Throughput Study of IEEE 802.15.4 ZigBee-Based WSNs for Greenhouse Environments

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ABSTRACT
Wireless sensor networks (WSNs) play major part in modern communication systems. The primary goal of this paper is to study the throughput in WSN applied in greenhouse's environment monitoring system using ZigBee technology to improve the networks performance. We created seven different scenarios of models with different setting of sensors for greenhouse environment. Each sensor was presented by a ZigBee end device that transmits traffic to a master node that is a ZigBee coordinator. The gathered information could be accessed via connecting the system to the server through an Ethernet LAN. The OPNET modeler V14.5 was used in this simulation study for building our 7 scenario designs. The outcomes of our comparison study demonstrate that the using of one coordinator model causes an increment in the throughput more than multiple coordinators model. Also, the effect of using routers was tested negatively from throughput point of view. These outcomes would help network engineers to improve their designs.

Keywords: *multiple coordinators systems, OPNET simulation application, single coordinator systems, Throughput, WSN, ZigBee technique.*

I. INTRODUCTION
There are large number of up-to-date applications that use wireless sensor networks (WSNs) like smart office, scientific exploration, intelligent surveillance, patient monitoring, … etc[1]. The WSNs are represented by small, simple, and inexpensive sensor nodes which are wireless devices. The sensor nodes work as an environment sensors and they do report its results to a central processing unit called sink. The nodes are restricted by the processing speed, memory, and energy due to the node small size.

The ZegBee technique supplies the framework required to support ad-hoc multiple hop wireless networks and neglects the gap between IEEE 802.15.1 Bluetooth and IEEE 802.11 WiFi standards by transmission range and data rates. Basically, ZigBee is one of the most promising and prevalent WSN today because of the low rate wireless personal area network (LR-WPAN). The ZigBee was built on IEEE 802.15.4 standard with low cost, low complexity, flexible routing, low power, and network scalability in mind[2].

An OPNET modeler version (V14.5) was used to study WSNs in greenhouse's environment monitoring. According to the IEEE 802.15.4 ZegBee standard, the WSN systems were tested for their throughput performance. The study emphases on the effect of increasing the number of sensors in the environment of single and multiple greenhouses and the effect of router existence as well.

II. WIRELESS SENSOR NETWORK (WSN)
The definition of WSN is a collection of separate nodes, each node is connected wirelessly over a limited frequency and bandwidth[3]. If we compare the WSNs with the traditional sensor networks we can conclude that WSNs depend on deployment and coordination of their tasks successfully when executed. The nodes' distribution enables closer placement of the events at the exact location of the particular event. In a wide range of WSN applications, battery powered sensors are used because re-charging or re-placement would not be practical, so disposable sensors are used. Increasing the lifetime and productivity of the disposable nodes would be expected to decrease eventual failure. The protocol security would be a light weight while retaining the usefulness to achieve this goal[4].

The throughput is the rate at which two nodes can send bits end-to-end across the communication medium. WSNs often use data processing directly in networks. One of the aims is to create large pools of data generated by the sensors. By applying computation close to the data source to trend, average, maximize and minimize, or out-of-range activities, user will be able to scale down the throughput as much as possible. Essentially to this, is the development of localised algorithms that assist major goals; desirable forms of collaborative signal processing are followed[4].

III. WSN ARCHITECTURE
In practical WSN, the network components consist of the following:-

- Sensor Motes are the field devices that placed in the process should be able to redirect packets on behalf of the rest of devices. In most cases, they control the equipment process. Whereas routers are field devices that do not have process sensors or control equipment, so do not interface with the process itself.
- Network Administrator is responsible for network configuration, scheduling connections between devices, routing tables managing, and monitoring with reporting on the network health.
- Security Manager is responsible for generating, storing, and key access to the network[5].

IV. OPNET SIMULATION APPLICATION

OPNET is a general purpose network simulation application[6]. OPNET simulation tool was selected to program our WSN. OPNET supports practically all physical radios, its configurations and thus, it is completely and easy to implement a physical layer in wireless communications. OPNET supports ZigBee technique and all three types of devices (RFD, FFD, and Coordinator). As for the physical layer and MAC layer there is a source code available but for the network and application layers only object code is available[7].

A hierarchical model is used to determine each aspect of the system. The top level is made up of the network model, where a topology is designed. While the node level is the next level in which the models of the data flow were defined. The process edition is the third level where handles control flow models. The parameter edition is the last level for supporting the three upper levels. OPNET can support many sensor models for specific hardware like transceivers and antennas in physical links. Also, custom packet formats can be used. A graphical interface is available for helping users to develop various models and for modeling, drawing, and animate the output results[8]. A C/C^{++} was used as a source code. The simulated data analysis was supported by a various built-in functions. Different kinds of nodes were used like ZigBee coordinator, end device and router nodes [9].

We used four processing models for our OPNET ZigBee model, which are:-

- ZigBee MAC model uses IEEE 802.15.4 MAC protocol. This model applies channel scanning, connecting, and failure/recovery operations of the protocol in the non-slotted mode.
- ZigBee application model introduces a less devoted version of the ZigBee application layer. This model implements network joins and formations, generates and gets traffic and creates different simulation reports.
- ZigBee Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) model achieves the MAC layer of the media access protocol.
- ZigBee Network model accomplishes the ZigBee network layer. This model leads the routing traffic, process network join, formation requests and generating beacons[9].

In a greenhouse system, there were many environment sensors which transmit the information to a node that located as a master node that connects the access point to a Local Area Network (LAN) or WiFi to Ethernet server for monitoring[10]. In this mode, the sensors' nodes were considered as a ZigBee end device, while the master node was represented by a ZigBee coordinator. The OPNET Modeler V14.5 was used in the simulation for the network. We used five sensors for each greenhouse. Different scenarios were selected to study system performance in terms of throughput. Other parameters were considered in different scenarios, like increasing the number of coordinators and greenhouses.

V. SIMULATION SCENARIOS

5.1 First Scenario Design

In this scenario, there was one greenhouse with five sensors to measure the temperature or humidity for example. Each sensor represented by a ZigBee end device and the master node was represented by ZigBee coordinator. The traffic would sent from the sensors to the master node (coordinator). This scenario is shown in Fig. (1).

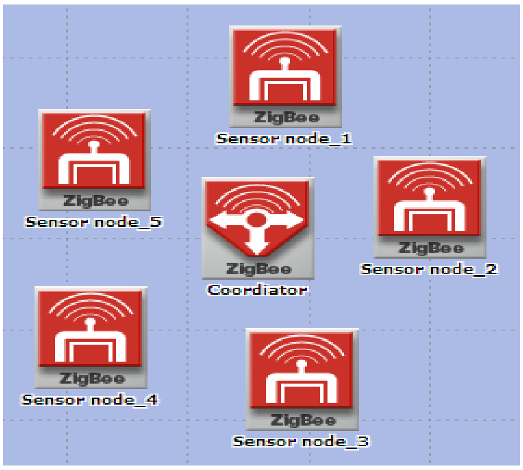

Figure 1 First Scenario

5.2 Second Scenario Design

In this scenario, the number of greenhouses was increased to two with five sensors in each greenhouse. This result in ten sensors as shown in Fig.(2). Again, the traffic was sent from each sensor node to the coordinator.

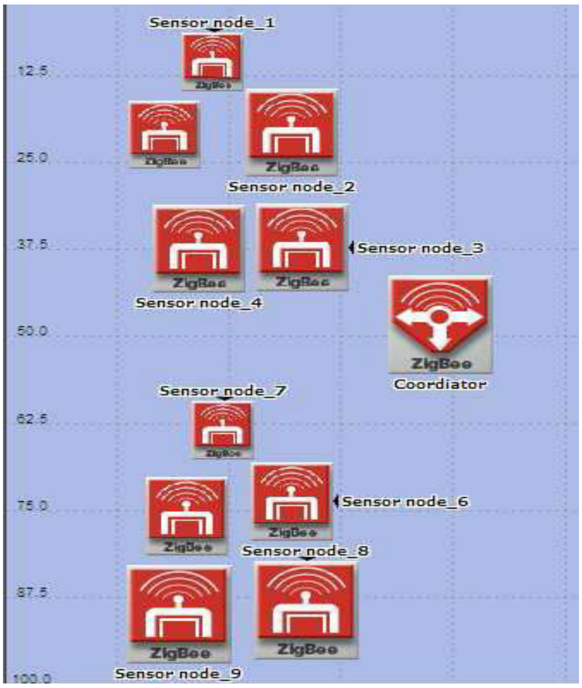

Figure 2 Second Scenario

5.3 Third Scenario Design

In this scenario, the number of greenhouses was increased to four which result in twenty sensors as shown in Fig.(3). All the 20 sensors are sending the traffic to a single coordinator (master node).

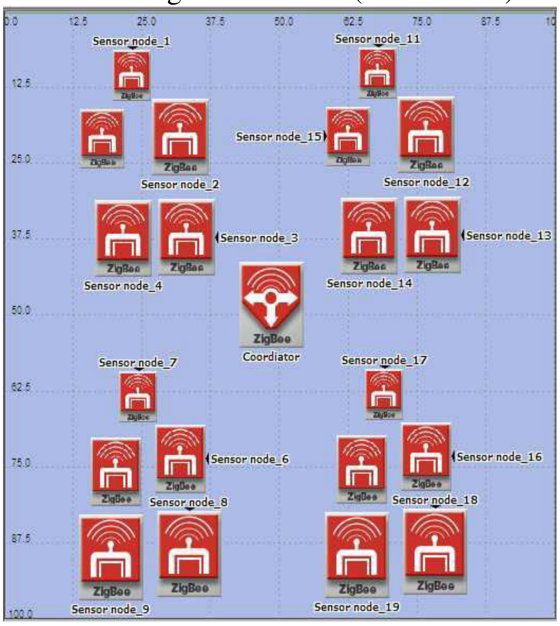

Figure 3 Third Scenario

5.4 Fourth Scenario Design

In this scenario, the number of the coordinators (master nodes) was increased to two. Each greenhouse has a coordinator and five sensors as shown in Fig.(4).

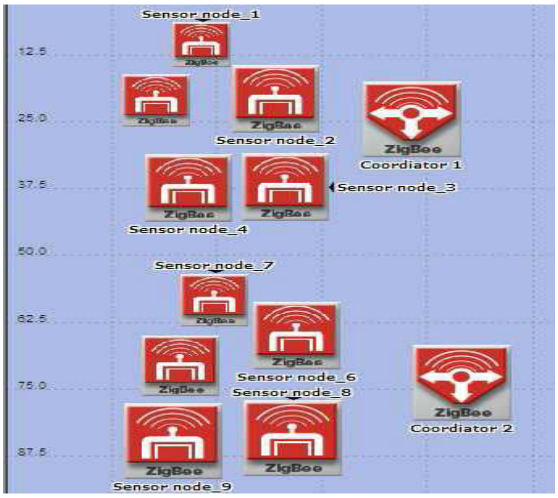

Figure 4 Fourth Scenario

5.5 Fifth Scenario Design

In this scenario, four greenhouses were considered with five sensors and one coordinator for each greenhouse. This design will lead to twenty sensors and four coordinators to receive data from the sensors as shown in Fig.(5).

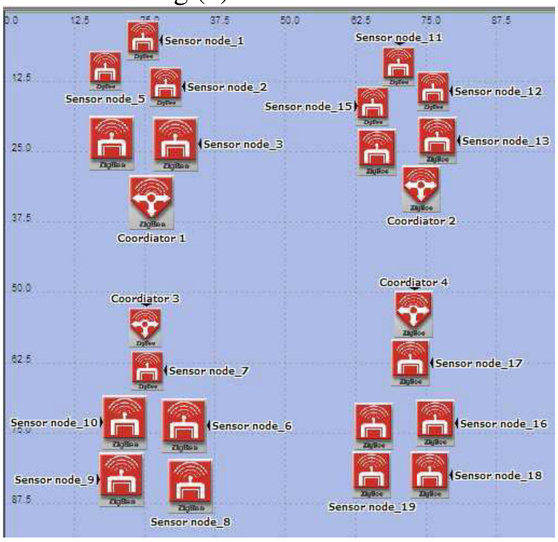

Figure 5 Fifth Scenario

5.6 Sixth Scenario Design

In this scenario, A ZigBee router was used to receive traffic from the coordinators (master nodes) as shown in Fig.(6). This model connects access points to server through ZigBee/Wifi gateway to be monitored by farmers (or agricultural engineers) for treatment.

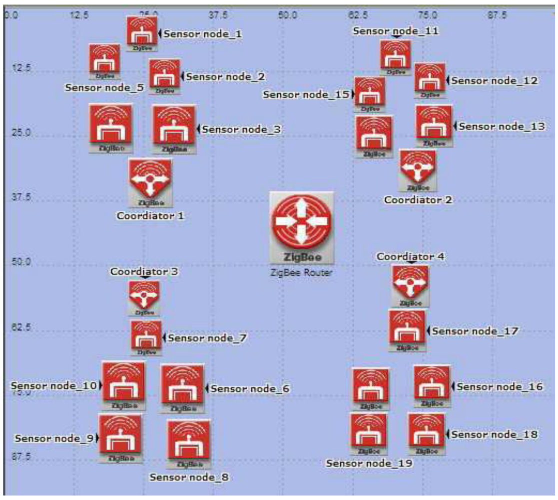

Figure 6 Sixth Scenario

5.7 Seventh Scenario Design

In this scenario, there were four greenhouses with one ZigBee router and one coordinator (five sensors in each greenhouse) as shown in Fig.(7).

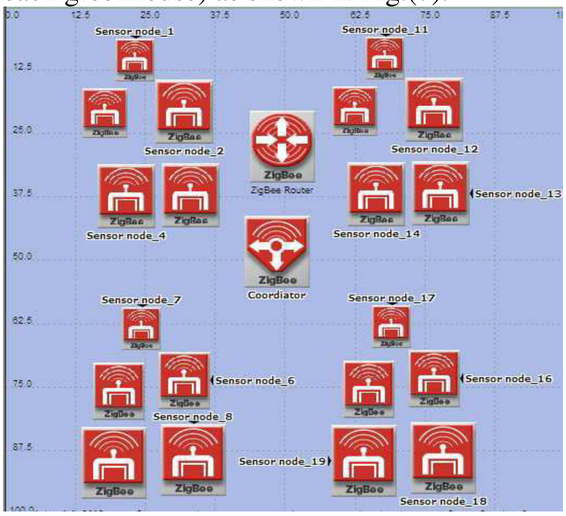

Figure 7 Seventh Scenario

VI. OUTCOMES AND DISCUSSIONS

The seven scenarios with 2000 seconds each of simulation were implemented by using the OPNET modeler. The results were statically analysed to identify the networks performance in terms of their throughput. Firstly, a single coordinator was used with multiple greenhouses and sensors. Secondly, the number of coordinators was increased too. The results will be discussed as follows:

6.1 First Outcomes and Discussions (One Coordinator)

Fig. 8 shows the total number of bits per second (bps) taken from 802.15.4 MAC to the next layers in all network's nodes. Throughput for design 1, 2 and 3 was sketched in the same graph to compare the number of greenhouses that increases from 1 to 2 then to 4 with a raise of the sensors from 5 to 10 then to 20 respectively.

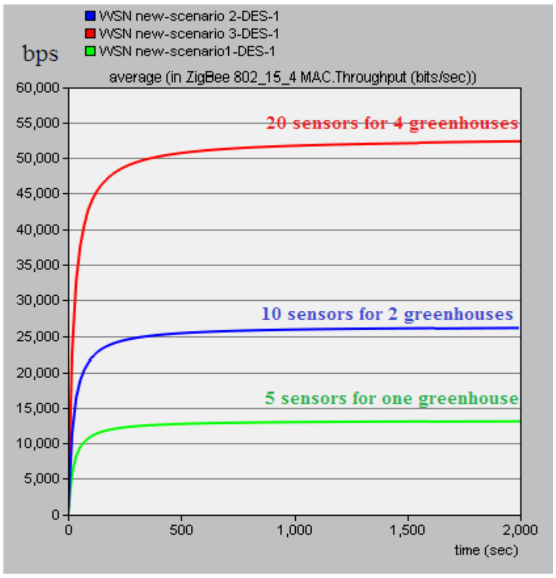

Figure 8 Throughput for Single Coordinator

It is obvious from Fig. 8 that for a single coordinator system, the throughput increases when the number of sensors increases too. At the beginning, the throughputs are equal for the scenario designs 1, 2, and 3 (for the first 40 sec). After that the throughputs are changed from one scenario to another. At the end time of simulation (2000 sec) the throughput reaches 13,656 bps for 5 sensors (scenario 1) while the throughput gets 26,246 bps for the 10 sensors design (scenario 2). Finally, the throughput reaches 52,386 bps for the 20 sensors (scenario 3).

6.2 Second Outcomes and Discussions (Multi Coordinators)

Fig. 9 shows the throughputs (in bps) that computed using the designs 2, 3, 4, and 5 for multiple coordinators' systems. Note, the graphs for design 3 and 4 are identical in a single graph.

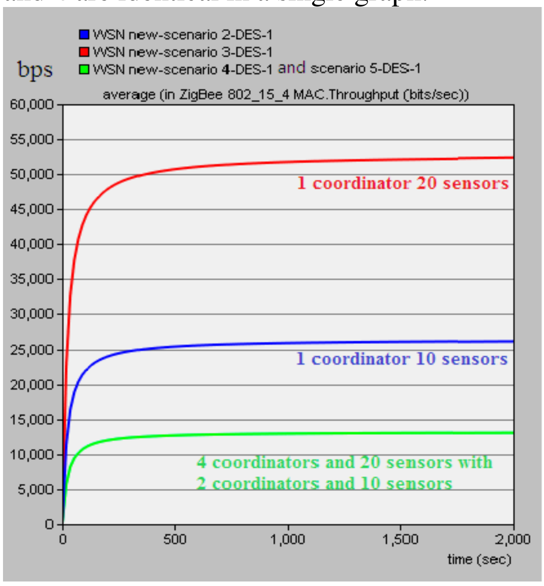

Figure 9 Throughput in Multiple Coordinators' Systems

With one coordinator, the throughput varies as the sensors increase. The throughput increases as the sensors increase too. As the number of coordinators increases more than one the throughput decreases for certain limit and stay unchanged regardless of changing the number of sensors and coordinators. For 10 sensors, the throughput becomes 26,348 bps at the end of simulation time (2000 sec) while the throughput for 20 sensors reaches 52,017 bps.

When the number of coordinators increases (multiple coordinators) the throughput stay unchanged independent of the increasing number of coordinators or sensors and reaches 13,148 bps at the end of simulation time.

6.3 Third Outcomes and Discussions (Single Coordinator with and without a router)

Fig. 10 displays the throughput of the systems with and without a router. This figure illustrates the total number of bits per second transmitted from 802.15.4 MAC to the higher layers in all network's nodes.

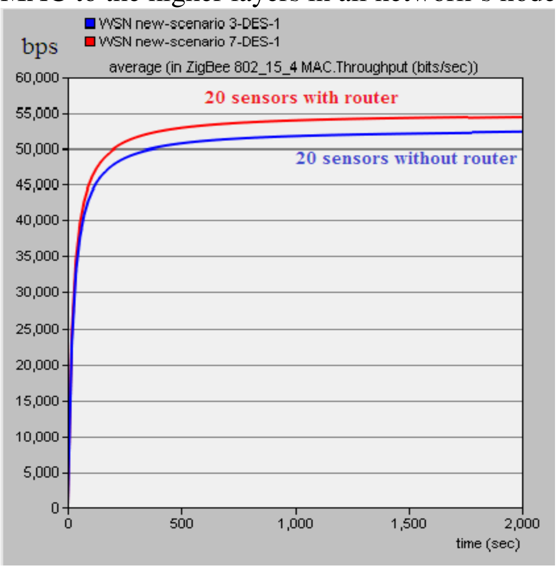

Figure 10 Throughput with and without a router for a single coordinator

In Fig 10, the router effect was tested with respect to the throughput. In this graph, 20 sensors were used with a single coordinator (scenario 3) then a router was added (scenario 7). It is obvious that at the end of simulation, the throughput was increased by 2,267 bps with the existence of a router.

6.4 Fourth Outcome and Discussions (Multi Coordinators with and without a router)

Design 6 is the same as design 5 except from that an extra router existence, so Fig. 11 illustrates the router effectiveness in terms of throughput in multiple coordinators' systems. Fig. 11 explains the throughput transmitted from 802.15.4 MAC to the higher layers in all network's nodes.

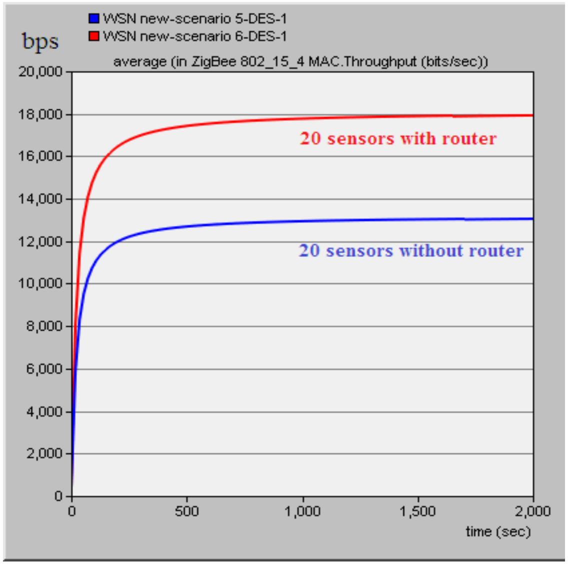

Figure 11 Throughput with and without a router for 4 coordinators

The router effect on throughput was tested in multiple coordinators' systems. It is clear from the figure that the router causes an increase amount of throughput. The additional throughput amount was 4,968 bps (the difference between the two graphs at 1800 sec).

VII. CONCLUSIONS

For single coordinator systems inside the greenhouse, the throughput increases as the sensors increase too. This increment in throughput is almost constant for every increment in the sensors (ZigBee end device inside the same greenhouse), while for multiple coordinators systems, the throughput decreases as the number of coordinators increases regardless of the number of sensors inside the greenhouse. So if any system needs a large number of nodes (micro environments inside a greenhouse) we highly recommend for the network designer to use more than one coordinator from throughput point of view.

For both single and multiple coordinators' systems, there is an extra throughput transmitted from 802.15.4 MAC to the upper layers when a router was used. So, we highly recommend for the network designer to avoid using a router from throughput point of view.

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