Journal of Al-Nahrain University Vol.17 (2), June, 2014, pp.219-226 Science

# A Monitoring System Using Wireless Sensor Network

Mumtaz M. Ali Al-Mukhtar*1 and Teeb Hussein Hadi**2
* Department of Internet Engineering, Information Engineering College, Al-Nahrain University.
** Department of Software Engineering, Iraqi Commission for Computers and Informatics, Informatics Institute for Postgraduate Studies.
1E-mail: eng_teebhussein@yahoo.com.
2E-mail: almukhtarmu@gmail.com.

## Abstract

The fast growing in wireless communications and electronics have helped to develop wireless sensor networks. To understand and be able to implement wireless sensor networks several concepts are necessary such as network topology, communication network, communication protocols, and routing that are needed in any monitoring system. In this paper, the performance of WSN based on various topologies scenarios has been investigated. Some techniques useful for managing wireless sensor networks are communication protocols and routing. AODV (Ad-hoc On Demand Distance Vector Routing) routing algorithm is adopted in this work. Cluster-tree, mesh and star topologies are considered in two cases. The first case compares these three ZigBee topologies. The second case compares two scenarios for each ZigBee topologies where all devices in first scenario are fixed and all devices in second scenario are mobile. These cases are simulated by taking into account the specific features and recommendations of the IEEE 802.15.4/ZigBee standard by using OPNET Modeler 14.5.

Keywords: Wireless Sensor Network (WSN), ZigBee, OPNET, Simulation, Scenario, Topology, Personal Area Network (PAN).

## Introduction

For the characteristics of self-organization, micro-size, low-cost and flexibility, WSN are being applied in many fields, such as military, environmental science, medical and health, space exploration, and commerce. WSNs belong to the Wireless Personal Area Network (WPAN) type.

Here, the word “personal” means short range communication [1]. A WSN is a self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world. The data is forwarded, possibly via multiple hops relaying, to a sink that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway [2]. In case of a monitoring scenario, all sensed data from one or several source nodes is sent periodically to a single sink or, in more complex scenarios, to multiple sinks. Data aggregation can be done in order to reduce traffic and power consumption. Monitoring applications do not require large amounts of data to be transmitted. When a source node sends message containing sensed information, it must propagate through the network towards the sink node by hopping from node to node. This hopping procedure is managed by routing protocols [3]. ZigBee devices are categorized as Full Functional Devices (FFD) and Reduced Functional Device (RFD). Coordinators and routers are categorized as FFD and end devices are categorized as RFD but all have the same type of node model. Node model has four layers: physical, MAC, network and application layers [4]. Physical layer consists of a transmitter and a receiver compliant to the IEEE 802.15.4 specification, operating at 2.4 GHz frequency band and data rate equal to 250 kbps. Network layer is responsible for end to end delivery of packets including routing through intermediate hosts. Finally the topmost Application layer is responsible for generation and reception of traffic [5].

## 2. Related Work

[1] **Jamil Y., et al., in 2008 [6]** Examined the performance of an IEEE802.15.4/ZigBee MAC based WBAN (Wireless Body Area Network) operating in different patient monitoring environment. They studied the performance of a remote patient monitoring

system using an OPNET based simulation model.

[2] **Hammoodi I., et al., in 2009 [7]** Studied and analyzed the QoS performance evaluation of the ZigBee protocol within the OPNET simulator for different WSN topologies and routing schemes.

[3] **Arrian P. Pike, in 2009 [5]** Analyzed the available IEEE standard 802.15.1(Bluetooth) and 802.15.4 (ZigBee) to decide the best fit for BAN.

[4] **Ramyah S., in 2012 [8]** Analyzed the variations in load metric in hexagonal configuration by enabling and disabling Acknowledgment message (ACK) depending on IEEE 802.15.4/ZigBee standard for WSN.

## 3. System Model

OPNET (OPtimized Network Engineering Tool) is a commercial modeling and simulation tool for analyzing communication networks. The user of OPNET graphically specifies the topology of his network which consists of nodes and links. Each node includes processors, queues, and traffic generators. The simulation environment uses a fast discrete event simulation (DES) engine operating with a 32-bit/ 64-bit fully parallel simulation kernel as the means of analyzing system performance and their behavior and the internal process of nodes and protocols has to be defined as C++ classes [9]. Monitoring requires real equipments which are not available such as real ZigBee devices considered in this paper so an OPNET Modeler simulator version 14.5 has been used to simulate and analyze different cases related for general sensors and investigate the effect of these cases and parameter settings for sensor network applications and monitoring. Two simulated cases are represented. Various topologies scenarios that include cluster-tree, mesh and star networks are represented in these cases.

### 3.1 First Case Study

This case compares three ZigBee topologies (star, mesh and cluster-tree) by using single ZC and 40 ZigBee devices represented by ZRs and ZEDs, and their number depend on the type of topology.

### A- Star Topology

This is a simple topology; it contains only one PAN coordinator surrounded with 40 ZigBee devices which are ZEDs; all are connected to the PAN coordinator but there is no a communication path between each ZED and another, as shown in Fig.(1).

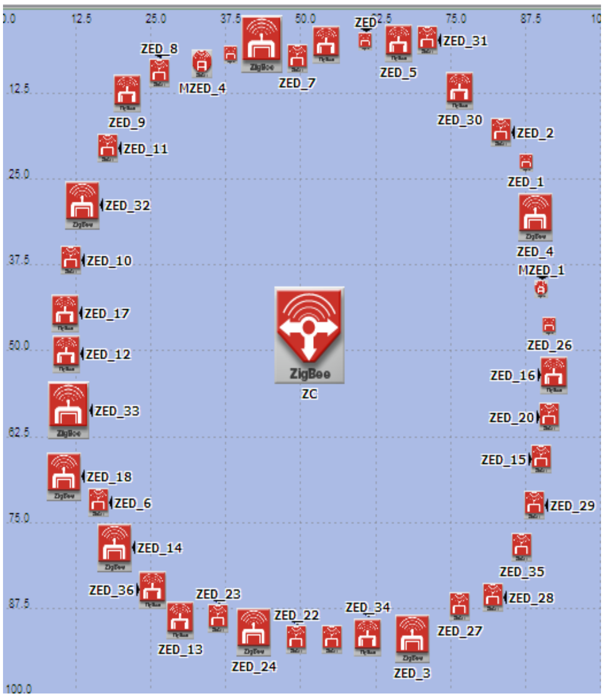


*Fig. (1) Star Topology.*

In order to communicate each end device with another, source end device must first communicate with the PAN coordinator and then the PAN coordinator communicates with the destination end. Star ZigBee network parameters are presented in Table (1).

***Table (1)***
***Application Traffic for Star Network.***

| Parameters | Mesh Network | | |
|---|---|---|---|
| ***Application Traffic*** | | | |
| ***Device type*** | PAN Coordinator | Router | End Device |
| ***Packet Interarrival time*** | Constant (1.0) | Constant (1.0) | Constant (1.0) |
| ***Packet Size*** | Constant (1024) | Constant (1024) | Constant (1024) |
| ***Start time*** | Uniform (20,21) | Uniform (20,21) | Uniform (20,21) |
| ***Stop time*** | Infinity | Infinity | Infinity |
| ***Destination*** | All Coordinators & Routers | All Coordinators & Routers | All Coordinators & Routers |

**B- Mesh Topology**

In mesh topology every FFD can communicate with any other FFD within its radio range. RFDs can join the network by associating with the ZC or ZRs. This topology has 40 devices: one ZC, 28 ZRs and 12 ZEDs. ZC is responsible for starting the network and for choosing certain key network parameters but the network may be extended through the use of ZRs, as shown in Fig. (2).

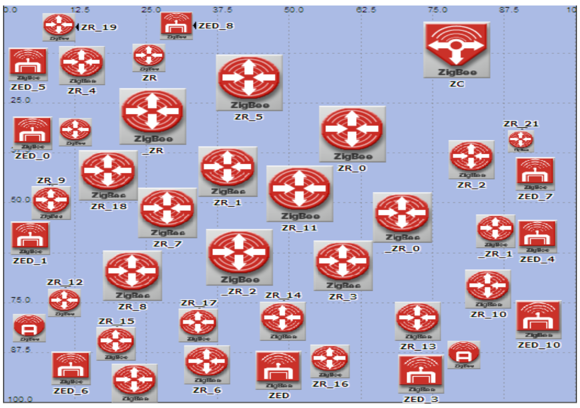

***Fig. (2) Mesh Topology.***

Data sent to the PAN coordinator use a multi-hop communication. However, for multi-hop communications an advanced routing algorithm is needed so that AODV ZigBee routing protocol algorithm is provided. Mesh ZigBee network parameters are presented in Tables (2).

***Table (2)***
***Application Traffic for Mesh Network.***

| Parameters | Star Network | |
|---|---|---|
| ***Application Traffic*** | | |
| **Device type** | PAN Coordinator | End Device |
| **Packet Interarrival time** | Constant (1.0) | Constant (1.0) |
| **Packet Size** | Constant (1024) | Constant (1024) |
| **Start time** | Uniform (20,21) | Uniform (20,21) |
| **Stop time** | Infinity | Infinity |
| **Destination** | All nodes | PAN Coordinator |

**C- Cluster-tree Topology**

In ZigBee cluster-tree topologies, one ZC identifies the entire network and each ZR assumes the role of cluster-head, allowing the association of other ZRs and ZEDs in a parent-child relationship, as shown in Fig. (3).

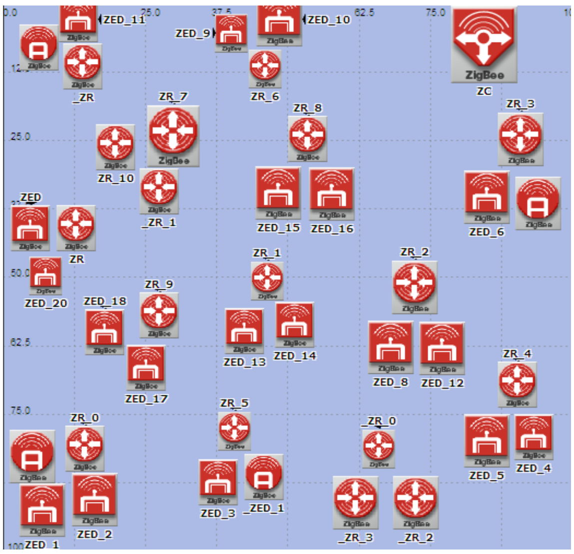

***Fig.(3) Cluster-Tree Toplology.***

This topology has 40 devices: one ZC and 18 ZRs. Each of these routers has different numbers of children represented by ZEDs connected to them as clusters. The PAN coordinator forms the first cluster by establishing itself as the cluster head (CLH) with a cluster identifier (CID) of zero. There can be multiple clusters in a network. When the association process is successful, the child device (ZED or ZR) has associated the network through its parent (ZR). Cluster ZigBee network parameters are presented in Table (3).

***Table (3)***
***Application Traffic for Cluster-tree Network.***

| Parameters | Application Traffic | | | | | |
|---|---|---|---|---|---|---|
| | *Device type* | *Packet Interval time* | *Packet Size* | *Start time* | *Stop time* | *Destination* |
| *Cluster-tree Network* | PAN Coordinator | Constant (1.0) | Constant (1024) | Uniform (20,21) | Infinity | All Coordinators & Routers |
| | Routers | Constant (1.0) | Constant (1024) | Uniform (20,21) | Infinity | All Coordinators & Routers |
| | End Device | Constant (1.0) | Constant (1024) | Uniform (20,21) | Infinity | Router (parent) |

The advantage of this clustered structure is the increased coverage area, so it is suitable for different applications such as environment monitoring, volcano monitoring, air pollution and habitat monitoring [10].

### 3.2 Second Case Study

This case compares two scenarios for each ZigBee topologies where all devices in first scenario are fixed and all devices in second scenario are mobile. These mobile devices have the ability to move in a covered area with easing the data collection in any point in this area and may these mobile devices in some times are moving out of the range causing the delay. Mobile communications nodes can be connected to fixed communications nodes and other mobile nodes via radio links only with speed equal to 10m/s. If a path is specified, the value is recomputed automatically each time the mobile node needs to update its position. If a path is not specified, the value can be updated dynamically via the Kernel Procedure of the simulator.

## 4. Results and Discussion

Simulation has been carried out for different topologies of WPAN. In this section various results have been presented and discussed to show the impact of different topologies on the performance factors of WSN monitoring.

### A- Throughput (Case 1)

Throughput is the average number of bits or packets successfully transmitted from the source to the destination per second. The results of throughput when approaches a steady state is 0.132, 0.084 and 0.078 Mbits/sec for cluster-tree, mesh and star topologies respectively as shown in Fig.(4). The maximum throughput is achieved in cluster-tree topology, while the mesh topology has second highest throughput and the star topology has the lowest throughput. The reason for this is because cluster-tree topology is communicating on the basis of the PAN coordinators and ZRs which are more efficient as compared to the end devices are with in hierarchy order arrangement for transmitting sensed data.

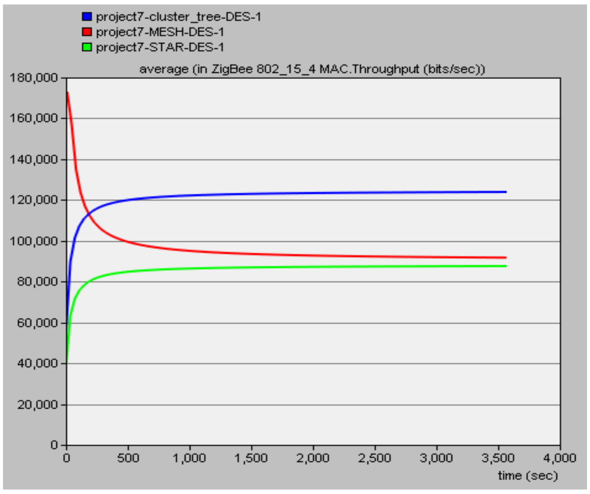


***Fig.(4) Throughput case(1).***

## B- Data Traffic Sent (Case 1)

Data traffic sent is the total number of data bits sent by the source to the destination per unit time irrespective of the condition whether all of the data bits reach the destination or not. Fig. (5) shows that data traffic sent is 0.149, 0.096 and 0.095 Mbits/ sec for cluster-tree, mesh and star topologies respectively. It indicates the maximum data traffic sent is more in case of cluster topology because cluster topology makes use of coordinator and routers for communication; these FFDs are responsible for traffic generation and maintaining routing tables in PAN coordinators. Also the lesser collision leads to the maximum data traffic in case of cluster topology.

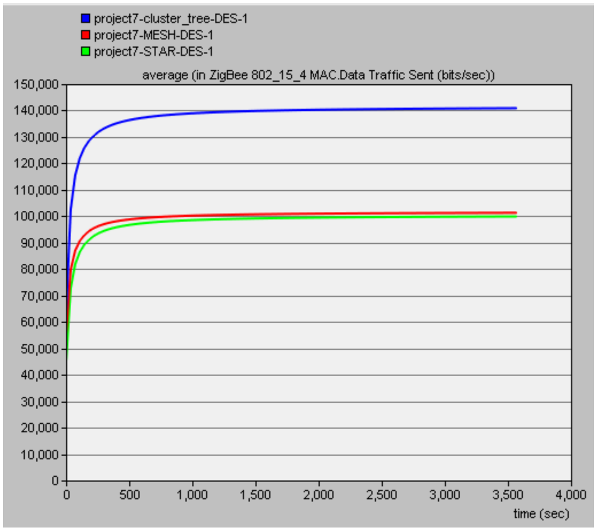


*Fig.(5) Data Traffic Sent (Case 1).*

## C- Data Traffic Received (Case 1)

Data traffic received is a number of bits of the data received per unit time. Fig. (6) shows that data traffic received is 5.944, 3.870 and 3.810 Mbits/ sec for cluster-tree, mesh and star topologies respectively. It indicates that the traffic received is maximum in the case of cluster topology because all end devices are communicating through PAN coordinates or Routers (FFDs) and these devices are responsible for traffic generation and routing. Also the less the collision, lower packet loss leads to maximum data traffic in case of cluster topology. Also it has been observed that received data traffic is minimum in case of star topology because this topology uses the end devices (RFDs) that need to communicate through the PAN coordinator which increases data traffic between devices and PAN coordinator and causes more collision and packet loss and reduces the received data traffic.

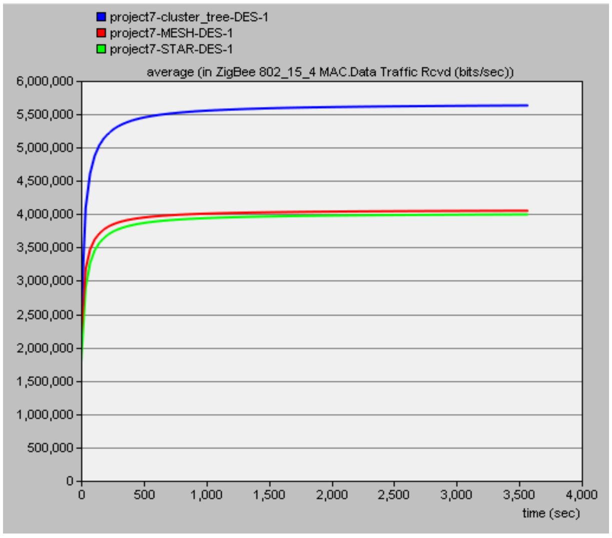


*Fig.(6) Data Traffic Received (Case 1).*

## A- Throughput of Star (Case 2)

Fig. (7) shows that throughput is (0.078) and (0.755) Mbits/ sec for fixed-star and mobile-star topologies respectively. These results show that mobile-star has a highest throughput results than fixed- star because the mobility expanded the communication range and if the mobile end device moves out of range, it resumes again to the same communication path with its parent (ZC). This moving capability will ease the sensing of the data and their transmission.

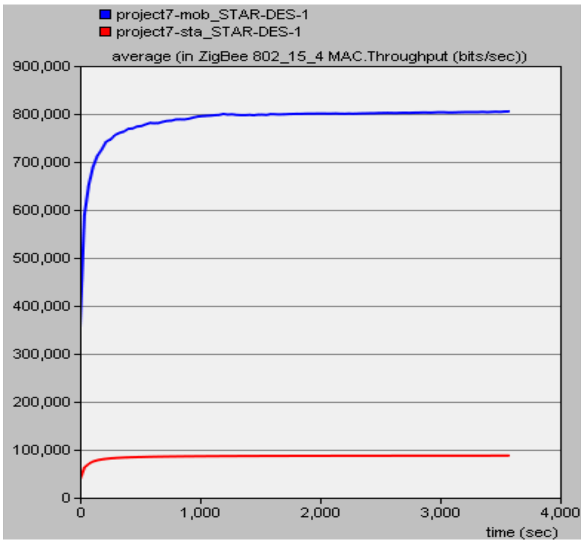


*Fig.(7) Throughput of Star (Case 2).*

### B- Delay of Star (Case 2)

Fig.(8) shows that delay is (13.2) and (82.5) m sec for fixed-star and mobile-star topologies respectively. These results show that mobile-star has a highest delay.

In fact, when the mobile end device moves out of range of its parent, it acquires a new network address from a new parent. In star topology there is only one parent represented by ZC so that this mobility end device causes some delay.

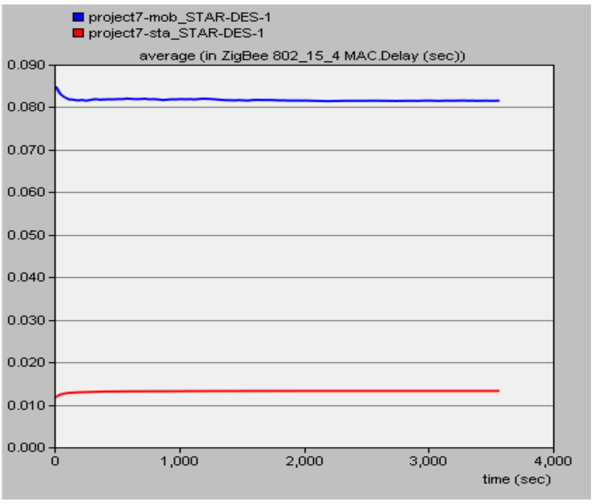


*Fig.(8) Delay of Star (Case 2).*

### A- Throughput of Mesh (Case 2)

Fig.(9) shows that throughput is (0.084) and (0.191) Mbits/ sec for fixed-mesh and mobile-mesh topologies respectively. These results show that mobile-mesh has a highest throughput results. ZRs actively participate in mesh routing and provide functionalities that maintain/repair routes whenever an existing route failed. With the built-in route recovery mechanism (via route discovery and route error), ZRs remain robust to effects from most mobility cases regardless whether the node is sending or receiving data so throughput will be kept in high rate.

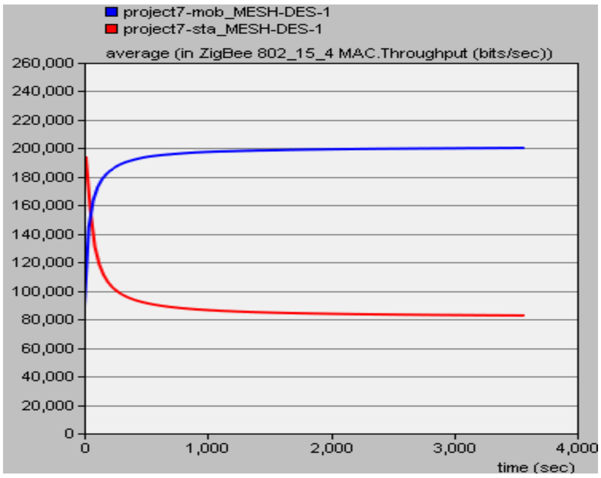


*Fig.(9) Throughput of Mesh (Case 2).*

### B- Delay of Mesh (Case 2)

Fig.(10) shows that delay is 15.6 msec for fixed- mesh network whereas mobile-mesh has a highest delay where the delay is increasing by increasing the time. For the case where the mobile end node acquires a new network address while it is sending data, data transmission will be temporally disrupted for the duration it takes for the mobile ZED to find a new parent router to associate itself with. Also mobile ZRs actually incur more routing overhead compared to the end devices that cause higher delay.

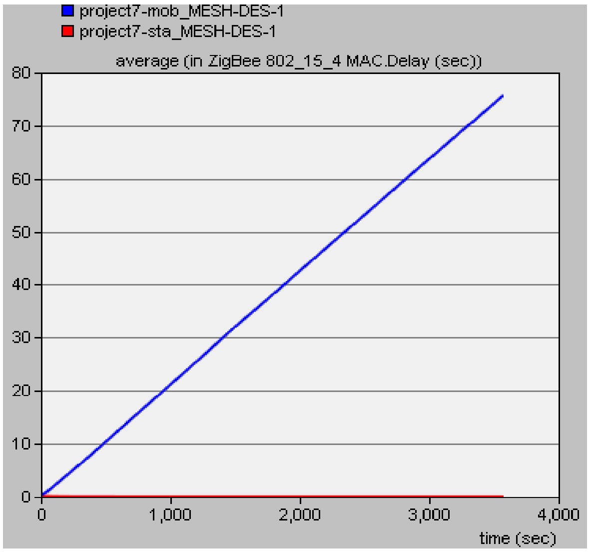


*Fig.(10) Delay of Mesh (Case 2).*

### A- Throughput of Cluster (Case 2)

Fig.(11) shows that throughput is (0.132) and (0.135) Mbits/ sec for fixed-cluster and mobile-cluster topologies respectively. These results show that mobile-cluster has a highest throughput results. Device type would remain indifferent when tree routing is deployed, since movement in cluster-tree topology would cause approximately the same amount of change regardless whether the node is a router or an end device.

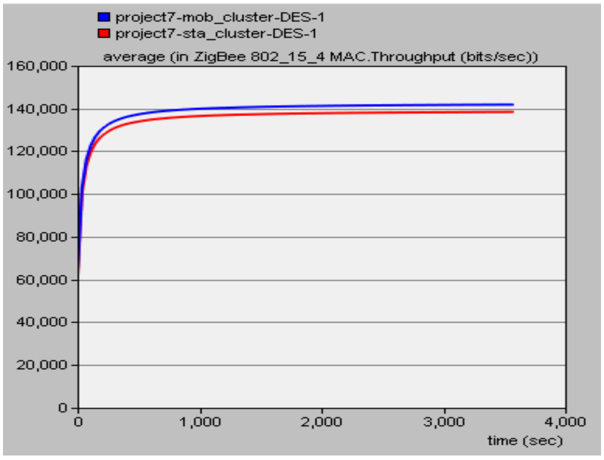


*Fig.(11) Throughput of Cluster (case 2).*

## B- Delay of Cluster (Case 2)

Fig.(12) shows that delay is (22.7) and (24.1) msec for fixed-cluster and mobile-cluster topologies respectively. The stability of the addressing structure is important for the proper delivery of packets. Therefore, when mobile ZR acquires a new parent router and a new network address, it could potentially start a cascading network address change to all of its descendant nodes on impacted branches, which generally creates varying levels of inconsistency to the cluster-tree addressing so that mobile-cluster has a highest delay.

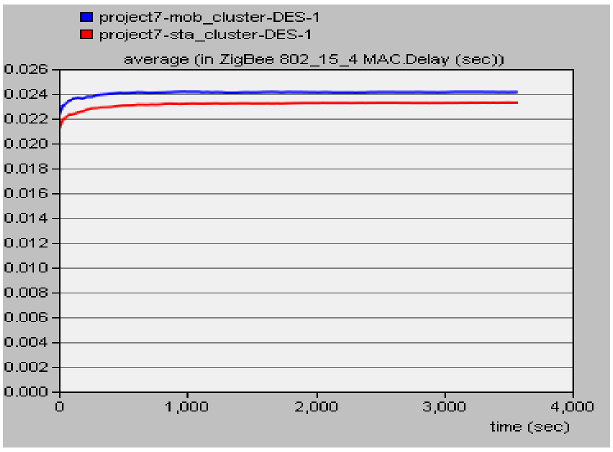


*Fig.(12) Delay of Cluster (case 2).*

## 5. Conclusions

In the light of the present study, the following points were concluded:

[1] In the first case, three ZigBee topologies (star, mesh and cluster-tree) have been considered using single ZC. The results showed that cluster-tree topology is more efficient and best suited compared with mesh and star topologies for IEEE 802.15.4/ ZigBee standard due to measured parameters (throughput, data traffic sent and data traffic received) that showed highest results for cluster-tree topology as well.

[2] In the second case, the results showed that mobile nodes in all topologies (star, mesh and cluster-tree) have highest throughput while mobile nodes have highest delay in star and mesh topologies due to changes in node's location, routing paths need to be updated periodically, thus possibly causing delays in packet delivery.

## 6. References

[1] Wuyi Y., Qingtian S. and Shunfu J., "Performance Analysis of Sensor Nodes in a WSN with Sleep/Wakeup Protocol", the Ninth International Symposium on Operations Research and Its Applications, pp. 370–377, August 19–23, 2010.

[2] Arturas L., "Opportunistic Routing in Multi-Sink Mobile Ad Hoc Wireless Sensor Networks", Master thesis, University of Bremen, September 2007.

[3] Zheng Y. Guan, "A Reliability Evaluation of Wireless Sensor Network Simulator: Simulation vs. Testbed", Master thesis, Department of Computer Engineering, UNITEC New Zealand, 2011.

[4] Kamaljit K. and Bhupinder S., "Wireless Sensor Network based: Design Principles & measuring performance of IDS", International Journal of Computer Applications, Vol. 1, No. 28, 2010.

[5] Arrian Prince-Pike, "Power Characterization of a ZigBee Wireless Network in a Real Time Monitoring Application", Master thesis, Department of Computer Engineering, Auckland Technology University, April 2009.

[6] Jamil Y., Mehmet R., and Farbood K., "Performance Evaluation of a Wireless

Body Area Sensor Network for Remote Patient Monitoring", 30th Annual International IEEE EMBS Conference, pp. 207-212, August 20-24, 2008.

[7] Hammoodi I. S., B. G. Stewart, A. Kocian and S. G. McMeekin, "A Comprehensive Performance Study of OPNET Modeler For ZigBee Wireless Sensor Networks", Third International Conference on Next Generation Mobile Applications, Services and Technologies, pp. 357-362, 15-18 September 2009.

[8] Ramyah S., "Load Density Analysis of Mobile ZigBee Coordinator in Hexagonal Configuration", Scientific Researches Conference, India, pp. 206-236, March 2012.

[9] Mayyada H. and Razan A., "Using OPNET to teach students computer networking subject", Tikrit Journal of Pure Science, Vol. 15, No. 1, 2010.

[10] Mompentzidou I., Computer Networks & Telematics Application lab, "Wireless Sensor Networks in environmental monitoring: existing application &basic guidelines", Master thesis, Macedonia University, January 2012.

**الخلاصة**

النمو السريع في مجال الاتصالات اللاسلكية والالكترونيات ساعد في تطوير شبكات الاستشعار اللاسلكية. لفهم ولتكوين القدرة على تنفيذ شبكات الاستشعار اللاسلكية العديد من المفاهيم الأساسية ضرورية مثل تشكيل وطريقة ربط الاجهزة (Topology Formation)، بروتوكولات شبكة الاتصالات والتواصل والتوجيه. تم في هذا البحث التحقق من كفاءة اداء شبكة الاستشعار باستخدام سيناريوهات ZigBee المختلفة. بعض التقنيات المفيدة لإدارة شبكات الاستشعار اللاسلكية تتضمن بروتوكولات الاتصال والتوجيه التي تكون ذات تأثير كبير على أي نظام مراقبة كان. تم اعتماد خوارزمية التوجيه AODV في هذا العمل. الشبكة العنقودية (Cluster-Tree)، الاتجاهات المتعددة (Mesh) والنجمية (Star) دُرِسَت في حالتين. الحالة الاولى تقارن شبكات ZigBee الثلاث. الحالة الثانية تقارن ثلاثة سيناريوهات لكل من طرق الربط الثلاثة في ZigBee، حيث ان كافة الأجهزة في السيناريو الاول هي ثابتة وكافة الأجهزة في السيناريو الثاني هي نقالة. هذه الحالات تمت محاكاتها عن طريق مراعاة التوصيات الخاصة لمعيار IEEE 802.15.4 /ZigBee وباستخدام برنامج محاكي الشبكاتOPNET Modeler 14.5.