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Performance Evaluation for Large Scale Star Topology IEEE 802.15.4 Based WSN

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Abstract**—** This paper evaluates the performance of IEEE 802.15.4 standard Wireless Sensor Network (WSN) in star topology for large scale applications. The OPNET simulator (version 14.5) is used to simulate and analyze the performance of the network in terms of the number of nodes, packet size and Packet Interval Time (PIT). Starting with a packet size of 1408 bit and PIT of 1s, network performance is evaluated for different number of nodes; and a comparison among different network performance parameters (number of nodes, packet size and PIT) is made in order to choose the best optimized network performances concerning throughput, end to end delay, and packet drop. Simulation results show that the best performance is obtained at 230 nodes number with a packet size of 2048 bits and PIT equals 2s.

Keywords**—** IEEE 802.15.4, OPNET, performance optimization, star topology, wireless sensor network.

I. INTRODUCTION

ZigBee is a home-area network designed specifically to replace the proliferation of individual remote controls. ZigBee has been created to satisfy the market need for a cost-efficient; and standard-based wireless sensor network that supports low data rates, low power consumption, security, and reliability [1]. There is a growing need for low data rate solutions which provide high reliability for activities such as control and monitoring applications. Furthermore, these applications often use simple devices that cannot handle complex protocols [2]. Applications such as building automation systems, logistics, environment or disaster monitoring, and pervasive database systems can be implemented above the sensor systems [3]. A number of communication protocols for wireless sensor networks exist; among those; ZigBee is the leading global standard for low-cost, short-range wireless networks with longer battery life [4].

A study of the performance using an OPNET simulator of an IEEE 802.15.4/ZigBee MAC based Wireless Body Area Network (WBAN) operating in different patient monitoring environments is presented in [5]. The study suggests using a star configuration WBAN for reliable data transmission, where all sensor nodes send data to the coordinator which, in turn, combines and transmits all sensor data. A novel analytical model of the IEEE 802.15.4 MAC protocol, considering a non beacon-enabled WSN (where a star topology is established), is provided in [6]. The results show how the distribution of traffic changes when different loads are offered; the model allows the evaluation of the optimum size which a packet should have in order to maximize the success probability of its transmission. In [7], an evaluation and comparison of IEEE 802.15.4 standard performance using OMNet++ simulator are performed. They focus on single sink scenario, in terms of data delivery rate, goodput, throughput and error rate metrics. In [8], IEEE 802.15.4 performance is analyzed for WBAN. The analysis focused on the long term power consumption of the sensors and presented a star network configuration for a body area network consisting of 10 body implanted sensors. The

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author in [9] presents mathematical performance analysis and simulations of IEEE 802.15.4 LR-WPAN in a large-scale WSN application with up to 1560 nodes. The network is formed in a beacon enabled cluster-tree topology. The device and coordinator performance is analyzed in terms of the average power consumption and throughput. In [10], a simulation of a large scale deployment for star, tree and mesh topologies using OPNET v14.5 simulator is presented. MAC throughput, end to end delay, number of hops and packet drop have been measured. The results show that the best throughput for star is at 210 nodes number, and mesh topology has the best network performance among star, tree and mesh topologies.

In comparison with the works mentioned above, most of them worked on small scale applications, focused on physical layer and power consumption and used beacon and non beacon mode as well as the best throughput in relation to the number of nodes. In this paper, the best performance of the IEEE 802.15.4 based WSN star topology is evaluated by changing a number of different parameters such as, the number of nodes, packet size and packet interval time. This is done by: first, increasing the number of nodes and choosing the best performance; second, increasing packet size for the best performance; third, changing packet interval time in order to reach the best performance at which the throughput is at its maximum value.

This paper is organized as follows: section 2 gives a brief overview about the IEEE 802.15.4; section 3 includes the modeled network parameter and the setting that are used in the simulator; in section 4, simulation results and performance curves are given; finally, conclusions are presented in section 5.

II. Brief Overview of IEEE 802.15.4

In IEEE 802.15.4 networks, a PAN coordinator is used to build the network in its operating space. This standard supports different topologies: star, tree and mesh. In the star topology, communication takes place between end devices and the coordinator; in mesh topology, it is possible for any device to communicate with any other device within its range; and in tree topology, most devices can establish communication with each other within the network [11]. Two channel access mechanisms can be identified by the standard. Slotted carrier sense multiple access mechanism with collision avoidance (CSMA-CA) can be used in the beacon-enabled mode; and the slot boundaries of each device are aligned with those of the coordinator. However, a simpler unslotted CSMA-CA is used when beacons are not available. The beacons are used to synchronize the attached devices, identify the PAN, and describe the structure of superframes. Superframes are bounded by network beacons and divided into 16 equally sized slots (Fig. 1). The beacon frame is sent to the first slot of each superframe. The superframe can have an active and inactive portion. During the inactive portion, the coordinator does not interact with its PAN and may enter a low-power mode. The active portion consists of a contention access period (CAP) and a contention free period (CFP). A device that wishes to communicate during the CAP competes with other devices using a slotted CSMA-CA mechanism. On the other hand, the CFP contains guaranteed time slots (GTSs). The GTSs appear at the end of the active portion that starts at a slot boundary immediately following the CAP. In the slotted CSMA-CA channel access mechanism, the backoff slot boundaries of every device in the PAN are aligned with the superframe slot boundaries of the PAN coordinator. Each time a device wishes to transmit data frames during the CAP, it must locate the boundary of the next slot period. Although (CSMA/CA) is an important mechanism for the channel access, it does not include the RTS/CTS handshake, because of the low data rate used in IEEE 802.15.4; transmission happens when the condition is suitable (no activities). Otherwise, algorithms will backoff for sometime before assessing the channel again [12].

There are three different frequency bands available in the Industrial Scientific Medical (ISM) bands [13]:

1) 1 channel in the 868 MHZ band with data rate of 40 Kbps.
2) 10 channel in the 915 MHZ band with data rate of 40 Kbps.
3) 16 channel in the 2.4 GHZ band with data rate of 250 Kbps.

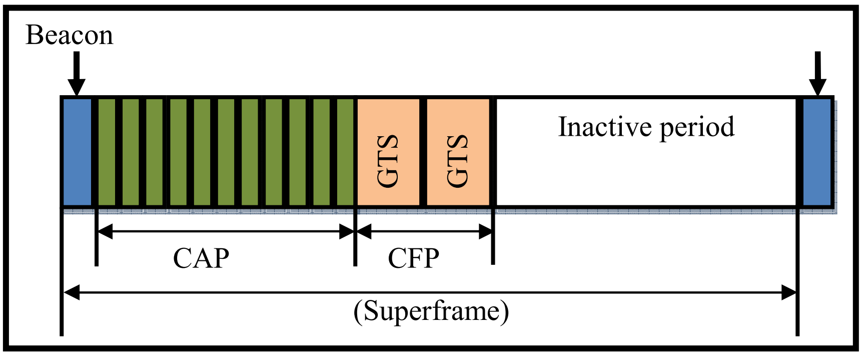

Fig. 1. Superframe structure in beacon enabled mode

III. NETWORKS MODELING

ZigBee Wireless module is used in our OPNET v14.5 to create a star topology WSN for testing and evaluating variations in the performance of network topology. The parameters that are used in the setting of the OPNET models (Fig. 2) are shown in Table 1 as follows:

TABLE 1
PARAMETERS SETTING

Parameters	Values
Payload (bits)	Variable (1024,1408,2048,3072,4096,8192)
Max. children	260
Max. depth	1
Mesh routing	Disabled
Packet Interval Time–PIT (s)	Variable (1 - 8)
Transmit Power (watt)	0.1
Channel Sensing duration (s)	0.2
Packets reception power threshold (dbm)	-90
Simulation time	10 minutes

Modeled networks are simulated according to the following assumptions:

1) All system nodes are distributed over 100X100 m^2 area.
2) ACK mechanism is not used.
3) Slotted CSMA/CA is not used.
4) All nodes are fixed.
5) Beacon-enabled mode is not used.
6) The addressing mechanism used in PANID is only 16 bit.
7) Destination is randomly chosen from their neighbors.

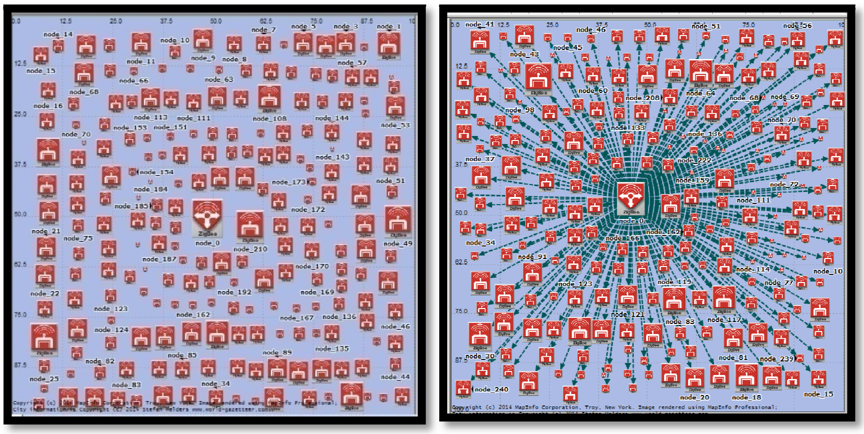

Fig. 2. Network models of 210 and 260 nodes

IV. Simulation Results and Analysis

The best performance of the IEEE 802.15.4 based WSN star topology is evaluated by changing a number of different performance parameters: number of nodes, packet size and PIT. At the beginning a packet size of 1408 bit with PIT of 1 sec is chosen; and the parameters are changed as follows:

A. Number of Nodes

Network performance is evaluated by changing the number of nodes from 30 to 260 nodes in order to obtain the best performance at which the global throughput is at maximum. The throughput increases by increasing the number of nodes up to 230 nodes; before it starts to decline by increasing the number of nodes up to 260 nodes, as shown in Fig. 3.

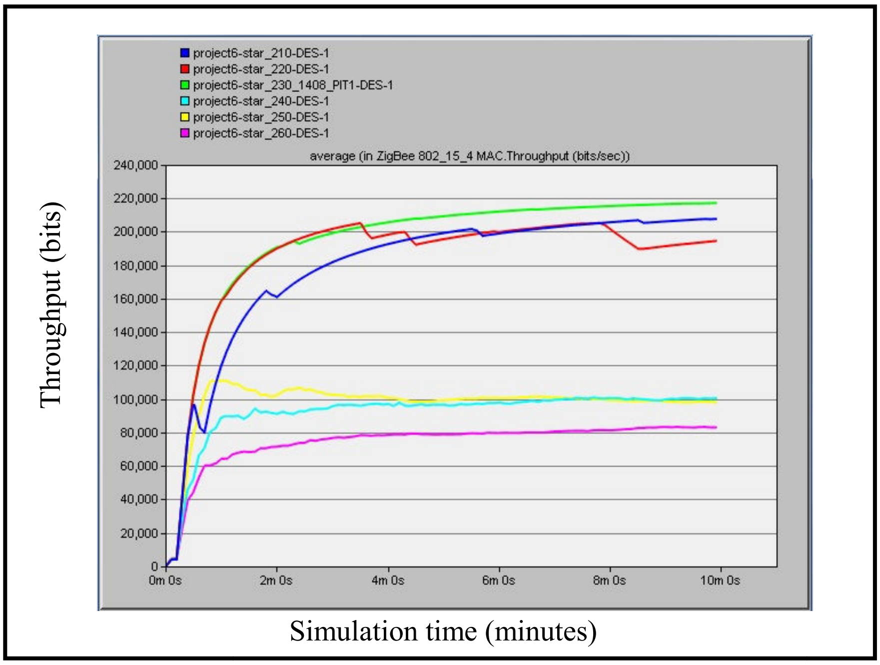

Fig. 3. Global throughput

The throughput curve in Fig. 3 shows that it is very stable at 230 nodes, while there is a sharp decline at 240-260 nodes due to an increased probability of packet collision by increasing the number of nodes. Consequently, the probability of packet drop increases as shown in Fig. 4, where there are 12, 60 and 138 packet losses in the cases of 240, 250 and 260 nodes respectively.

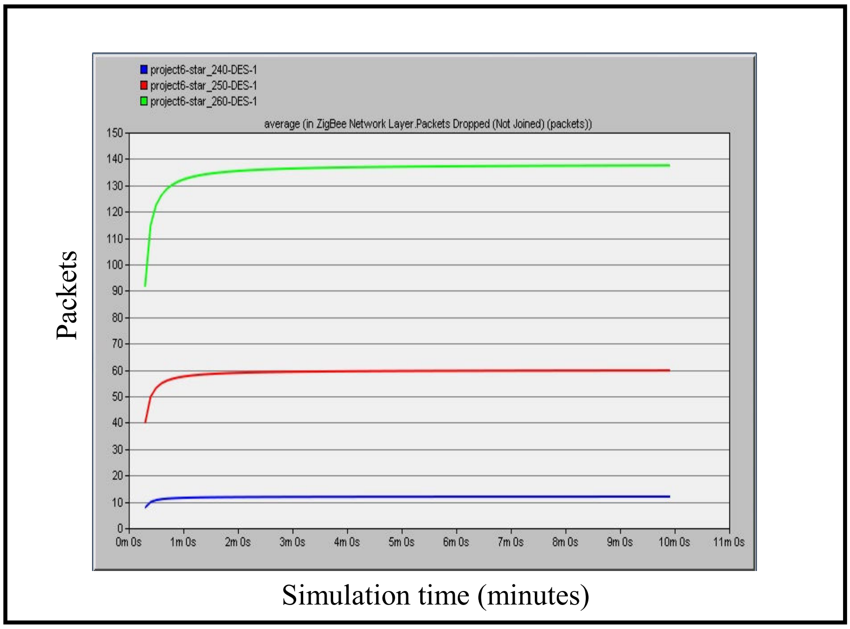

Fig. 4. Packet drop

Fig. 5 shows that the least average number of hops is at 230 nodes (about 1.4), which reflect the best throughput.

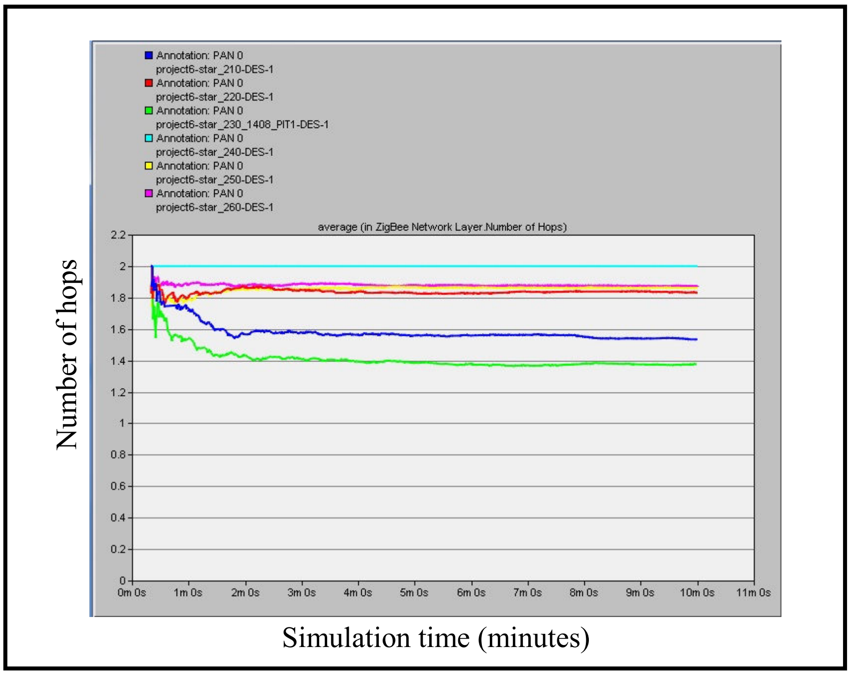

Fig. 5. Average number of hops

The least end to end delay is also at 230 nodes as shown in Fig. 6. For star topology (or single hop) network, this is true because when the delay decreases the throughput increases.

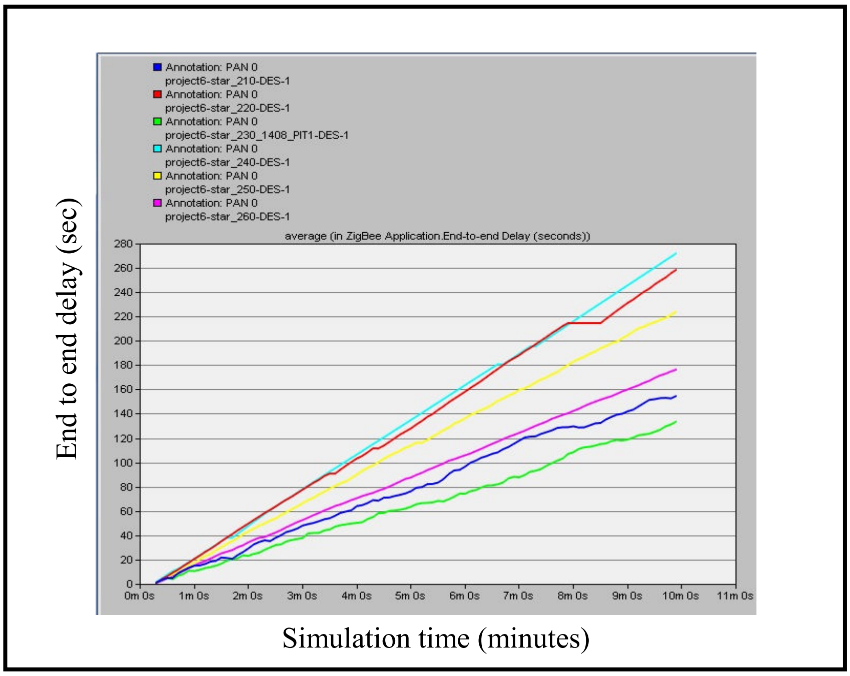

Fig. 6. End to end delay

B. Packet Size

To check how performance can be changed, the packet size of the best performance network (which is at 230 nodes) is changed to (1024, 1408, 2048 and 3072 bits) different sizes. Fig. 7 shows that there is a stable performance of network at a packet size of 1408 bits. Increasing packet size to 2048 bits shows initial improvement during the first three minutes (up to throughput value of ~212 Kbit/s). The throughput starts to decline gradually until it reaches the same value of throughput at packet size of 1408 bits, where it stabilizes at this value.

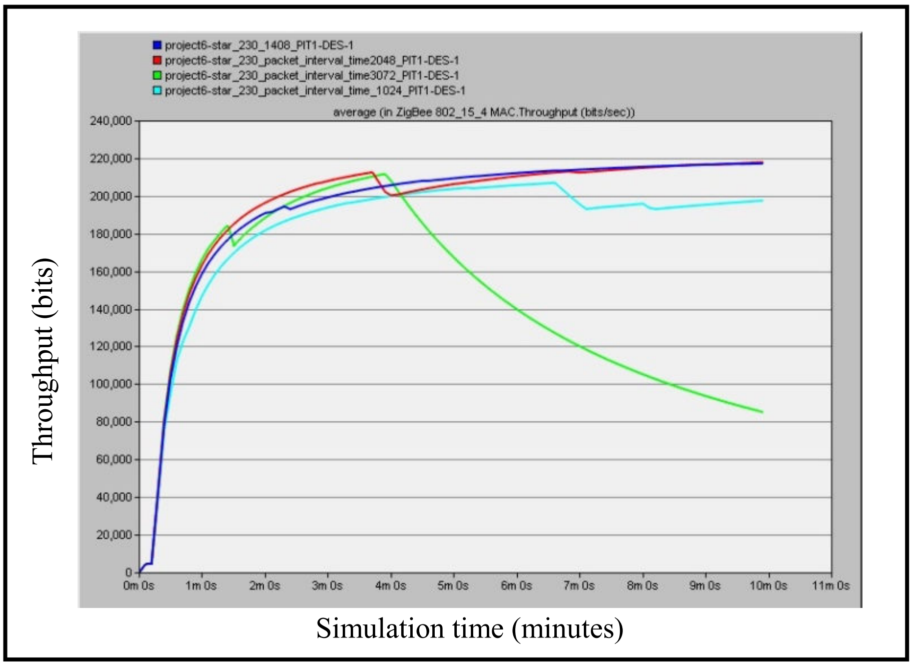

Fig. 7. Network throughput variations for different packet sizes

When the packet size is increased to 3072 bits, an improvement occurs during the first four minutes (up to throughput value of ~210 Kbit/s) but performance declines sharply after that.

Increasing packet size (> 1408 bits) improves in throughput up to the above mentioned levels. Soon after that, packet collision highly happens (which have higher effect than header lengths) and causes a sharp decline, which is quite obvious in the case of 3072 bits packet size. However, as the packet size decreases (< 1408 bits), the effect of the number of headers (PHY, MAC, etc. lengths) which starts to increase as well as the collision probability which starts to decrease causes the gradual degradation in the throughput performance.

C. Packet Interval Time

The PIT of each of the previous cases is changed in an attempt to improve network performance. Increasing PIT decreases the data rate as well as throughput. Fig. 8 illustrates that increasing PIT (1, 2, 3 and 5s) of the 1024 bits packet size decreases the throughput.

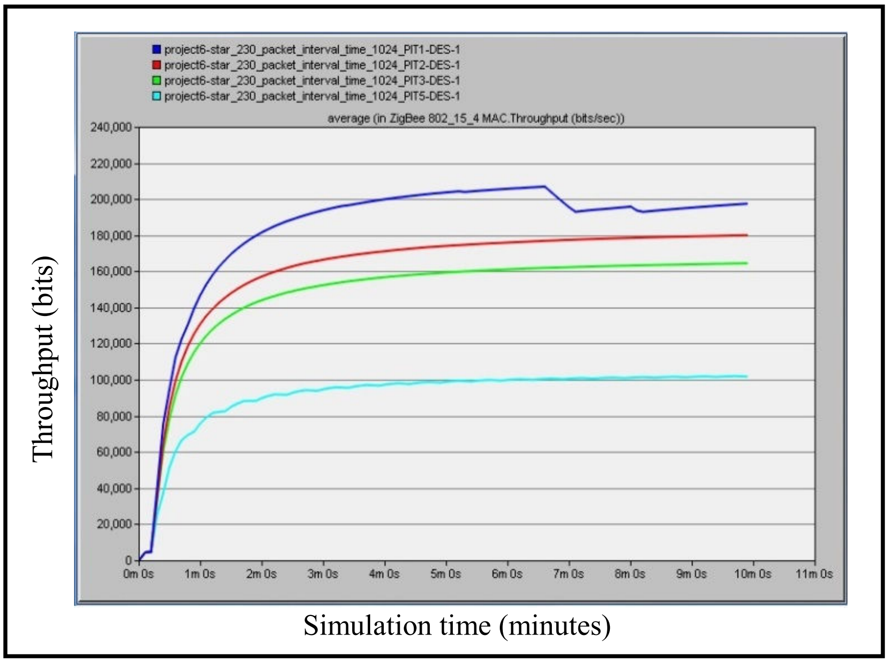

Fig. 8. Changing PIT at packet size of 1024 bits

The same procedure is repeated with packet sizes of 1408, 2048 and 3072 bits. The results are shown in Fig. 9, 10 and 11, respectively. It can be seen that the best throughput in Fig. 9 is when PIT equals 1, but in Fig. 10 the best result is when PIT equals 2; Fig. 11 shows a sharp decline in throughput when PIT equals 1. Moreover, when the PIT increases, performance improves to reach the best result at PIT equals 5.

Any further increase results in the decline of the throughput. Therefore, when the PIT increases, it can be concluded that the packet size should be increased in order to make an efficient use of the increased PIT and maintain the best throughput. Fig. 12 shows a comparison among the best network performances. It also shows that the best performance is at 230 nodes with a packet size of 2048 bits and PIT equals 2.

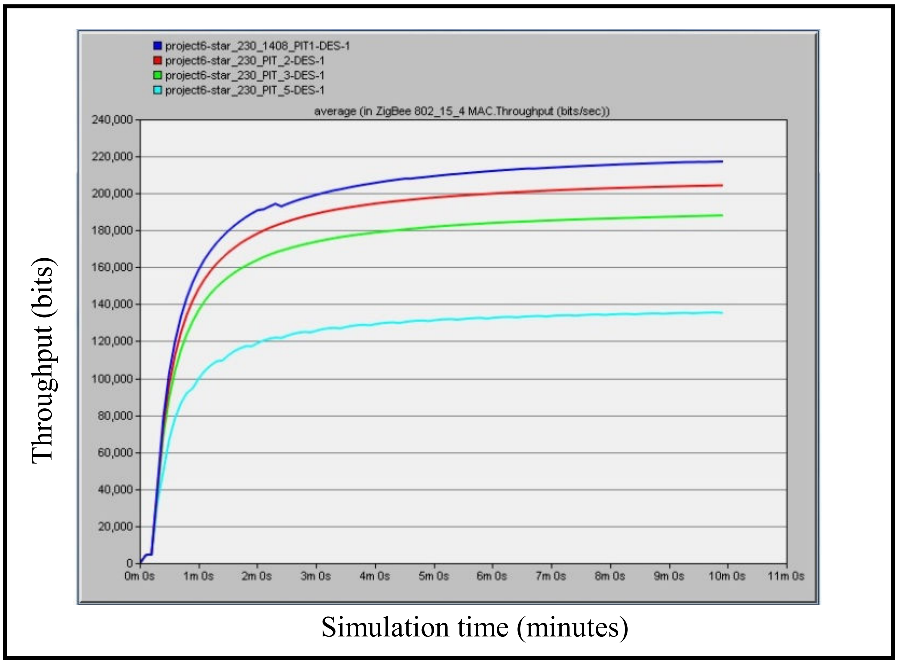

Fig. 9. Changing PIT at packet size of 1408 bits

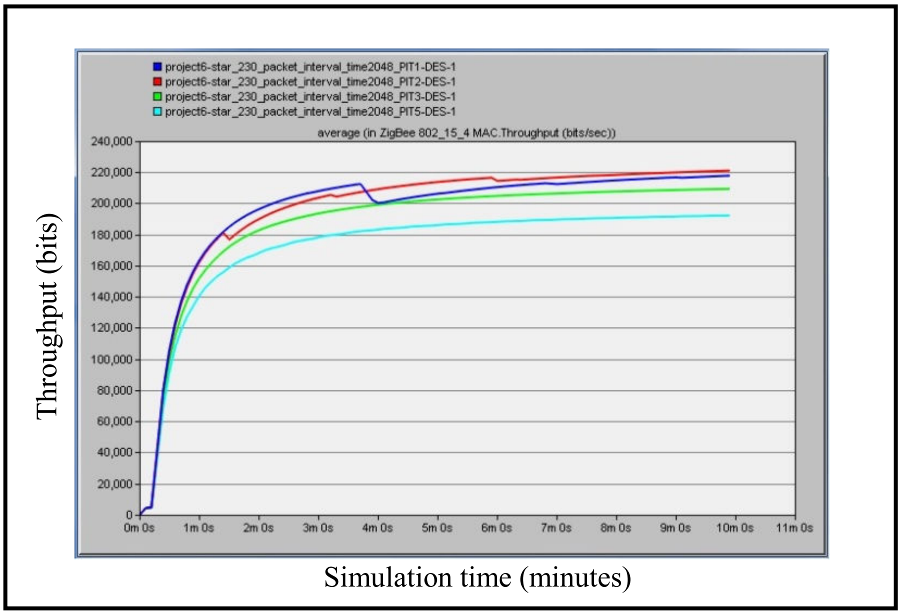

Fig. 10. Changing PIT at packet size of 2048 bits

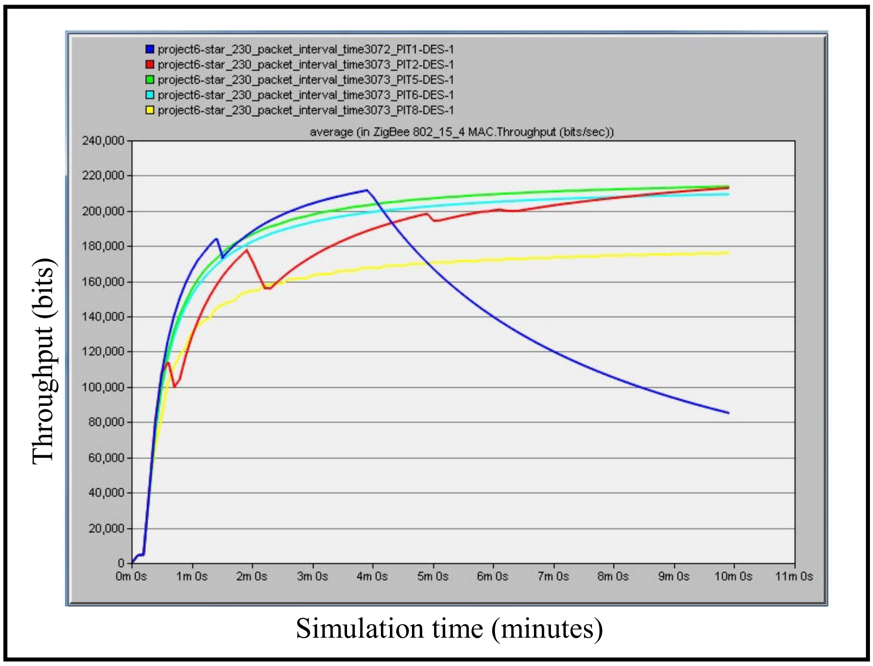

Fig. 11. Changing PIT at packet size of 3072 bits

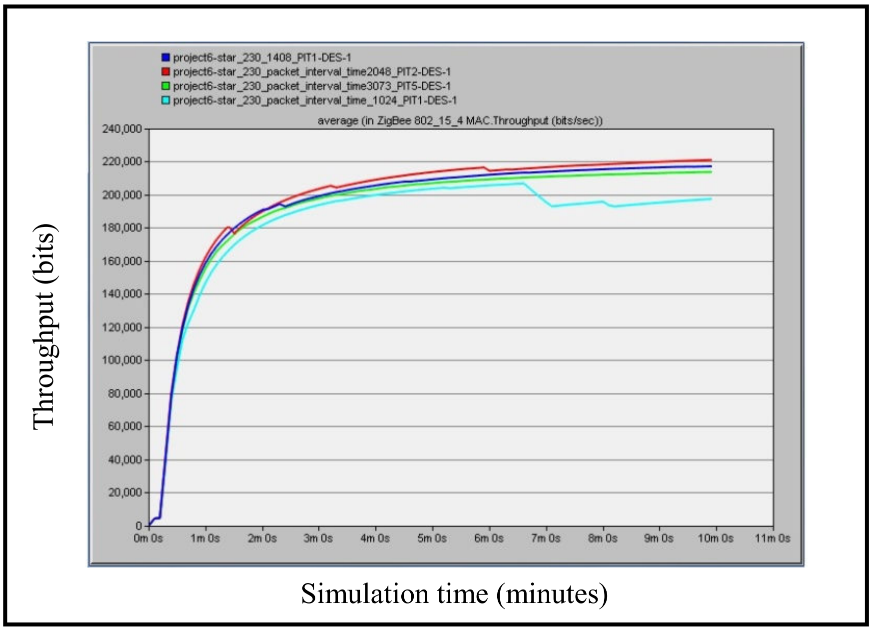

Fig. 12. Comparison among the best network performance cases

V. CONCLUSION

In this paper, the performance of IEEE 802.15.4 based WSN star topology is evaluated and optimized by changing performance parameters (number of nodes, packet size and PIT). It is found that the throughput increases by increasing the number of nodes up to 230 nodes before it starts to decline by increasing the number of nodes up to 260 nodes. At PIT value of one, it can be seen that there is a stable performance of network at a packet size of 1408 bits. An enhancement is accomplished by changing PIT to improve network performance. The results show that the packet size should be increased in order to make an efficient use of the increased PIT and maintain the best throughput. Finally, it can be concluded that the best optimized performance is obtained at 230 nodes number with packet size of 2048 bits when

PIT equals 2s. As there are many different types of applications for WSN and each application needs a suitable topology, it can be concluded that a star topology (with a maximum of 230 nodes) is very suitable for biomedical applications because of its single hop and fast delivery of information with a stable and saturated throughput. However, in different (large area) applications, where the range is required to be expanded, routers are introduced to form a tree or mesh topology; therefore, the maximum number of nodes can be employed in the field according to the desired topology.

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