IEEE 802.15.4 ZigBee-Based Wireless Sensor Network in Medical Application

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Abstract

As a new and promising technology, wireless sensor networks (WSN) plays an essential part in a large number of modern applications. Wireless Sensor Networks comprised of small, simple, and inexpensive wireless devices – the so-called sensor nodes. ZigBee technology provides the framework required to support wireless networks and fills the gap between the IEEE 802.11 WiFi and IEEE 802.15 Bluetooth standards in terms of transmission range and data rates. Generally ZigBee classified as a low-rate wireless personal area network (LR-WPAN) technology. This paper concerns with the use of WSN in one of many applications which it is patient monitoring. It performs patient monitoring system using ZigBee WSN. The modeled system consists of number of wards, each ward had number of sensors for each patient. Each sensor node represented with ZigBee end device that transmit the traffic to the master node which it is ZigBee coordinator. Then, The information can be accessed by the doctor by connecting the system through Ethernet LAN to the server. This simulation study was done using OPNET modeler V14.5. This paper study the performance of the modeled system in terms of delay, throughput, traffic received and other parameters that could be taken to study the performance of the modeled system if the number of patients was increased, the effect of increasing master nodes and the existence of router. The results showed that single coordinator (master node) system cause more delay, throughput than multiple coordinators system and the existence of router cause additional delay to the system. ZigBee based WSN for patient monitoring application resulted in online treatment, history as a database to lead the doctor in order to give proper instructions to the patient.

استخدام معايير IEEE 802.15.4 وتكنلوجيا ZigBee في شبكات المتحسسات اللاسلكية للتطبيقات الطبية

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الخلاصة

كتكنولوجيا جديدة وواعدة، شبكات الاستشعار اللاسلكية (WSN) تلعب دوراً أساسيا في عدد كبير من التطبيقات الحديثة. شبكات الاستشعار لاسلكية تتكون من أجهزة لاسلكية صغيرة وبسيطة وغير مكلفة– ما يسمى عقد الاستشعار. ان تكنولوجيا ZigBee يوفر الإطار اللازم لدعم الشبكات اللاسلكية ويسد الفجوة بين IEEE 802.11 ومعايير IEEE 802.15 البلوتوث من حيث نطاق الارسال و معدلات نقل البيانات. عموما تصنف الZigBee كشبكة اتصال شخصية لاسلكية منخفضة المعدل (LR-WPAN). هذا البحث يتعلق باستخدام شبكة الاستشعار اللاسلكية WSN في واحدة من العديد من التطبيقات التي هي مراقبة المرضى. انها تمثل نظام مراقبة المرضى باستخدام شبكة الاستشعار اللاسلكية المبنية باستخدام تكنولوجيا الZigBee. يتكون النظام من عدد من الأجنحة، كل جناح يتكون من عدد من أجهزة استشعار لكل مريض.

كل عقده استشعار تتمثل بـZigBee end device الذي يرسل المرور الى العقدة الرئيسية الذي تتمثل بمنسق ZigBee. لاحقا يمكن الوصول إلى المعلومات من الطبيب عن طريق ربط النظام بواسطة Ethernet LAN إلى الخادم. وأجريت دراسة محاكاة هذا النظام استخدام OPNET modeler V14.5. هذا البحث درس أداء النظام النموذج من حيث التأخير وسرعة النقل وحركة المرور الواردة والمعلومات الأخرى التي يمكن اتخاذها من أجل دراسة أداء النظام النموذج في حالة إذا زاد عدد المرضى وأثر زيادة العقد الرئيسية ووجود الراوتر. النتائج اظهرت ان النظام مع عقدة رئيسية واحدة يسبب تاخير اضافي ونقل بيانات اكثر من النظام المتعدد العقد الرئيسة (منسق الزيجبي) ZigBee . ان شبكات الاستشعار اللاسلكية المبنية باستخدام الزيجبي في تطبيقات مراقبة المرضى تنتج عن معالجة مفتوحة وتاريخ يعتبر كقاعدة بيانات تقود الطبيب حتى يعطي الوصفات الصحيحة للمريض.

1- Introduction

As a new and promising technology, wireless sensor networks (WSN) plays an essential part in a large number of modern applications, such as the intelligent surveillance, smart office, scientific exploration and so forth. Thus the standard of IEEE 802.15.4 is proposed for WSN and the corresponding Zigbee products have been produced [1]. Wireless Sensor Networks are best described as ad-hoc, multi-hop networks comprised of small, simple, and inexpensive wireless devices – the so-called sensor nodes. The nodes are responsible for sensing an environment and reporting their results to a central processing unit commonly referred to as sink. Due to their small size, sensor nodes are constrained in processing speed, memory, and most importantly, energy. ZigBee technology provides the framework required to support ad-hoc multi-hop wireless networks and fills the gap between the IEEE 802.11 4 WiFi and IEEE 802.15 Bluetooth standards in terms of transmission range and data rates. Generally classified as a low-rate wireless personal area network (LR-WPAN) technology, ZigBee is one of the most promising and prevalent WSN standards in use today. Built on top of the IEEE 802.15.4 standard, ZigBee is designed with low-cost, low-power, low-complexity, flexible routing, robustness to failures, and network scalability in mind. With all of these requirements satisfied, ZigBee technology is meant to lead the world closer to the ultimate dream of ubiquitous and autonomous computing [2]. The IEEE 802.15.4 / ZigBee suite of standards is commonly recognized as the technology of choice for applications involving sensor networks, due to their ability to ensure reliable, low-power and cost-effective communication. While the general performance of the IEEE 802.15.4 / ZigBee standards has been well researched in the past, there are just a handful of studies on the use of mobile sinks in IEEE 802.15.4/ ZigBee-based WSNs [3]. In this paper, WSN in medical application is studied using OPNET modeler (V14.5) based on ZigBee IEEE 802.15.4 to show the performance of system in one of the important applications of WSN when the number of patients was increased.

2- Sensor Network

A sensor network is an infrastructure comprised of sensing (measuring), computing, and communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment. The administrator typically is a civil, governmental, commercial, or industrial entity. The environment can be the physical world, a biological system, or an information technology (IT) framework. There are four basic components in a sensor network: (1) an assembly of distributed or localized sensors; (2) an interconnecting network (usually, but not always, wireless-based); (3) a central point of information clustering; and (4) a set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining [4].

3- Wireless Sensor Network

A Wireless Sensor Network (WSN) can be defined as a group of independent nodes, communicating wirelessly over limited frequency and bandwidth. The novelty of WSNs in comparison to traditional sensor networks is that they depend on dense deployment and coordination to execute their tasks successfully. This method of distributed sensing allows for closer placement to the phenomena to be achieved, when the exact location of a particular event is unknown, than is possible using a single sensor. Battery powered nodes are a common feature of many WSN applications, where recharging or replacement would not normally be feasible, and so are considered to be disposable. Many methods of powering these devices have been explored, including solar power, but they remain to be seen typically as "one-use" devices. Eventual failure is expected and so maximizing their lifetime and productivity is extremely important. This notion of battery conservation extends to the primitives used to enforce security in WSNs. Security protocols strive to be light-weight, in terms of code size and processing requirements, whilst retaining their usefulness, in order to assist in achieving this goal [5].

4- WSN In Medical Application

The intervention of WSN in human life starts when Defense Advanced Research Agency (DAPRA) implemented this technology to achieve defense related objectives. Since then it has revolutionized human life and currently it existence can be sensed in every field of life. The continual efforts of researchers to boost the Micro Electro Mechanical Systems (MEMS) and communication technologies make it possible to make economical sensor nodes with reduced size and increased intelligence. A wide range of wireless sensor network applications can be found for monitoring hostile environments such as wild forests, in household items to make living easy and in industries to obtain high quality management [6]. Applications of wireless sensor networks focused on monitoring the health status of patients have been in demand and various projects are in the development and implementation stages. Sensor networks are being researched and deployed in wide range of applications in healthcare. Typical application scenarios could be monitoring of heart beats, body temperature, body positions, location of the person, overall monitoring of ill patients in the hospital and at home and so on [7].

5- Wireless Body Area Network

Wireless Body Area Network (WBAN) is a special purpose sensor network designed to operate autonomously to connect various medical sensors and appliances, located inside and outside of a human body. The main advantages of WBAN are that it provides portable applications that can move along with the patient. The wireless sensors are either implanted into the patient body or attached to them as un-obstructive wearables. Various sensors are designed to detect medical signals such as ECG, PPG, EEG, pulse rate, blood flow, pressure and temperature. This technology has improved the quality of patients' lives by not restricting them to stay in hospitals.

The WBAN is capable to connect to communication network and transmit data. The sensors communicate with a local control devices which are either on patient body or at accessible distance. The local control devices then communicate with remote destination to exchange data for diagnostic and therapeutic purposes. In emergency case, such as abnormal readings received by ECG for example, an alert is sent to the caring group of people. An appropriate action is then taken according to the severity of the alert. It reduces costs and avoids regular visits to the hospital. The memory aid services helps in restoring the lost independence [6].

In a WBAN scenario, where a person wears various devices, a centralized control device for data transmission could be used from in and out of the network. This device can also act as the gateway between the internal network and outside world communication. Security measures such as authentication, firewalls and other checks can be applied at the controller level to monitor the traffic as shown in Fig.1 [7].

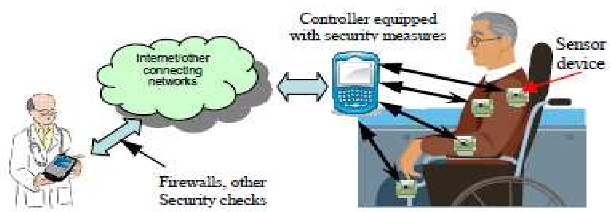

Figure 1- Security Measures At Controller/Gateway In Wireless Body Area Networks [7].

6- WSN Architecture

In a typical WSN, the following network components was considered [8]:–

- Sensor motes (Field devices) – Field devices are mounted in the process and must be capable of routing packets on behalf of other devices. In most cases they characterize or control the process or process equipment.
- Network manager – A Network Manager is responsible for configuration of the network, scheduling communication between devices (i.e., configuring super frames), management of the routing tables and monitoring and reporting the health of the network.
- Security manager – The Security Manager is responsible for the generation, storage, and management of keys.

7- ZigBee and IEEE 802.15.4

The Zigbee/IEEE 802.15.4 protocol is considered the newly introduced WPAN standard which was approved and published in 2003. It defines the characteristics of the physical layer (PHY) and the Medium Access Control (MAC) layer [9]. The IEEE 802.15.4 standard (which describes the PHY Layer and MAC) and ZigBee jointly specify a protocol stack for the development of short-range and low power communications for Wireless Personal Area Networks (WPANs). This stack is aimed at providing networking architectures for low-cost wireless embedded devices with consumption and bandwidth limitations. [10].

7-1 IEEE 802.15.4

IEEE 802.15.4 [11] is a simple packet data protocol designed for lightweight wireless networks. This standard was not developed specially for Wireless Sensor Networks (WSN), but still can be used with WSNs because the main requirements are related. Low power consumption, low cost, low data rate are typical requirements for WSNs. The IEEE 802.15.4 protocol describes physical and Medium Access Control (MAC) layers. The IEEE 802.15.4 standard's main advantages are long battery life, selectable latency for controllers, sensors, remote monitoring and portable electronics. Configured for maximum battery life, it has the potential to last as long as the shelf life of most batteries. This is very important if a large number of node devices is used, where a frequent changing and recharging of batteries is impractical. Depending on the power consumption allowance, a transmission range can reach from 30 up to 100 meters and even more [12].

7-2 ZigBee

The ZigBee [13] technology has recently become one of important and significant options for Wireless Sensor Network (WSN), since it possesses many advantages such as low power consumption, low data rate, low cost and short-time delay characteristics [14]. ZigBee is a technology based on a standard (IEEE 802.15.4) that defines a set of communication protocols for small coverage, low data rate wireless networks. The transfer rate can reach a maximum of 250 kbit/s in the case of the 2.4 GHz frequency band. This transfer rate is quite small when compared with the 1 Mbps that Bluetooth can reach or the 54 Mbps that WiFi can reach. In order to maximize battery life in many ZigBee applications, transceivers are active only for a short period and for the remaining time, they enter a low energy state (sleep). Because of this it is possible for ZigBee wireless nodes to be active for up to several years without maintenance and that is why this technology is preferred in many sensor networks [15]. ZigBee Specification defines a network layer, application framework as well as security services. Since ZigBee devices are designed for low cost and low data rates, it is expected their use in home and building automation with significantly small costs. Moreover, ZigBee networks support star and mesh topology, self-forming and self-healing as well as more than 65000 address spaces; thus, network can be easily extended in terms of size and coverage area [16].

ZigBee can operate in the following frequency bands:

- 868-868.6 MHz (the 868 MHz frequency band) ~
- 902-928 MHz (the 915 MHz frequency band)
- 2400-2483.5 MHz (the 2.4 GHz frequency band)

The 868 MHz frequency band is used mainly in Europe for wireless networks with low coverage radius. The 915 MHz and the 2.4 GHz bands are part of the so called industrial, scientific and medical frequency bands (ISM). The 915 MHz band is used mainly in North America while the 2.4 GHz is used worldwide [15].

The Zigbee standard defines two types of devices, a full-function device (FFD) and a reduced function device (RFD). The FFD can operate in three different modes: a personal area network (PAN) coordinator, a coordinator, or a device. The RFD is intended for very simple applications that do not require the transfer of large amounts of data and need minimal resources. A WPAN is formed when at least two devices are communicating with one device acting as an FFD assuming the role of a coordinator [9].

8- Simulation Tools

A survey on WSN simulators find 40 active simulators in this area. They operate in different levels of simulating: hardware emulation, operating system and application level. The supported hardware platforms are mainly TmoteSky, MSB (Modular Sensor Board), MICA, MICA2,

MICAZ and etc. Operating system is mostly either Contiki or TinyOS therefore the programming language for sensor nodes is

Contiki C or NesC respectively. Application-level programs are usually written in C++, Java or Python. NS2: a general purpose popular simulator and OPNET: a general-purpose simulator with WSN support [17].
After evaluating WSN simulators, OPNET simulation tool was selected for simulating WSN. OPNET supports practically all physical radios, it's modulations and therefore, it is quite easy to implement custom PHY layer for wireless communications. Among other models OPNET supports ZigBee and all three types of devices (RFD, FFD and Coordinator). For PHY and MAC layer there is source code available but for the network and application layer there is only an object code available [18].

9- OPNET (Optimized Network Engineering Tools)

OPNET [19] is a general-purpose application-level network simulator. It uses a hierarchical model to define each aspect of the system. The top level consists of the network model, where topology is designed. The next level is the node level, where data flow models are defined. A third level is the process editor, which handles control flow models. Finally, a parameter editor is included to support the three higher levels. Unlike Network Simulator 2 (NS2), OPNET supports modeling of different sensor-specific hardware, such as physical-link transceivers and antennas. It can also be used to define custom packet formats. The simulator aids users in developing the various models through a graphical interface. The interface can also be used to model, graph, and animate the resulting output [17]. The source code is based on C/C++. The analysis of simulated data is supported by a variety of built-in functions. Different graphical presentations for the simulation results are available and node mobility can be easily implemented in different kinds of nodes i.e. ZigBee coordinator, end device and router nodes [20].
The OPNET ZigBee model uses four process models:

- ZigBee MAC model which implements a model of the IEEE 802.15.4 MAC protocol. The model implements channel scanning, joining and failure/recovery process of the protocol in the unslotted operation mode.
- ZigBee Application model which represents a low fidelity version of the ZigBee Application Layer as specified in the ZigBee Specification. The process model initiates network joins and formations, generates and receives traffic and generates different simulation reports ZigBee Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) model which implements the media access protocol of the MAC layer.
- ZigBee Network model which implements the ZigBee Network Layer as specified in the ZigBee specification. This model is responsible for routing traffic, process network join, formation requests and generating beacons [20].

In medical system, there were number of sensors for each patient which transmit the data from the patients to node which located as a master node that can be connected to access point to Local Area Network or Wifi to Ethernet server for monitoring [21].

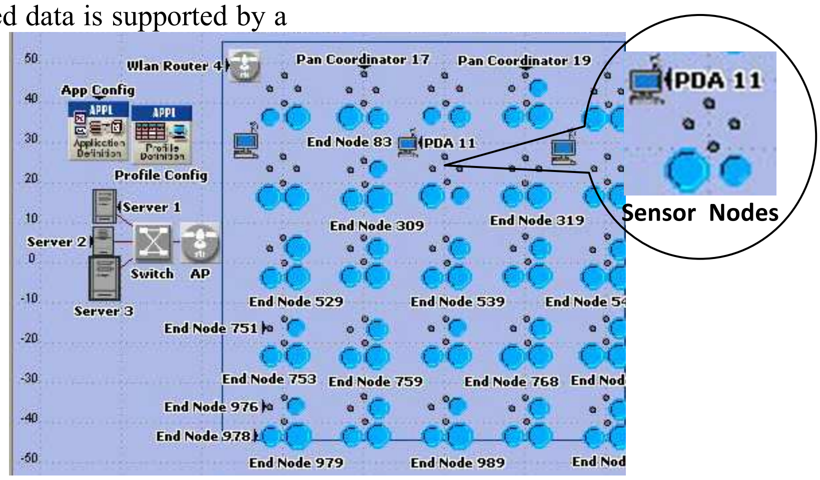

Figure 2- Sensor Nodes Connected To Access Point (AP) To Switc To Server For Monitoring [21]

In the modeled system, the sensors nodes were represented by ZigBee end device, and the master node was represented by ZigBee coordinator. The network simulation was done using OPNET Modeler V14.5 as a most powerful simulation tool for WSN. There were five sensors for each patient. Different scenarios were taken to study the performance of system in terms of delay, throughput and other parameters for single coordinator with increasing number of patients and multiple coordinators with increasing number of patients.

10- Simulation Design:

Scenario 1:

In this scenario, there was one patient in the ward with five sensors to measure the blood pressure for example. Each sensor represented by ZigBee end device and the master node was represented by ZigBee coordinator. The traffic would sent from the sensors (end devices) to the master node (coordinator). This scenario was shown in Fig. (3).

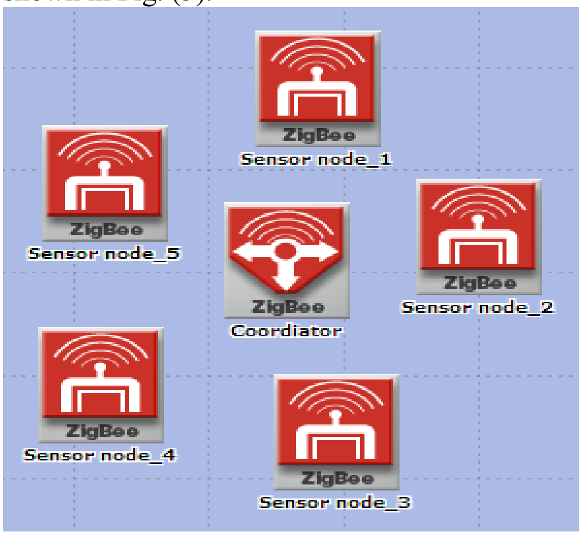

Figure 3-

Scenario 2

In this scenario, the number of patient was increased to two with five sensors for each patient. This result in ten sensors as shown in Fig.(4). Also the traffic sent from each sensor node to the coordinator which considered to be the sensor node.

Figure 4-

Scenario 3:

In this scenario, the number of patients had been doubled to four which result in twenty sensors as shown in Fig.(5)

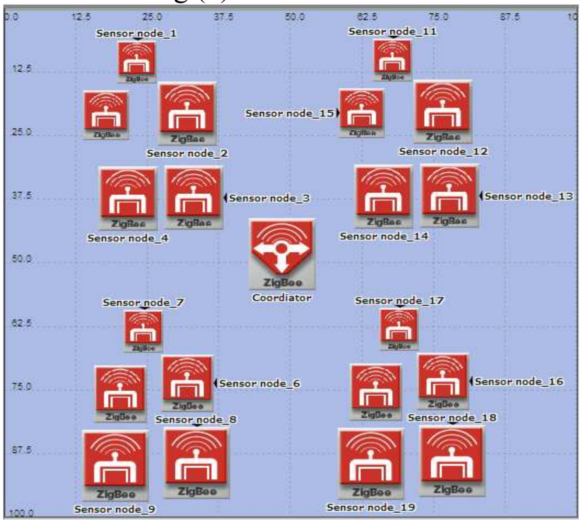

Figure 5-

Scenario 4:

In this scenario, the number of master nodes (coordinators) had been increased such that there will be one coordinator for each patient. In this scenario, two patients would be considered with five sensors for each and one master node (coordinator) for each patient as shown in Fig.(6)

Figure 6-

Scenario 5:

In this scenario, four patients would be considered with five sensors for each and one master node (coordinator) for each patient. This resulted in twenty sensors and four coordinators to receive data from the sensors of each patient as shown in Fig.(7)

Figure 7-

Scenario 6:
In this scenario, there would be a ZigBee router which receive traffic from the coordinators (master nodes) as shown in Fig.(8).

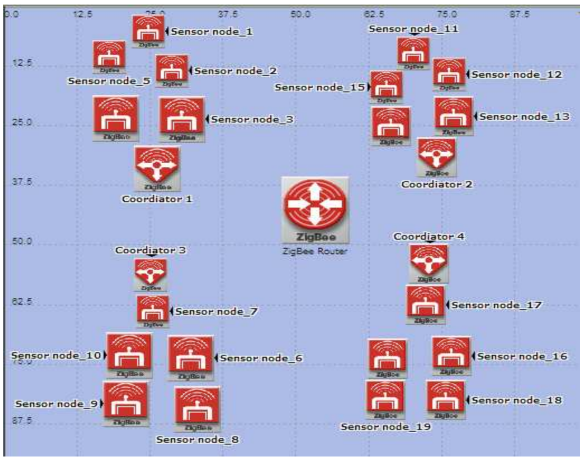

Figure 8-

This modeled system shown in Fig.(8) could be connected to access point to server through ZigBee/ Wifi gateway to be monitored by doctor for treatment.

Scenario 7:
In this scenario, there would ZigBee router for single coordinator system with 20 sensors (4 patients) as shown in Fig.(9)

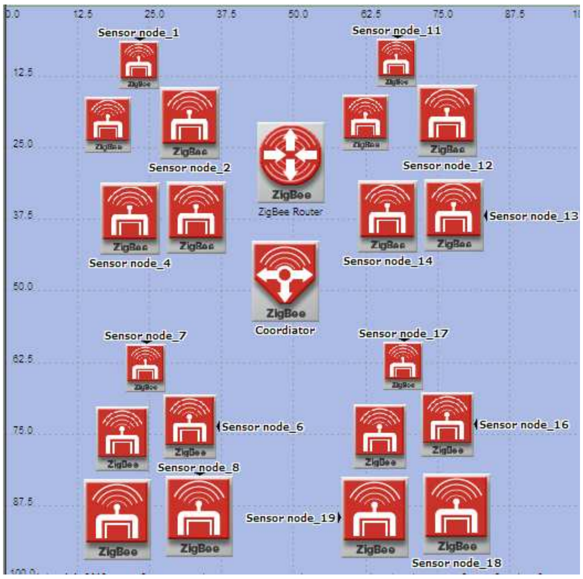

Figure 9-

11- Results

After configuring the scenarios in OPNET modeler, global statistics could be taken to study the performance of system in terms of many parameters. In this paper, throughput, media access delay and data traffic received were taken for comparison between the networks when the number of patients and sensors were increased with one coordinator (master node) . Then objective statistics were taken for ach coordinator to show the performance of system when the master nodes were increased. The objective statistics taken in this paper would be traffic received, load, and delay. The simulation was run for 1800 seconds to study the performance of system for many parameters. The results were collected as follows:

Result 1 (Single Coordinator):
Media Access Delay: The total of queuing and contention delays of the data frames transmitted by all 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. Media Access Delay for scenario 1, 2 and 3 is taken on the same graph for comparison when the number of patients was increased from 1 to 2 to 4 patients with number of sensors was increased from 5 to 10 to 20 sensors as shown in Fig.(10).

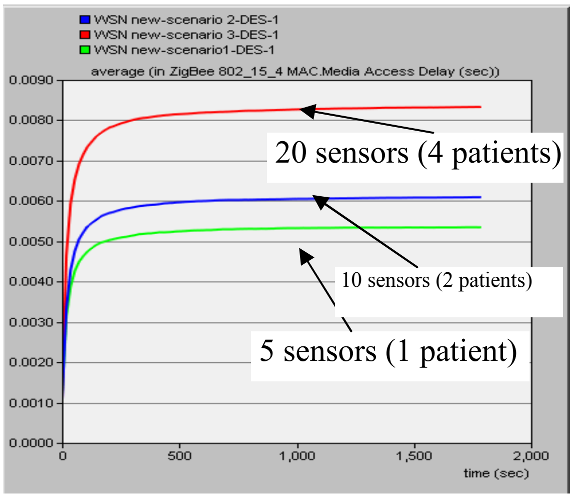

Figure 10-

Result 2 (Single Coordinator):
Data Traffic Received (bits/sec): Represents the total traffic successfully received by the MAC from the physical layer in bits/sec. This includes retransmissions. Data traffic received for scenario 1, 2 and 3 is taken on the same graph for comparison when the number of patients was increased from 1 to 2 to 4 patients with number of sensors was increased from 5 to 10 to 20 sensors as shown in Fig.(11)

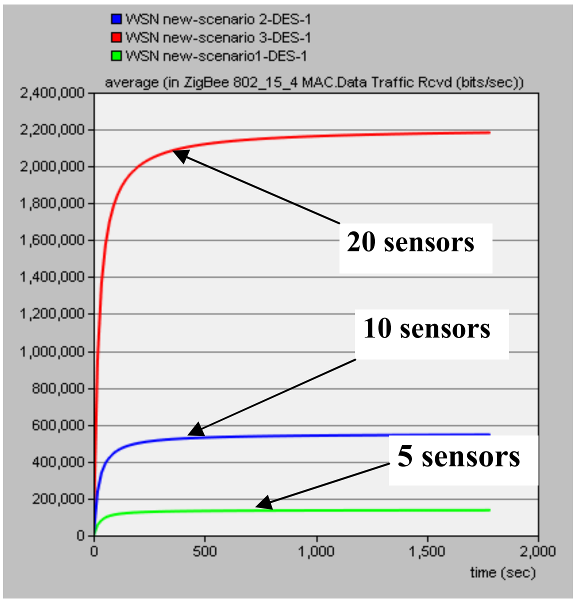

Figure 11-

Result 3 (Single Coordinator):
Throughput: Represents the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to higher layers in all WPAN nodes of the network. Throughput for scenario 1, 2 and 3 is taken on the same graph for comparison when the number of patients was increased from 1 to 2 to 4 patients with number of sensors was increased from 5 to 10 to 20 sensors as shown in Fig.(12)

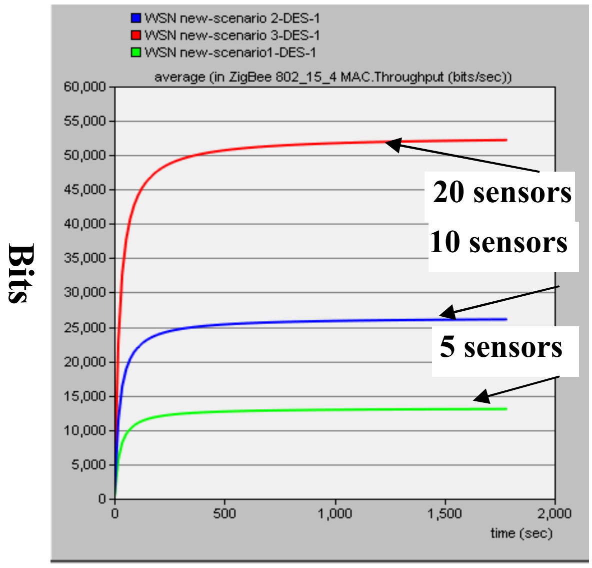

Figure 12-

Result 4 (Single coordinator):
Data Traffic Received on coordinator (master node) (bits/sec): the object statistic would be taken on coordinator which receive traffic from sensors when the number of sensors was 5, 10 and 20 as shown in Fig.(13)

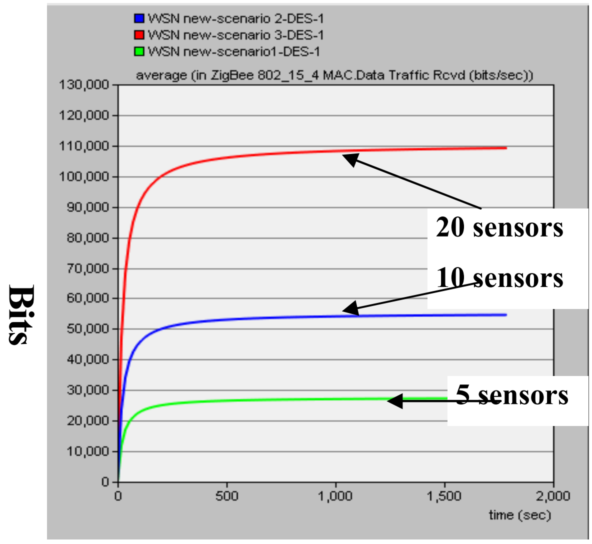

Figure 13-

After the study of the increasing number of patients with one master node (coordinator), then the following results shows the comparison if there would be one coordinator for all patients or one coordinator for each patient (Multiple coordinators).

Result 5:
Comparison between Scenario 2, Scenario 3, Scenario 4 and Scenario 5 showed the difference in delay and throughput between single coordinator system and multiple coordinator system for 10 sensors (2 patients) and 20 sensors (4 patients). As shown in Fig.(14) and Fig.(15)

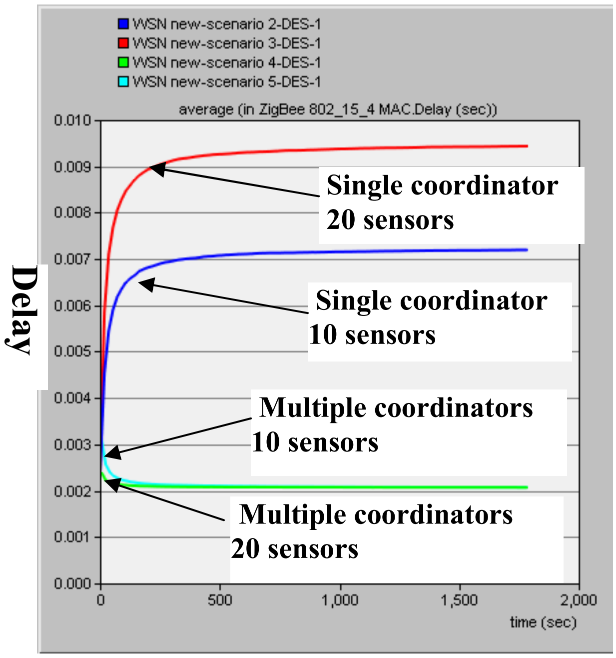

Figure 14- Delay

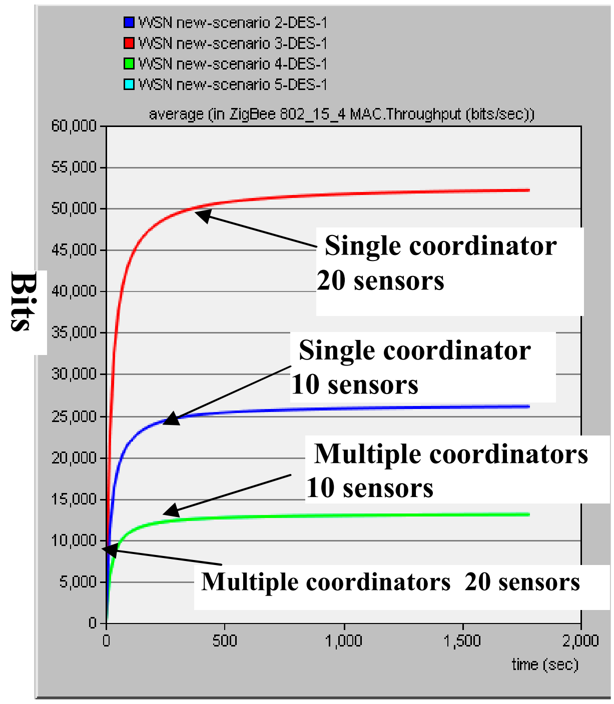

Figure 15- Throughput

The following results showed the difference in delay and throughput to study the effect of ZigBee router for single-coordinator system.

Result 6 (Single Coordinator with and without Router):
End to end delay of all the packets received by the 802.15.4 MACs and throughput (the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to higher layers in all WPAN nodes of the network for single coordinator - 20 sensors modeled system with ZigBee router and without ZigBee router shown in Fig.(16) and Fig.(17).

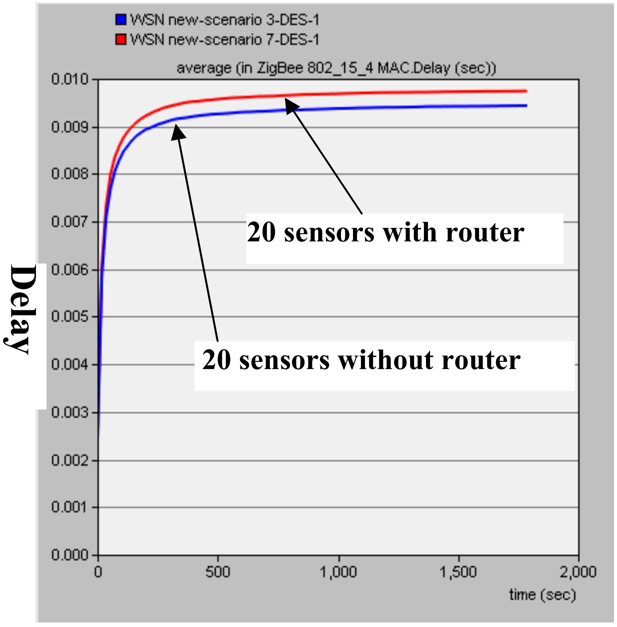

Figure 16- Delay

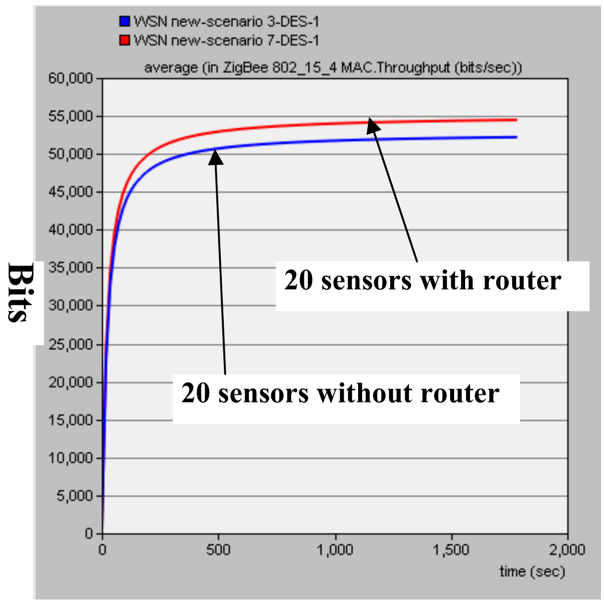

Figure 17- Throughput

Result 8 (Multiple Coordinators with and without Router):

End to end delay of all the packets received by the 802.15.4 MACs and throughput (the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to higher layers in all WPAN nodes of the network for multiple coordinators - 20 sensors modeled system with ZigBee router and without ZigBee router shown in Fig.(18) and Fig.(19).

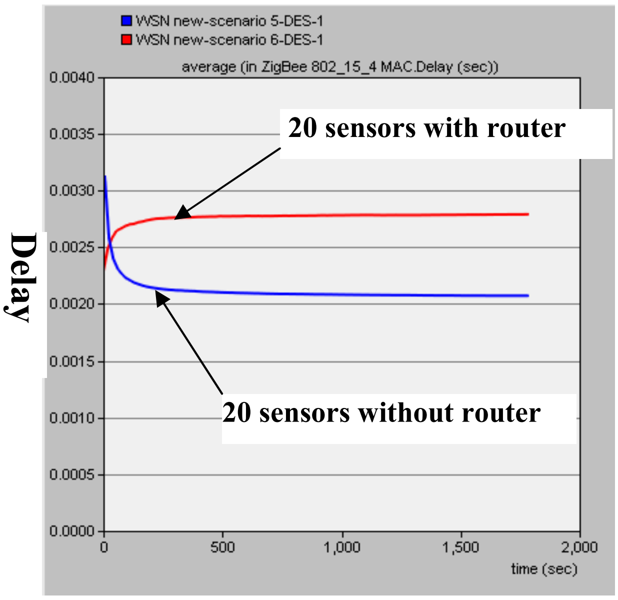

Figure 18- Delay

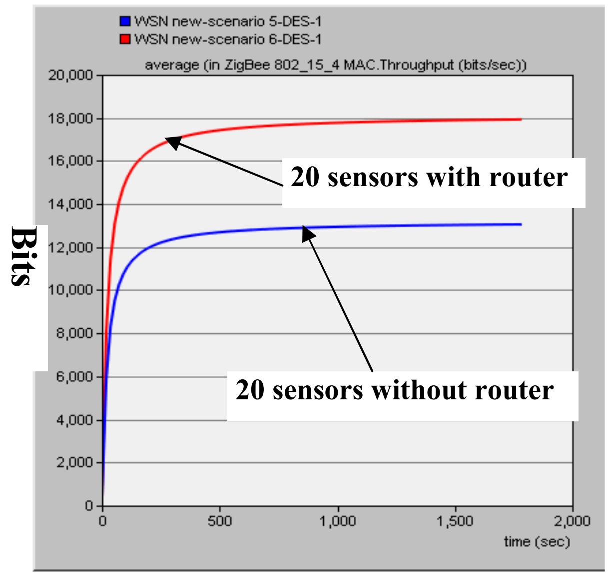

Figure 19- Throughput

12- Discussion and Conclusions:

1- In single coordinator system ,Media access delay was increased when the number of sensors was increased from 5, 10 to 20 sensors. At the beginning from 0 sec to 36 sec, the delay of system with 5 sensors and 10 sensors and 20 sensors are approximately equally. From this time, media access delay differs and increased as well as the number of sensors was increased. For 5 sensors, media access delay reaches 0.00534 at 1,76 seconds, for system with 10 sensors, media access delay reaches 0.006 at 1,76 seconds, for system with 20 sensors, media access delay reaches 0.0083 at 1,76 seconds. This difference in media access delay showed the increase in delay as the number of sensors was increased in single coordinator system.

2- In single coordinator system, Data traffic received was increased when the number of sensors was increased from 5, 10 to 20 sensors. When the number of sensors was five, data traffic received reaches average of 136,427 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to ten, data traffic received reaches 565,670 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to 20, data traffic received had been so increased which it reached 2,182,561 bits/sec at time = 1,764 seconds of the simulation.

3- In single coordinator system, throughput was increased when the number of sensors was increased from 5, 10 to 20 sensors. When the number of sensors was five, reaches average of 13,050 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to ten, throughput reaches 26,098 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to 20, throughput had been increased which it reached 52,194 bits/sec at time = 1,764 seconds of the simulation.

4- In single coordinator system ,all load would be received by the master node (coordinator), so that it was increased as the number of sensors was increased when the number of sensors was increased from 5, 10 to 20 sensors. When the number of sensors was five, data traffic received for the master node reaches average of 27,285 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to ten, data traffic received on the master node reaches 54,566 bits/sec at time = 1,764 seconds of the simulation. As the number of sensors was increased to 20, data traffic received on master node had been increased which it reached 109,127 bits/sec at time = 1,764 seconds of the simulation.

5- The delay comparison between single coordinator system and multiple coordinator system for 10 sensors and 20 sensors showed that the delay was very high in single coordinator system (for both 10 and 20 sensors) with respect to the delay for multiple coordinator system. The delay for multiple coordinator system (two coordinators in 10 sensors and four coordinators in 20 sensors) begins with slightly varying and then began to be approximately same from time equal to 198 seconds of the simulation and then they had same delay and reach average of (0.00207) at time = 1,764 seconds of the simulation.

6- The throughput comparison between single coordinator system and multiple coordinator system for 10 sensors and 20 sensors showed that the throughput was high in single coordinator system (for both 10 and 20 sensors) with respect to throughput for multiple coordinator system. The throughput for multiple coordinator system (two coordinators in 10 sensors and four coordinators in 20 sensors) had same throughput and reach average of (13,050.31) bits/sec at time = 1,764 seconds of the simulation.

7- As described above in 5 & 6, in multiple coordinator system , if the number of coordinators was increased then the delay would be approximately the same as the number of sensors was increased because each master node was receive traffic from the five sensors.

8- In multiple coordinator system , if the number of coordinators was increased then throughput would be the same as the number of sensors was increased because each master node was receive traffic from the five sensors.

9- Studying the effect of router in single coordinator system showed that:

a- existence of router caused additional delay. In single coordinator system without router, the delay reached average of 0.00943 at time=1,764 seconds of the simulation. In single coordinator system with router, the delay reached 0.00974 at time=1,764 seconds of the simulation.

b- Throughput in single coordinator system with router was higher than single coordinator system without router, throughput reached average of 52.194 at time=1,764 seconds of the simulation. In single coordinator system with router, throughput reached 54,462 at time=1,764 seconds of the simulation.

10- The effect of router In multiple coordinator system showed that:

a- In the system without router, the delay began higher than system with router and then it decreased to be smaller than delay in system with router which reached average of 0.002073 at time = 1,764 seconds of the simulation. The average delay in system with router reached 0.002790 at time = 1,764 seconds of the simulation. Existence of router caused very small additional delay.

b- Throughput in system with router was larger than throughput in system without router. In system with router, it reached average of (17,952) bits/sec at time = 1,764 seconds of the simulation while it reached (13,052) bits/sec at time = 1,764 seconds of the simulation.

11- As a result, multiple coordinator system was more suitable as the number of sensors was increased because the load would be on individual coordinators (master nodes) instead of a single coordinator which received all traffic from the sensor so it caused more delay but the increased number of coordinators requires additional hardware which result in additional cost

12- Router caused additional delay but it increased the number of bits transmitted per second.

13- In this paper delay and throughput were taken, additional parameters existed in OPNET V14.5 for studying such that (Control Traffic Received, Control Traffic sent, data dropped, load per coordinator, management traffic received, management traffic sent, retransmission attempts). Other object statistics could be taken for each node in the system.

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