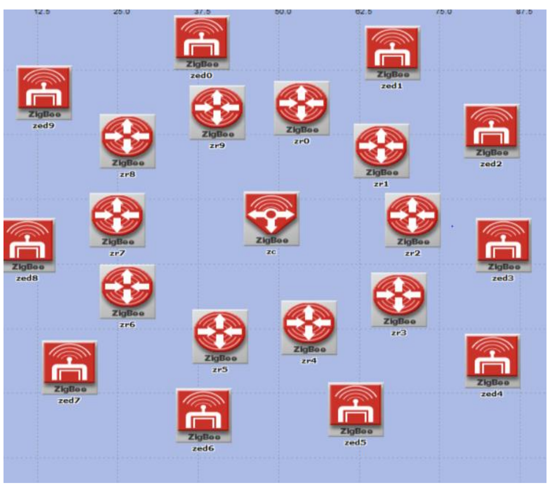

Fig 3.Sample Node 20 Zigbee OPNET Modeler

The Fig2 shows the sample zigbee OPNET modeler with the five number of nodes which consists of one ZC, two ZED's and three ZR. The Fig3 and Fig4 shows the sample 20 nodes and 50 nodes Zigbee OPNET modeler. All these nodes are selected from the object palette tree. This paper gives a detailed analysis of the effect of the Zigbee topologies with the increased number of nodes for the parameters ETD throughput and the mac load by utilizing the OPNET Modeler Simulation tool.

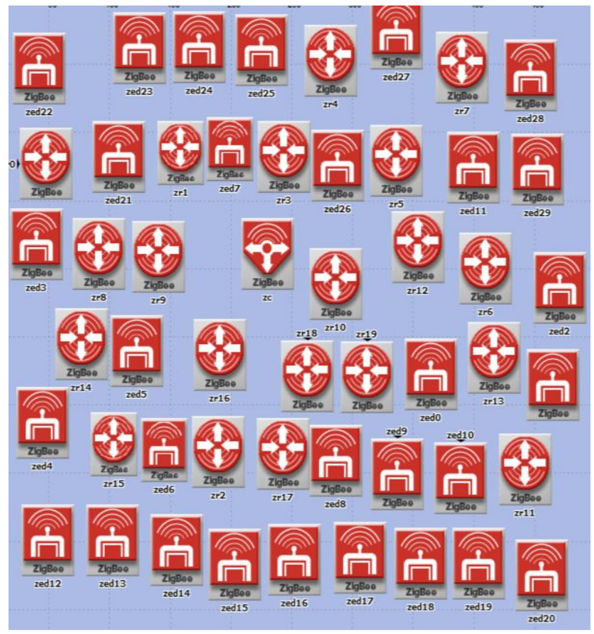

Fig4.Sample Node 50 Zigbee OPNET Modeler

4. SIMULATION RESULTS

In this scenario, the star, tree, and mesh topologies were compared with each other based on parameters like end-to end delay, throughput, mac load .Figure 5, Figure 6, Figure 7 show the analysis results of 3 topologies according to the end-to-end delay, throughput, Mac load , respectively.

i. End-To-End Delay(ETD)

End-to-end delay is a measure of a package's network delays. It is the duration that starts as soon as a message is queued and lasts until the last bit reaches the destination node. As seen in Figure 5, end-to-end delay time is the lowest in the mesh topology network, and it is understood that the tree topology network causes the longest delay. This is due to the mesh topology holding a routing table as a structural need and ability to determine various alternative routes that take less time for a message to pass from one end to another.

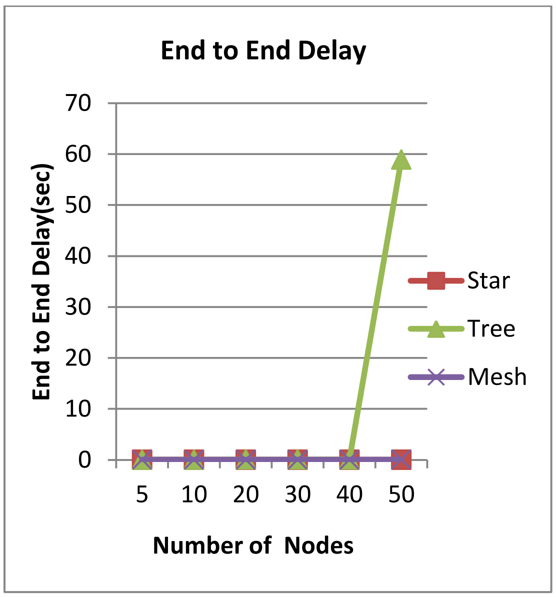

Fig5.Average ETD for star, tree and mesh topologies

ii. Throughput

Throughput can be comprehended as a quality service parameter if it is defined as the power to deliver data correctly from source to destination at a specific time. As a result of user intervention or package jams and collisions between sensors, efficiency is reduced. Figure 6 shows the analysis result of the 3 topologies according to the throughput parameter. It is observed that the tree topology is higher throughput However, the mesh and star topologies are similar to each other .This is because the tree topology can communicate with PAN coordinators and ZRs. Communicating with ZRs but less with end devices and determining better routes to circulate on less nodes decreases collisions, and as a result achieves better output efficiency.

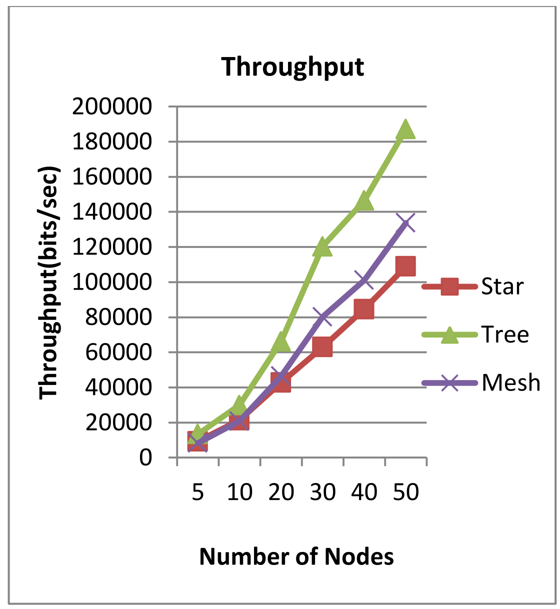

Fig6.Average Throughput for Star, Tree and Mesh topologies

iii. Mac load

Mac load is the forwarding load for each PAN to transfer the packages to the IEEE 802.15.4 Mac layer, i.e., physical layer, by the upper layers. Figure (7) displays that the highest mac load is carried out in Tree topology, the mesh topology has second highest load while the lowest load is for the star topology.

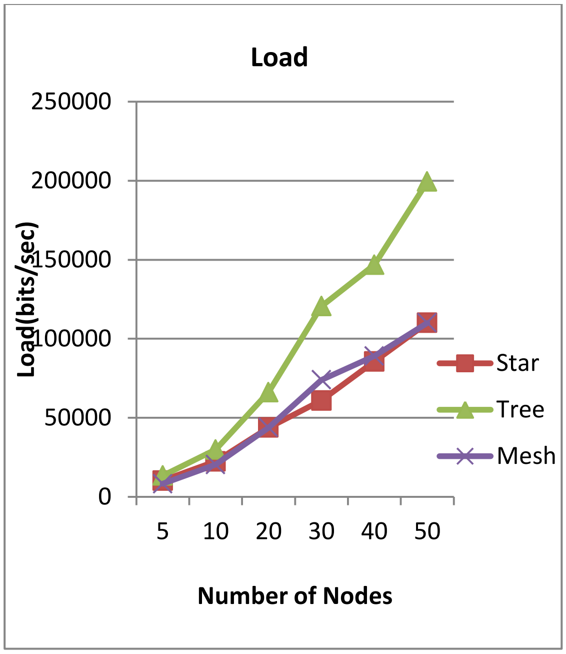

Fig7.Mac load for Star, Tree and Mesh topologies

5. CONCLUSION

In this paper, The IEEE 802.15.4/ Zigbee protocol stack provides a practical application solution for low data rate, low cost, low energy consumption, and characteristics WSNs. This project focuses on simulation an IEEE 802.15.4/ Zigbee protocol using OPNET simulator. To test topological characteristics of WSNs, we compared the three possible topologies (Star, Mesh and Tree) for increasing number of nodes with different simulation time. From the analysis, we can observe that the throughput, delay, load increases with the increases in the simulation time. The ETD for the tree topology for 50 nodes is of 58.8 seconds and for star, mesh topologies is of 0.03seconds. Thus ETD is high for the increased number of nodes compared to the other topologies. The throughput is 130000bits/sec for mesh topology is highly suited and gives better performance compared to the other topologies. And we conclude that the tree topology is better with respect to throughput, but performs worse than mesh topology when it comes to end-to-end delay time. It was also observed that a tree topology network has a higher Mac load values as compared to the star topology however these values are lower than that of the mesh topology. While considering the ETD, load, Throughput, mesh topology is highly suited and gives better performance compared to the other topologies because of its flexible network configuration.

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