Study and test performance of the Zigbee Wireless technology in some network models by using Opnet software

(1)Mariam Aboajela Msaad, (2) Almoatasem Aboaisha , (3)Ahmed Eshoul
(1) Tripoli Unversity -Faculty of Information Technology "network Department
Tripoli, Libya, meemee_02@yahoo.com
(2) Tripoli Unversity -Faculty of Information Technology "network Department
Tripoli, Libya
(3) Tripoli Unversity -Faculty of Information Technology "network Department
Tripoli, Libya

Abstract— **ZigBee Wireless Technology is the leading global standard for implementing low-cost, Low-data-rate, short-range wireless networks with extended battery life. The ZigBee standard provides network, security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard. It employs a suite of technologies to enable scalable, self-organizing, and self-healing networks that can manage various data traffic patterns, The low cost allows the technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range. ZigBee has been developed to meet the growing demand for capable wireless networking between numerous low power devices.**

In this paper , we will try to give a complete picture about ZigBee technology including the structure of this technology, the layers where this technology works referred to the OSI model, how this technology works, the main components that use to create a ZigBee network, The objective of this simulation is to establish tree topology networkby; using an OPNET Modeller 14.5 program, and to investigate the performance of the network model, and see the effect on data when we change the time of transmission and finally we will investigate the performance of some network models that employ IEEE 802.15.4 protocol using different scenarios.

Keywords— **ZigBee; formatting; MAC; PHY; IEEE; OPNET**

I. Introduction

The cellular network was a natural extension of the wired telephony network that became pervasive. As the need for mobility and the cost of laying new wires increased, the motivation for a personal connection independent of location to that network also increased. Coverage of large area is provided through (1-2km) cells that cooperate with their neighbors to create a seemingly seamless network.[1]

During the mid-1980s, it turned out that an even smaller coverage area is needed for higher user densities and the emergent data traffic. The IEEE 802.11 working group for WLANs is formed to create a wireless local area network standard.

*

Whereas IEEE 802.11 was concerned with features such as Ethernet matching speed, long range(100m), complexity to handle seamless roaming, message forwarding, and data throughput of 2-11Mbps, WPANs are focused on a space around a person or object that typically extends up to 10 min all directions. The focus of WPANs is low-cost, low power, short range and very small size.[1]

The IEEE 802.15 working group is formed to create WPAN standard. This group has currently defined three classes of WPANs that are differentiated by data rate, battery drain and quality of service (QoS). The low rate WPANs (IEEE802.15.4/LR-WPAN) is intended to serve a set of industrial, residential and medical applications with very low power consumption and cost requirement not considered by the above WPANs and with relaxed needs for data rate and QoS. The low data rate enables the LR-WPAN to consume very little power.[3].

II. ZIGBEE Tecnology

ZigBee is expected to provide low cost and low power connectivity for equipment that needs battery life as long as several months to several years but does not require data transfer rates as high as those enabled by Bluetooth. In addition, ZigBee can be implemented in mesh networks larger than that is possible with Bluetooth.

ZigBee compliant wireless devices are expected to transmit 10-75 meters, depending on the RF environment and the power output consumption required for a given application, and will operate in the unlicensed RF worldwide (2.4GHz global, 915MHz Americas or 868 MHz Europe). The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz.[2]

IEEE and ZigBee Alliance have been working closely to specify the entire protocol stack. IEEE 802.15.4 focuses on the specification of the lower two layers of the protocol (physical and data link layer). On the other hand, ZigBee Alliance aims to provide the upper layers of the protocol stack (from network to the application layer) for interoperable data networking, security services and a range of wireless home and building control solutions, provide interoperability compliance testing, marketing of the standard, advanced engineering for the evolution of the standard. This will assure consumers to buy products from different manufacturers with confidence that the products will work together.

IEEE 802.15.4 is now detailing the specification of PHY and MAC by offering building blocks for different types of networking known as ”star, mesh, and cluster tree”. Network routing schemes are designed to ensure power conservation, and low latency through guaranteed timeslots. A unique feature of ZigBee network layer is communication redundancy eliminating ”single point of failure” in mesh networks. Key features of PHY include energy and link quality detection, clear channel assessment for improved coexistence with other wireless networks.

III. OPNET

The OPNET Modeler gives the facility of the graphical user interface in which the users can model and simulate their networks. For developing different communication structures and implementing different scenarios’, different hierarchal layers are present in the environment of the modeling. Users can build a detailed model according to the requirement needed to do the analysis of the system. The systems are designed in the object oriented way, on compilation of the model its produces a discrete event simulation in the C language. After performing the simulation, the results are analyzed with the different statistics related to the performance provided by the OPNET [12].

The primary goal of this project is to use the OPNET Modeler14.5, simulation tool to study the protocol of interest, ZigBee. In order to achieve this goal, we will simulate several simple ZigBee WPAN networks while altering certain parameters using OPNET Modeller 14.5.

The objective of this simulation is to establish tree topology network by using an OPNET Modeller 14.5 program, and to investigate the performance of the network model, and see the effect on data when we change the time of transmission. Appendix B shows the steps used to create this network.

The program offers several parameters, which by right clicking to any node can change. Samples of these parameters are illustrated in Figure (1)

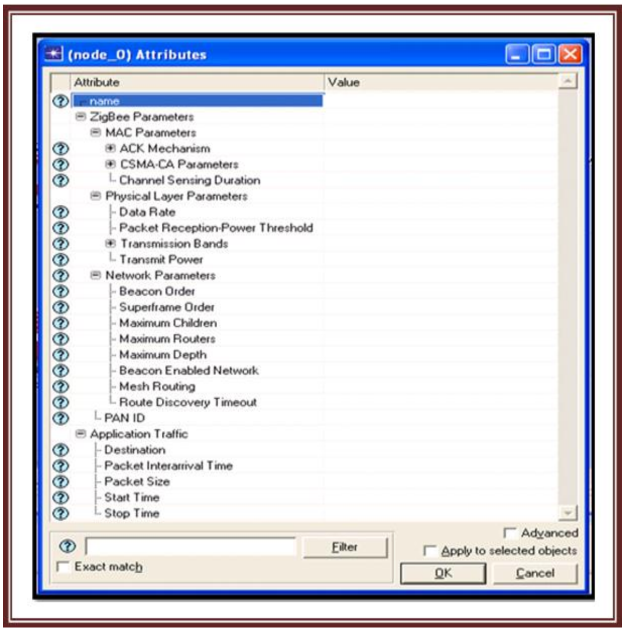


Figure.1 Editing Attributes for the ZigBee Network Set-up

IV. ZIGBEE PARAMETERS

There are three types of ZigBee parameters: MAC parameters, physical layer parameters and network parameters (NOTE: The network properties are available only for change in Coordinator).

A. *MAC Parameters*

I. ACK Mechanism

This attribute defines ACK related behavior for the MAC. Figure 2 illustrates this parameter.

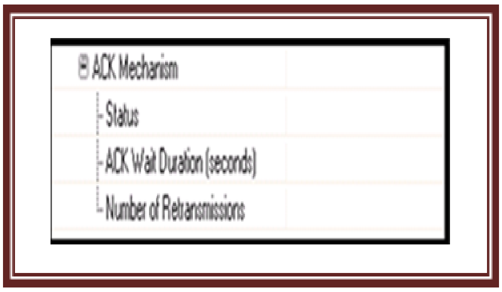


Figure 2 ACK Mechanism parameters

- Status: This attribute tells whether the ACKs are enabled for this node's transmission or not.
- ACK Wait Duration (seconds): This is the duration for which the MAC will wait to receive ACK for a given transmission. If the ACK did not receive during this duration, the MAC will retransmit.
- Number of Retransmissions: Number of times a packet retransmitted before it is marked as failed. CSMA-CA Parameter: This set defines the parameters for the CSMA-CA implementation of the 802.15.4 MAC. Figure 3 illustrates CSMA-CA Parameters

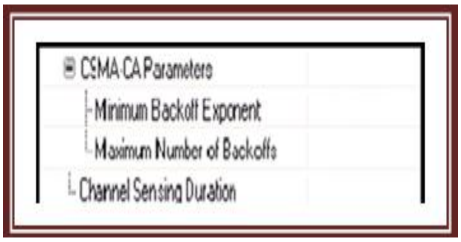


Figure 3 CSMA-CA Parameters.

- **Minimum Back off Exponent**: The minimum value of the back off exponent in the CSMA-CA algorithm. Note that if this value is set to zero collision avoidance disabled during the first iteration of the algorithm.
- **Maximum Number of Back offs**: The maximum number of back offs the CSMA-CA algorithm will attempt before declaring a channel access failure.
- **Channel Sensing Duration**: This is the duration for which each channel will be scanned for beacons after the beacon request is sent out.

If 'Auto-Compute' was specified, the node will automatically determine the channel sensing duration based on the data rate of the channel being scanned [12].

B. Physical Layer Parameter

The Physical Layer Parameters were illustrated in Figure 4

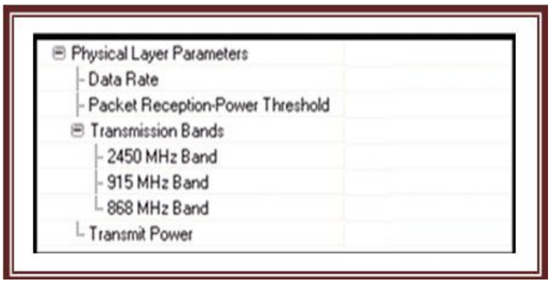


Figure 4 Physical Layer Parameters

I. **Data Rate:** Specifies the data rate that will be used by the MAC for the transmission of the data frames via physical layer. "Auto Calculate" will determine the data rate based on the transmission band the channel that is belongs to it. For example if the channel is in the 2450 MHz band, the data rate will be auto selected to be 250000 bps.
II. **Packet Reception – Power Threshold: Defines** the received power threshold (receiver sensitivity) value of the radio receiver in dBm for arriving WPAN packets.
III. **Transmission Bands: Specifies** the transmission bands the device may use. A ZigBee device may choose a channel in any of the bands that are enabled 868 or 915 or 2450MHz
IV. **Transmit Power: This** attribute specifies the transmission power allocated to packets transmitted through the channel , [12].

C. Network Parameter: Specifies

The type of network (star/tree/mesh) that the coordinator will form.

D. PAN (Personal Area Network) ID

Allows the user to specify the PAN ID of the node. A coordinator will form a network with that PAN ID. A router or end device will attempt to join a network with that PAN ID. A coordinator with PAN ID set to 'Auto Assigned' will choose an arbitrary PAN ID. A router or end device with PAN ID set to 'Auto Assigned' will join any network, regardless of its PAN ID.

F. Applications Traffic

Figure 5 specifies the application traffic parameter setting.

Figure 5 Application traffic

I. **Destination: Name** of the traffic destination node. The following special symbolic values can be specified :
    - "Random"-The node will choose a random destination node within its own PAN.
    - "All Nodes" - The node will broadcast traffic to all nodes in its PAN.
    - "All Coordinators and Routers" - The node will broadcast traffic to all Coordinators and Routers in its PAN.
    - "Parent" - The node will always send traffic to its parent node. If this specified on a Coordinator, the traffic had dropped.
    - "No Traffic" - The node will not send application traffic.
II. **Packet size**: Specifies the distribution name and arguments to be used for generating random outcomes for packet size.
III. **Start Time: Specifies** the distribution name and arguments to be used for generating random application traffic start time.
IV. **Stop Time: Specifies** the stop time for application traffic.

V. ENTITIES OF THE NETWORK

We have selected different network elements and configure it according to the requirement of our scenario. The following are the entities which we have selected from the Object Palette Tree in the OPNET Modeler.

- Coordinator.
- Router.
- End Device.

All these network entities are configured according to the requirements of this scenario. This scenario is explained in the following sections.

VI. SIMULATION OF TREE TOPOLOGY NETWORK

A network model of tree topology is built to cover the area which required from End Devices at least one coordinator is needed. Also choose routers that needed to establish the connection the network of the nodes to relay messages from node to other nodes.

as shown in figure 6 We want to investigate the performance of ZigBee network in tree topology, which consists of :

- one coordinator,
- two routers,
- five fixed end devices,

We noticed the ZigBee model in OPNET has some limitations and unfinished features; one of these limitations is connecting only up to two End Device per router [12].

Four different scenarios used to test and analyze the ZigBee performance using tree topology.

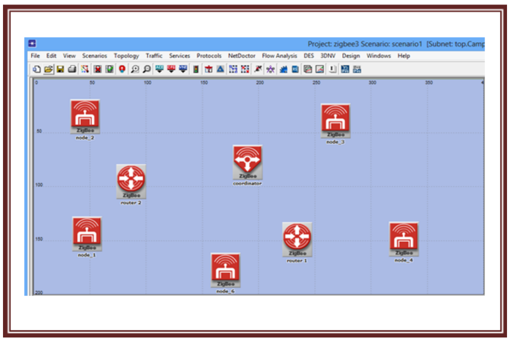


Figure 6 Tree topology of ZigBee network model

A. *General Assumptions for all scenarios:*

The main parameters in our simulation (for all scenarios) are indicated in Table 1.

Table 1 Simulations parameters.

Parameters
Transmission Band
Transmit Power
Packet Reception-Power Threshold
Data Rate
ACK Wait Duration
Number of Retransmission
CSMA-CA
Channel Sensing Duration

B. ***Scenario 1***

This scenario is general and simple case to observe the behavior of a ZigBee network in OPNET model. The settings of application traffic for this scenario are indicated in table.2, and all nodes are fixed in the network.

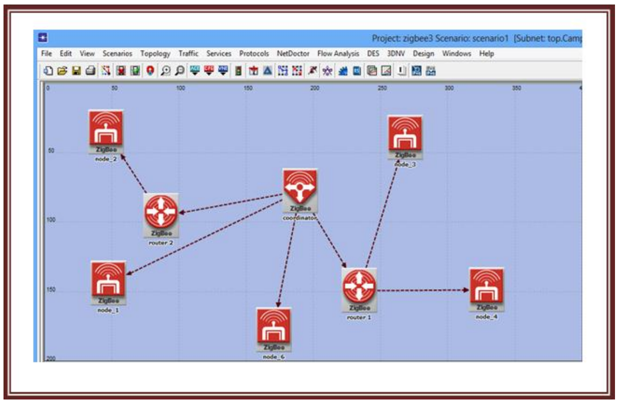
Table.2: Application traffic parameter setting

Parameters	Values
Destination	Random
Packet size	Type of Distribution : constant
	Mean outcome : 1024 byte
Start time	Type of Distribution : uniform
	Minimum outcome : 20s
	Maximum outcome: 21s
Stop time	Infinity

In this scenario the transmission times for all devices are same, they start at 20sec, and all nodes don't stop transmission throughout the simulation time. And observe the effects on the (throughput, end-to-end delay, media access delay).

I. Simulation Results:

When we run the program and insert a period of time (a period of time for the simulation is set at 900 seconds). The program calculates all the required results and presented graphically. Figure 7 illustrates the traffic paths from the Coordinator to End Devices through the Routers.



II. Figure 7 Tree topology of ZigBee network model during simulation

ZigBee performs route discovery to determine the optimal path for messages to take to its destination. The end devices will be sending data with a constant bit rate to the coordinator by first sending to the router, and then allowing the router to relay the message to the destination. Alternatively, sending directly from end devices to coordinator.

Figure 7 shows that the routers in the tested model are receiving traffic from all neighboring devices initially. And notice that the End Device 1 and End Device 6 sends data directly to the Coordinator and End Device 2 send data through the Router2, and both End Devices 4 and End devices 3 sending data through the Router1

- Throughput:

In Figure 8, we can see that the throughput starts to increase after 10 seconds, and after 45 seconds, the throughput is almost constant on a maximum value (17160bps) throughout the simulation time for Throughput of global ZigBee network.

The throughput defined as total data traffic in bits/sec successfully received and forwarded to the higher layer by the 802.15.4 MAC. Figure 8 shows the throughput of global ZigBee network; we can notice that the throughput is almost constant on a maximum value (17,160 bps) throughout the simulation time.

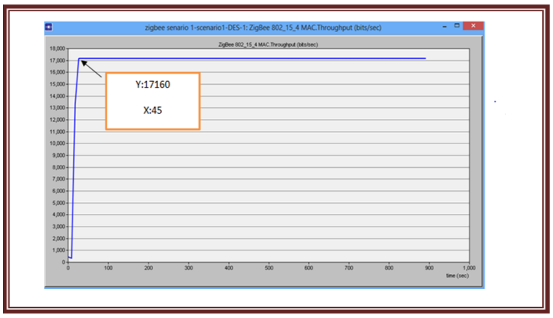


Figure 8 Throughput of global ZigBee network model

- End -To - End Delay :

The end-to-end delay represents the total delay between creation and reception of application packets generated by the node.

Figure 9 shows the average end-to-end (ETE) delay of traffic from the end devices to coordinator, and we can see that data traffic much less delay at End device 1, because it is connected directly to the coordinator without router.

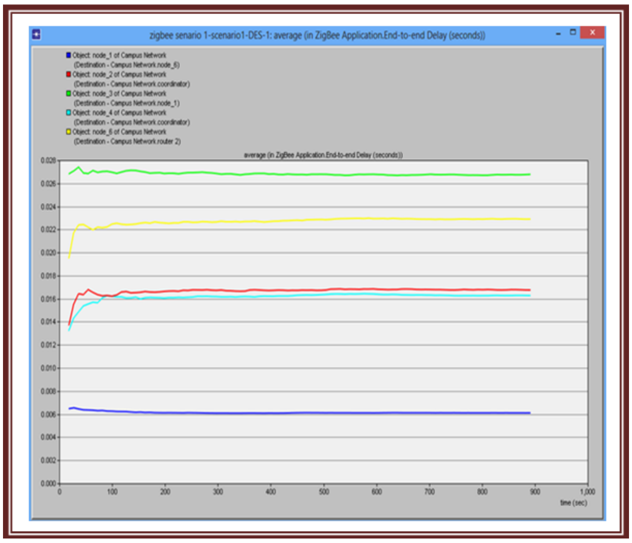


Figure 9 End -To - End Delay from each end device to coordinator (average)

- Media access delay

This represents the total of queuing and contention delays of the data frames transmitted by the 802.15.4 MAC. For each frame, this delay is calculated as the duration from the time when it is inserted into the transmission queue, which is arrival time for higher layer data packets and creation time for all other frames types, until the time when the frame is sent to the physical layer for the first time [12].

Figure 10 shows average Media access delay for each end device, we observe that the access delays for all end devices are nearly with same value and reach a maximum value of (0.13 sec) in the first (10 sec) in the simulation time. As we can see from Figure 10 about (0.1 sec) is spent from each node at the beginning which represent channel sense duration.

After the first 10 sec the delay until stable around (0.006 sec) at throughout the simulation time. (Note: The values for average Access Delay are nearly the same for each end device. And this makes the colors mixture together).

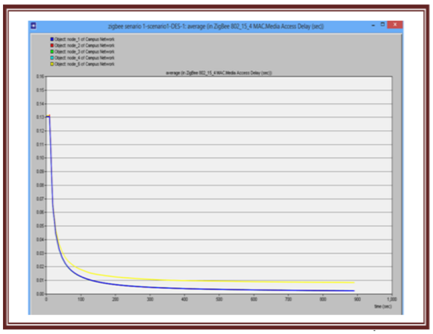


Figure.10 Media Access Delay for each end device (average)

C. Scenario 2

In this scenario, we will stop sending data after a period of time from the time of simulation in one of the End Devices, and will observe the effects on the network; we make the End Devices1to stop the transmission after (400seconds).

We can stop the transmission of any device by changing the stop time as indicated before in figure 11, from infinite to 400 second. The settings of application traffic are indicated in table .3.

Table.3 Application traffic parameter setting

Parameters	Values
Destination	Random
Packet size	Type of Distribution : constant
	Mean outcome : 1024 byte
Start time	Type of Distribution : uniform
	Minimum outcome : 20s
	Maximum outcome: 21s
Stop time	400s

❖ Throughput

The Throughput performance of the network model taking into consideration two scenarios is isullrated in Figure 11. We observe that when sending of data from end device 1 is stopped at 400 sec for scenario 2, the throughput is decreased from the (17100 bps) to (16000 bps), the difference is about (1100 bps) which is equivalent to the throughput of End Device 1 for scenario 1.

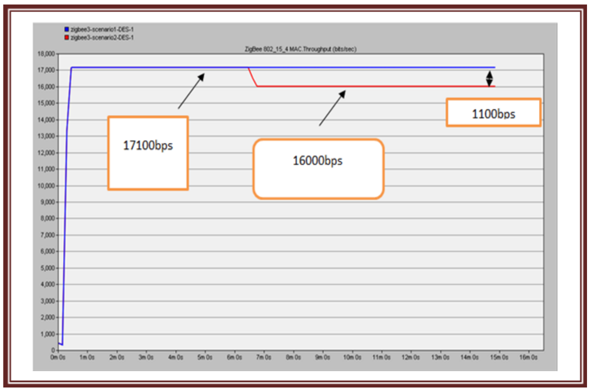


Figure.11 Throughput of global network for scenario 1 and 2.

❖ Media Access Delay

Figure 12 shows the performance of the network model, taking into consideration the Media Access Delay for end device 1 for both scenario 1 and scenario 2. We observe that both scenarios here equal value of access delay up to 400 sec, but when end device 1 stopped transmission data in scenario 2 only scenario 1 access delay remains while the access delay for scenario 2 is not calculated, because not necessary for channel sense if there is no data for send.

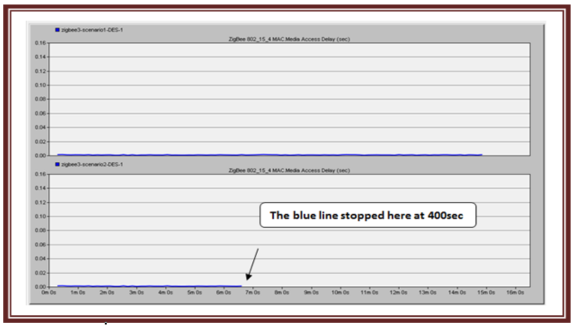


Figure 12 Media Access Delay of end device 1 for scenario 1 and 2

D. Scenario 3

In this scenario, we will change the start and stop times of the transmitter of End Device1, where we change the starting time for the beginning of data transmission of End device 1 at 300 seconds. This means that it will start transmission after all end devices, and will stop after a time of less than the time of the end of the simulation, and in this scenario we will put the stop time to be 600 seconds. And settings of application traffic for this scenario are indicated in Table 4.

Table 4 Application traffic parameter setting

Parameters	Values
Destination	Random
Packet size	Type of Distribution : constant
	Mean outcome : 1024 byte
Start time	Type of Distribution : uniform
	Minimum outcome : 300s
	Maximum outcome: 301s
Stop time	600s

❖ Scenario Results:

❖ Throughput:

The Throughput performance of the Router 1 for both scenarios 1 and 3 is shown in figure 13. We observe that when end device 1 without sending any data, the Throughput of Router 1 will be less than for scenario 1 about (1144bps). In addition, when start to send data at 300 sec; we observe increase the Throughput until arrive to (2288bps). This value was in the first scenario.

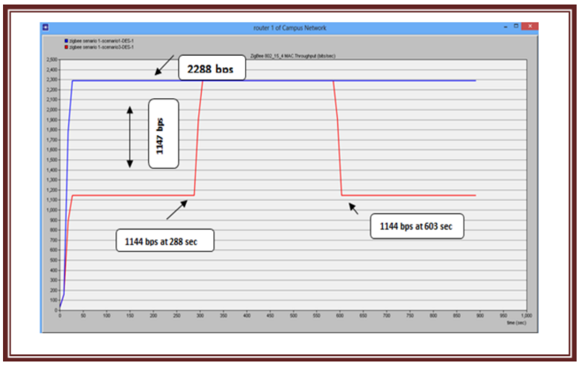


Figure 13 Throughput of Router 2 for scenario 1 and 3.

❖ Media Access Delay

Figure 14 shows the Media Access Delay of End Device 1 for both scenario 1 and 3. We observe there is no delay where there is no any send data in scenario 3 (blue line). But after 300 sec (when start of send data).

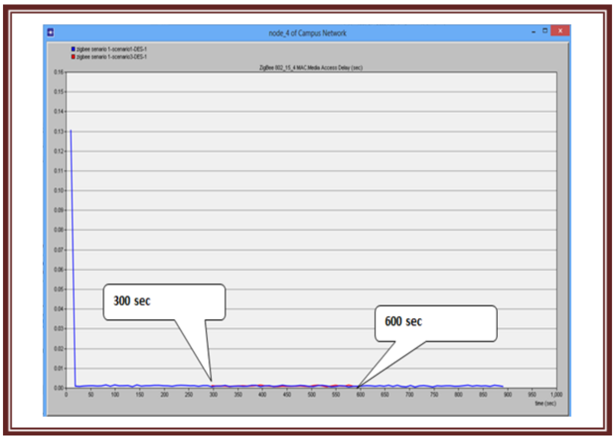


Figure 14 Media Access Delay of End Device 1 for both scenario 1 and 3

VII CONCLUSION

Referring to the main task of this paper it conclude that The incomplete implementation of the beaconing2 capability ("Note: Beacon Enabled mode is not currently supported. This attribute is a placeholder"). Lacking, is support for slotted CSMA/CA mode and contention – free operation mode. This seemed to prevent the devices from having "fair" use of the resource by scheduling the end devices to gain access to the channel.

One of the difficulties at the early stages of this project was the lack of mention in the range capability of ZigBee. Since the OPNET ZigBee model was incomplete we expected an earlier version of ZigBee with specified range of ~100meters. However, the OPNET ZigBee model was capable of handling ranges beyond 1200meters at default settings for transmission power and reception power. This initially caused the end devices to skip over the routers and communicate directly with the coordinators. Through simplified scenarios with an assortment of variations, we were able to better understand the results in reasonable time compared to having complex scenarios and results, then having to spend a lot of the project time trying to make sense of things.

With the data collected from the four scenarios a few observations and conclusions noted: The throughput is depend on the the number of the end devices and the time distribution and for result of that when we use a position distribution we get the maximum throughput The media access delay depends on the sending data from the end devices to their destination because if there is no data to send the access delay will be zero, and the reason for that belong to the queuing theory.End device that is not in the network has a higher end-to-end delay than those that are inside the network.

REFERENCES

[1] J. Gutierrez, et al, "Low-*Rate Wireless Personal Area Networks,*" IEEE Press, 2007.

[2] Shahin Farahani, "***ZigBee Wireless Networks and Transceivers***", UK, 2008, Oxford OX2 8DP.

[3] IEEE 802.15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), Sept. 2006.

[4] Castro Jose Manuel Tome, "Design of low-cost ZigBee modules", 3/07/06.

[5] Open Systems Interconnection Basic Reference Model: The Basic Model, ISO/IEC7498-1:1994.

[6] European Radio communications Committee (ERC)/CEPT Report 98, available at www.learnZigBee.com.

[7] The OSI Model: Understanding the Seven Layers of Computer Networks by Paul Simoneau, 2004.

[8] ZigBee Specification 053474r17, Jan. 2008; available from www.zigbee.org

[9] IEEE 802.11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 2005.

[10] D. M. Dobkin, "RF *Engineering for Wireless Networks,*" Elsevier Science, 2005.

[11] H. LABIOD , H. AFIFI, C. DE SANTIS, "WI-FI T M , BLUETOOTH T M , ZIGBEE T M A ND WIMAX TM ", © 2007 Springer, Published by Springer, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

[12]http://www.opnet.com/support/des_model_library/umts.html [Accessed: March. 25.2010, 5:00 PM].

[13] Austen Chan, Brian Cheung, Wing Kit Lee,"ENSC427:ZigBeeTransmission Analysis in Tree Topology", Spring 2009, http://www.sfu.ca/~kyc1