

Performance Comparison of the IEEE 802.15.4 Standard (ZigBee) Topologies

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Abstract— The ZigBee standard is one of the wireless network technologies such as Wi-Fi and Bluetooth. It offers several advantages over other communication standards in terms of features such as low power consumption, low battery consumption and short-range effectiveness. Various network simulations are used for inspecting and displaying wireless networks. The OPNET Modeler simulator is one of them. In this study, different ZigBee standard network topologies are evaluated using OPNET Modeler simulation tool. The performance of star, tree and mesh network topologies of ZigBee standards were compared according to the criteria of delay, load, throughput, end-to-end delay and numbers of hops. According to the simulation results obtained, the star topology for the delay value, the tree for the load value, the tree for the yield value and the star topology for the end-to-end delay value gave the best results. When the number of hops are considered, the lowest value belongs to the star topology.

Keywords— ZigBee, Wireless Networks, OPNET, Throughput, Delay

I. INTRODUCTION

As a result of the development of wireless network technologies, the dependence on the cable is gradually decreasing. Thanks to wireless communication, information collection, transmission and fulfilment of tasks are carried out. Infrared, Bluetooth, WiFi, GPRS are used in wireless network communication. One of the most used of these technologies is ZigBee technology. In addition to providing advantages compared to other technologies with features such as security and durability, it also has disadvantages. ZigBee takes its name from the movement of honey bees between flowers. It represents the communication between nodes in a network [1].

There are many studies examining ZigBee technology and comparing network performance values of ZigBee topologies. Comparisons in these studies are made according to different evaluation criteria. In the study of Sharma et al., yield (32,413 bit / sec) and delay (0,01982 sec) values in tree topology were higher than yield (27,456 bit / sec) and delay (0,01492 sec) values in mesh topology. In addition, it has been observed that data transmission rates have decreased in tree and mesh topologies with increasing number of hops [2]. In the study of Rana et al., star and tree topologies were evaluated according to load, delay, media access delay, yield and total traffic sent / received criteria. Similar results were obtained for these two topologies [3]. In the study of Hussnain et al., mesh, grid and

tree topologies were compared. With tree topology, better network usage and yield are discussed. Yield value is highest in tree topology (79.00 bits / second) and lowest in grid topology (22.00 bits / second) [4]. Naseer et al. stated that cluster-tree topology was better than star and mesh topology. Cluster-tree topology provides the highest performance with yield (295,632 Kbps), load (45,315 Kbps), and minimal latency with media access latency (0.01159 seconds) [5].

In this study, it is aimed to raise awareness about the structure and topologies by examining the ZigBee standard. Different ZigBee topologies are handled one by one and simulation applications are performed. The data obtained from the simulations of different topologies were analysed and comparisons were made. In addition, comparisons were made for ZigBee topologies according to certain criteria (delay, load, throughput, end-to-end delay and number of hops) and performance was interpreted.

In the first part of the study, introduction is given. The next section provides information about the ZigBee standard and topologies. In the third part, the design of the study and in the fourth part the performance evaluation results of the topologies are given. In the last part, comments were made about the results of the study.

II. ZIGBEE STANDARD

ZigBee is based on the IEEE 802.15.4 standard. It is designed to be used in applications with low data rates, long battery life and secure networking requirements [6]. As shown in Figure 1, two different types of devices can be joined to ZigBee: FFD-Fully Functional Device and RFD-Reduced Functional Device.

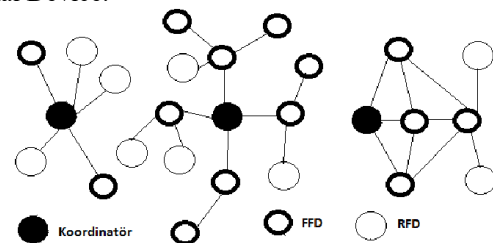


Fig. 1 Star, tree and mesh topologies [7].

FFD can operate as a router or device. RFD works as the last device. All of these elements have different properties within

the same application. FFDs can talk to other FFDs or other RFDs. RFD can only speak to one FFD [8]. ZigBee applications in home screened electricity meters and traffic management systems include wireless light switching [6]-[9].

A. ZigBee Layers

ZigBee, which is the IEEE 802.15.4 standard, consists of four layers. These are application, network, mac and physical layers. The ZigBee Alliance, which sets production standards, provides the features of the application and network layers. The IEEE 802.15.4-2006 standard enables wireless protocols to coexist without interference and blocking. In addition, properties of MAC and physical layers are provided by this standard [10].

The Application Layer allows the user to use the device comfortably. The self-healing mechanism of the IEEE 802.15.4 Standard is achieved through the Network Layer. The MAC sub layer is derived from the IEEE 802.15.4 standard and serves the network layer above it. The MAC layer is the addressing of the incoming or outgoing data frame between the destination and the source. The physical layer is provided by the IEEE 802.15.4 standard. The task of this layer is to transmit data with radio waves in different frequency bands which are not licensed worldwide [11],[12].

B. ZigBee Topologies

ZigBee technology has different topologies. These are star, tree and mesh topologies. The image of these topologies is given in Figure 1.

1) *Star Topology*: This topology consists of a coordinating device and a plurality of end devices. The master-slave model is used. The ZigBee coordinator, which is FFD device, is used as the master. FFD and RFD devices are used as slaves. It is attractive because of its simple structure but it has some disadvantages. The information is transmitted through the coordinator and the devices only communicate with the coordinator. For these reasons, multi-hop or mesh network is not supported. Since all network traffic passes through the coordinator, this topology becomes invalid when the coordinator is not working [1], [12].

2) *Tree Topology*: In this topology, the coordinator at the top of the tree initiates the functionality of the network. Unlike star topology, nodes can communicate with each other. Each router can connect to more sub nodes of the router. Thus, more RFD / FFDs can be connected to non-coordinator FFDs. The advantage of this topology is that it supports the possible geographical expansion of the network. The disadvantage is that if a router fails, sub nodes cannot communicate with other nodes in the network [1],[12].

3) *Mesh Topology*: This topology is the most flexible topology. The message sent from the source can be divided into multiple paths, and each node can communicate with another node in its range. Maintaining the functionality of the mesh topology is complex. However, it is more robust and has a higher fault tolerance. When a particular router fails, route

discovery is made to find a suitable way for the message to go [1],[12].

III. METHODOLOGY, NETWORK DESIGN AND SIMULATION

Simulation is one of the best ways to improve system performance and reduce cost. OPNET Modeler's ZigBee module was used to simulate the ZigBee network. This version supports star, tree, cluster and mesh topologies [13].

The parameters of the simulation performed for this study are shown in Table 1. Accordingly, the simulation was performed for 3 different topologies (star, tree, mesh) and the values in Table 1 were used.

TABLE I
SIMULATION VARIABLES

ZigBee Variables	Values		
	Star	Tree	Mesh
Maximum Child	255	7	7
Maximum Router	0	5	5
Maximum Depth	1	5	5
Mesh Router	Passive	Passive	Active
Transmission Power	0.05	0.05	0.05
Transmission Band	2450 Mhz	2450 Mhz	2450 Mhz
Pan ID	Automatic	Automatic	Automatic

The assumptions of the topologies modelled with an OPNET Modeler are:

- 10 end devices and 1 coordinator node were used for each topology.
- 1 for star, 4 for tree and 4 for mesh topology were used.
- Each of the sub nodes can be the last device or another router.
- An end device only communicates with one of its parent and cannot function as a router. These devices often go into sleep mode to ensure energy efficiency.
- 100x100 square meters office network structure is selected for all system nodes.
- ACK mechanism is not used.
- Slotted CSMA/CA is set to default.
- All nodes are made mobile.
- Beacon-enabled mode is disabled.
- The PANID value for the addressing mechanism is automatically assigned.
- The destination selection is set at random.
- Packet size is selected as 1024 bytes.
- Simulation models were run for 20 minutes.

Simulations were performed for three different topologies according to the settings given above. The assumptions of the networks modeled with OPNET Modeler are shown in Figure 2 for star topology, Figure 3 for tree topology and Figure 4 for mesh topology.

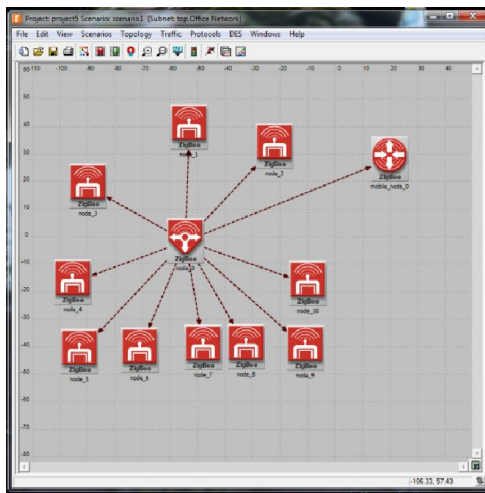


Fig. 2 Network structure of star topology

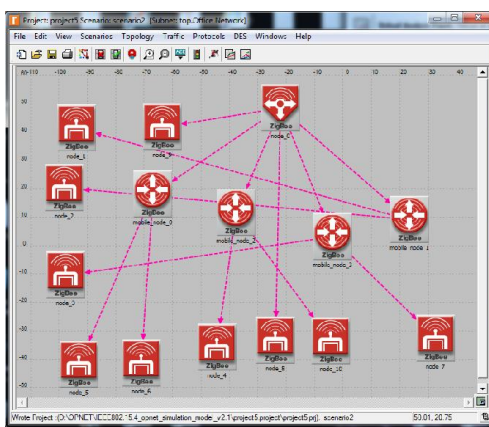


Fig. 3 Network structure of tree topology

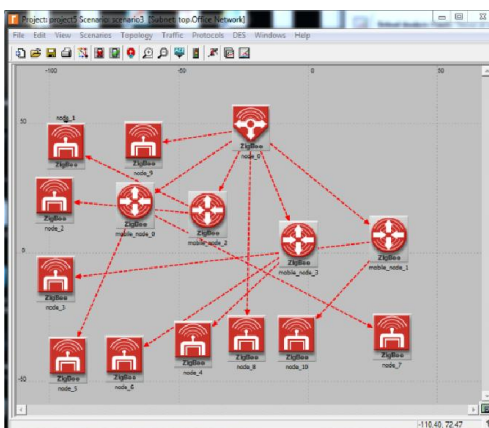


Fig. 4 Network structure of mesh topology

IV. RESULT ANALYSIS AND PERFORMANCE EVALUATION

Performance comparisons were made according to the criteria of delay, load, throughput, end-to-end delay and number of hops in star, tree and mesh topologies.

A. Delay

The delay value is the time taken to pass one bit of data from one device to another [4]. The time it takes to send a message from the source to the destination. The delay value of the network is calculated by averaging all destination values. Figure 5 shows the delay values for 3 different topologies.

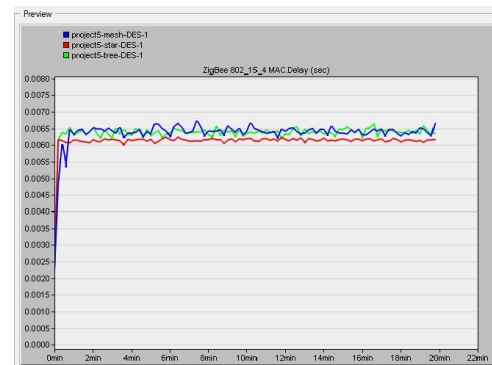


Fig. 5 delay values for 3 different topologies.

As shown in Figure 5, delay values for each of the 3 topologies are close to each other. If examined in detail, the lowest value belongs to the star topology (0.006242 seconds). The delay values of mesh and tree topologies are very close to each other and slightly higher than star topology.

B. Load

The load value gives the result of the average load (bits / second) [4]. It can also be expressed as the number of packets sent to the network at one time. Figure 6 shows the load values of all three topologies.



Fig. 6 Load values of all three topologies.

When the load values are examined, it is seen that there are different values for each topology. Accordingly, it has the highest load rate of tree topology (42.042 kbps), 2nd largest rate of mesh topology (36.226 kbps) and lowest rate of star topology (22.880 kbps).

C. Throughput

The throughput value is the amount of correctly transmitted data from the source to the destination within a given time (seconds) [4]. The throughput value of the network is the sum

of the throughput values of all destinations. Figure 7 shows the throughput graph of 3 topologies.

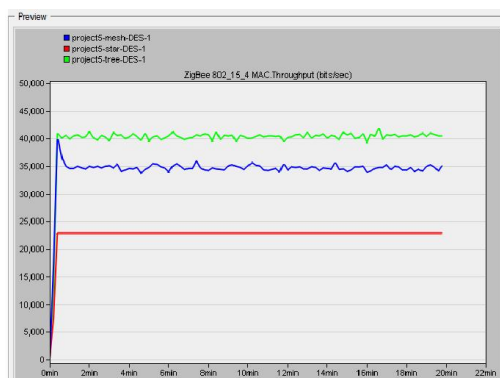


Fig. 7 Throughput graph of 3 topologies.

Figure 7 shows that the throughput values are different for each of the three topologies. The highest value is seen in the tree topology (41.851 kbps) because it uses routers that are more efficient than the end devices. In the tree topology, less collision and packet drop occur because the total load of the network is shared. The lowest value is observed in the remaining star topology (22.880 kbps) and the median value is seen in the mesh topology (39.964 kbps).

D. End-to-end Delay

End-to-end delay is the measurement of network delay in a packet. Figure 8 shows the end-to-end delay graph of 3 topologies.

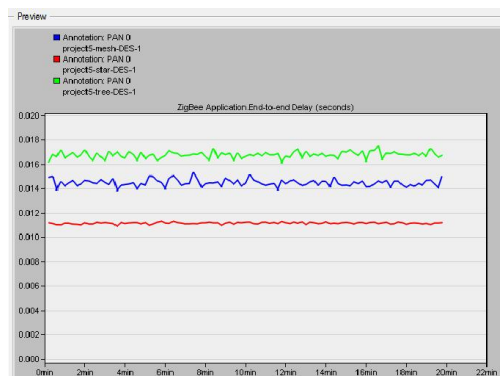


Fig. 8 End-to-end delay graph of 3 topologies.

When the end-to-end delay values are examined, it is seen that there are close values for the topologies of the tree (0.01752 seconds) and mesh (0.01534 seconds). Tree topology has the highest value and star topology has the lowest value (0.01135 seconds).

E. Number of Hops

The number of times a packet passes from intermediate nodes to the source to reach the destination gives the number of hops. Figure 9 shows the number of hops of 3 topologies.

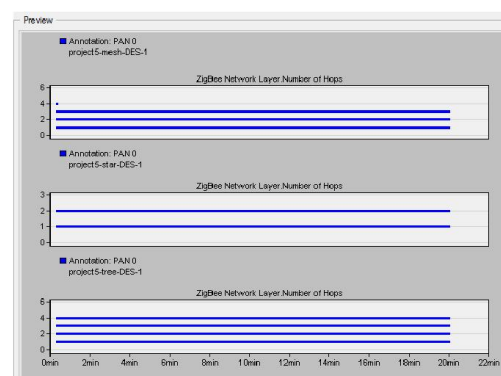


Fig. 9 Number of hops of 3 topologies.

When the number of hops is examined, it is seen that the number of hops for star topology is between 1-2. That is, there are other intermediate nodes that transfer data between the source and random destinations. In tree topology, the number of hops is between 1-4. The mesh topology uses a routing table. Here, the average number of hops is 2 and the values range from 1-3.

V. RESULTS

In this study, ZigBee which is one of the wireless network technologies has been simulated with 3 different protocols and the results were examined. Star, tree and mesh topologies were selected and performance evaluations were made. IEEE 802.15.4 / ZigBee protocol was simulated using OPNET Modeler to select the most suitable topology for specific applications.

In this study, according to obtained simulation results, star topology for delay value, tree topology for load value, tree topology for throughput value and star topology for end-to-end delay value gave the best results. When the number of hops is considered, the lowest value belongs to the star topology.

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