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Performance Analysis of ZigBee Topologies Networks

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Abstract

ZigBee or IEEE 802.15.4 is a unique communication standard, developed for wireless personal area network (WPAN). It has been developed for low-rate WPAN (LR-WPAN), which has a feature of long battery life by having low data rate. In this paper we present a performance evaluation of IEEE 802.15.4 standard. We examine the effect of topologies variation, and compare the three topologies (Star, Tree and Mesh) to each other. Parameters of interest are the throughput, end-to-end delay, number of hop and network load using OPNET simulator.

Keywords: *IEEE-802.15.4, ZigBee WSN, Topology, MAC Layer, OPNET Modeler, Throughput, Load, Delay, No. of Hop.*

1. Introduction

ZigBee is a wireless networking standard that, aimed at remote control and sensor applications, which is suitable for operation in harsh radio environments and in isolated locations.

ZigBee technology is based on IEEE standard 802.15.4 which defines the physical and MAC layers. Above this, ZigBee defines the application and security layer specifications for enabling interoperability between products from different manufacturers. In this way ZigBee is a superset of the 802.15.4 specification.

Zigbee device can form networks with Mesh, Star, and Tree topologies among themselves. A ZigBee network can have three types of nodes, which havesome unique property: Zigbee Coordinator (ZBC), Zigbee router (ZBR) and Zigbee End Device (ZBE) each having.

2. Methodology

Studying the ZigBee specification and simulation is the starting point for the IEEE 802.15.4 standard. On this base, an approach to estimate the behavior of ZigBee devices in different types of networks is developed.

3. ZigBee IEEE 802.15.4 Standard

The goal of the IEEE 802.15.4 standard is to provide a low-power, low-cost, and highly reliable protocol for wireless connectivity among inexpensive, fixed, and portable devices. These devices can form a sensor network or a Wireless Personal Area Network (WPAN). Three different frequency ranges are offered, and the most important one is the 2.4 GHz range.

3.1. ZigBee Applications

ZigBee enables broad-based deployment of wireless networks with low-cost and low-power solutions. It provides the ability to run for years on inexpensive batteries for a host of monitoring and control applications. Smart energy/smart grid, AMR (Automatic Meter Reading), lighting controls, building automation systems, tank monitoring, HVAC control, medical devices and fleet applications are just some of the many spaces where ZigBee technology is making significant advancements.

3.2. ZigBee Architecture

ZigBee consists of three layers and provides manufacturing standards for Application and Network as top two layers pecifications.
IEEE 802.15.4-2006 standard provides bottom Data Link Layer (DLL) to ensure coexistence without interference with other wireless protocols such as Wi-Fi.

Table 1: ZigBee Protocol Layers

Application layer (APL)
Network layer (NWK)
Medium access control layer (MAC)
Physical layer (PHY)

3.3 Node Types

There are only three general types of node:

3.3.1. Co-ordinator: There is one ZigBee coordinator in each network to act as the router to other networks.

3.3.2. **End Device**: End devices are capable of talking in the network but it cannot relay data from other devices. This device talks only to a network coordinators and routers.

3.3.3. Router: ZigBee routers are used to transmit data from other devices and it is also able to have other nodes attached to it, such as a router or an end device. These other nodes are referred to as child nodes.

3.4. ZigBee Topologies

A ZigBee network can adopt one of the three topologies:

3.4.1. Star Topology

A Star network has a central node, which links to all other nodes in the network. All messages travel via the central node. The main advantages of star topology are its simplicity and predictable and energy efficient behavior. The drawbacks are limited scalability and ZC as a single point of failure [2,4].

3.4.2. Tree Topology

A Tree topology consists of a Coordinator, to which other nodes are connected as follows:
1. The Coordinator is linked to a set of Routers as well as to End Devices and its children.
2. A Router may then be linked to more Routers and End Devices - its children.

A Tree network has a top node with a branch-leaf structure below. To reach its destination, a message travels up the tree and then down the tree.

3.4.3. Mesh Topology

A Mesh network has a tree like structure in which some leaves are directly linked. Messages can travel across the tree, when a suitable route is available. The advantage being that, if any individual router becomes inaccessible, an alternative route can be rediscovered and used. The limitation of this topology has a higher communications overhead than the star topology, which can result in increased latency.

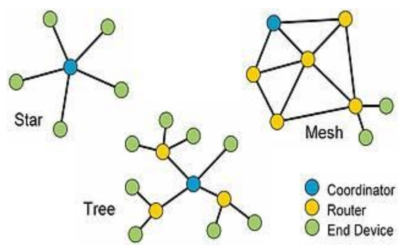

Figure 1: ZigBee nodes and topologies

4. Simulation Model & Scenario

In this paper we evaluated three ZigBee topologies by creating the network model and simulation environment using OPNET modeler 14.5 to compare simulation results.

4.1. Basic Setup

The basic setup of each topology implemented under OPNET 14.5, Figure 2 below, demonstrated the symbols that used by OPNET for router, coordinator,and end device.

Figure 2: OPNET Representations of ZigBee Devices

4.2. The Topologies Simulation

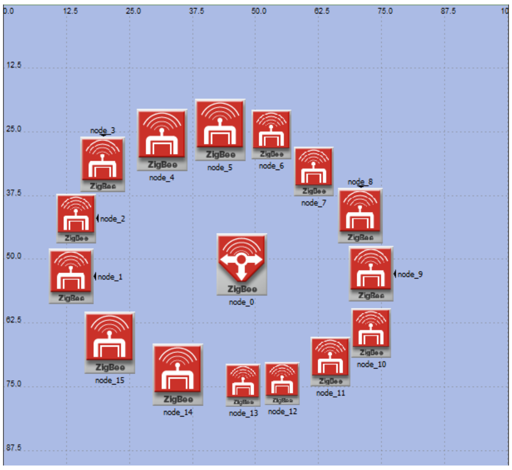

Figure 3: Star Topology Scenario

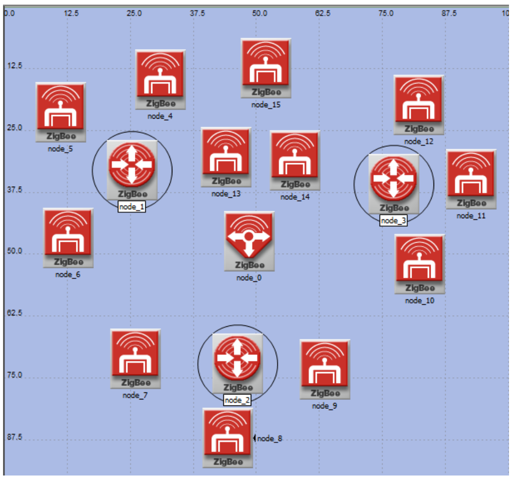

Figure 4: Tree Topology Scenario

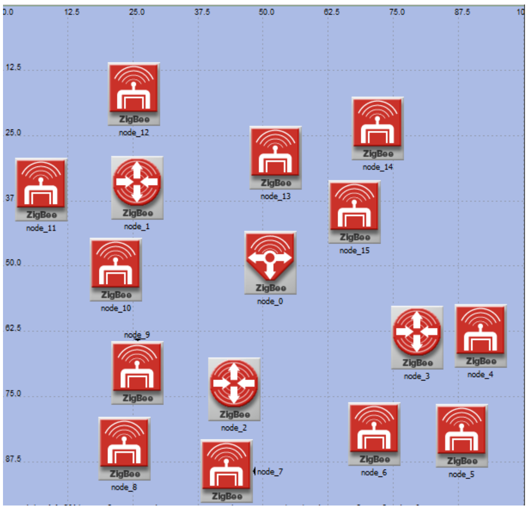

Figure 5: Mesh Topology Scenario

Note: The difference between tree and mesh topology is that, we enable the routing in a mesh topology.

5. Results and Description of Overall Design

The simulation results concerning the Throughput, End-to-End Delay, No. of Hops, Load per PAN, across the full ZigBee network.

5.1. Throughput

Throughput is the ratio of the total amount of data that a receiver receives from a sender to a time it takes for the receiver to get the last packet. Figure 6 shows the maximum throughput is achieved in mesh topology compared to tree and star topologies.

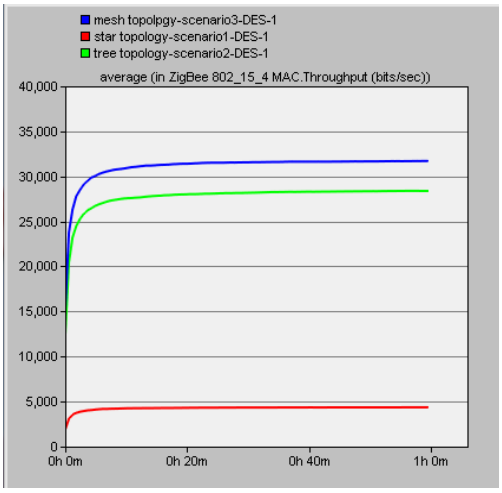

Figure 6: Average Throughputs of Star, Tree and Mesh Topology

5.2. End-to End Delay

End-to-end delay refers to the period for a packet to be transmitted across a network from source to destination. The result is shown in figure 7, concludes that Mesh topology has a maximum value of end-to-end delay and star topology has minimum end-to-end delay. This is due to more traveling number of hops, and extra time that the information takes to reach its destination in mesh and tree topologies compared to star topology.

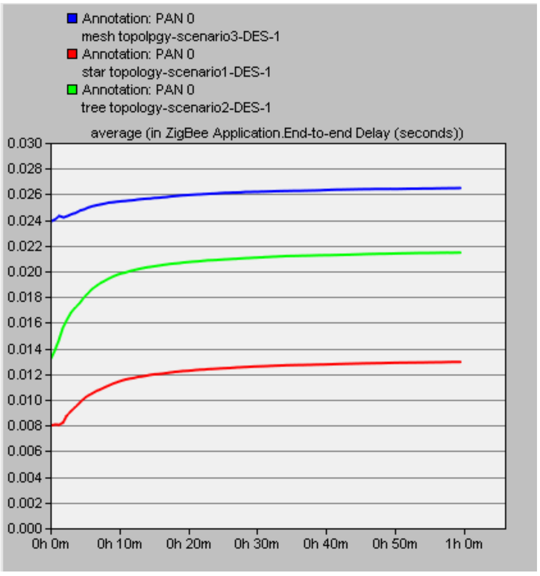

Figure 7: Average End to End Delay in Star, Mesh and Tree Topologies

5.3. Number of Hops

It is the average number of hops, which travel through application traffic in the PAN. In figure 8 we see that star topology has the minimum number of hops.

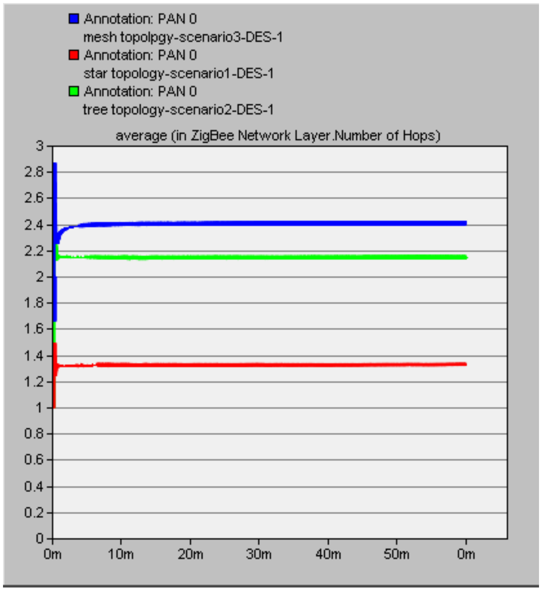

Figure 8: Average No. of Hops in Star, Mesh and Tree Topologies

5.4. Network Load

Represent the submitted total load (in bits/Sec) to 802.15.4 MAC by all higher layers in all WPAN nodes of the network. In the below figure mesh topology has the maximum networking load compared to tree and star topologies.

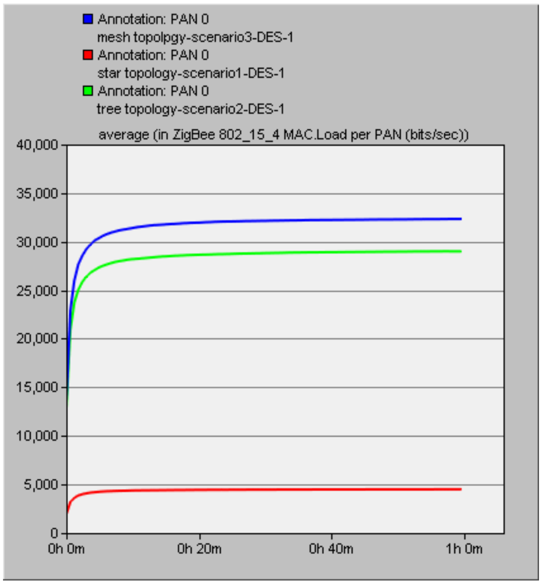

Figure 9: Average Network Load in Star, Tree and Mesh Topologies

6. Conclusion

In this paper, we presented three WPAN ZigBee topologies. They are star, mesh and tree topology. The simulation studies the topologies parameters like throughout, end-to-end delay and number of hop and network loads.

The results show that mesh topology has the highest throughput, and in other side has a highest load in network. The star topology has the lowest load and throughput. The tree topology has medium results in all parameters. So, the type of topology is selected in accordance with the network tasks. Overall, the performance evaluations show that the ZigBee can only be use for low-data rate and low-power smart grid applications not having very high reliability requirements and real-time deadlines.

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