Throughput and Delay Behaviour in ZigBee Wireless Sensor Networks

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***Abstract*— In terms of transmission range and data speeds, ZigBee technology bridges the gap between IEEE 802.11 WiFi and IEEE 802.15 Bluetooth standards and offers the architecture needed to support WSNs. ZigBee is typically categorized as a low-rate wireless PAN technology. WSNs based on ZigBee are utilized in many different applications. There are single and multiple coordinators and routers for each of the 24 sensors in the modelled system. Every sensor node is represented by a ZigBee endpoint, which sends signals to the ZigBee coordinator master node. Next, by connecting the system to the server via Ethernet LAN, the data can be accessed. A Riverbed (OPNET) Modeler Academic Edition 17.5 was used to conduct this simulation. In order to examine the performance of the four modelled WSNs, this paper analyses the system's performance in terms of throughput and delay. The findings demonstrated that both throughput and delay rise as the number of routers increases. Moreover, throughput and delay are unaffected by adding more coordinators.**

***Keywords*— Wireless Sensor Networks; ZigBee; IEEE 802.15.4; Throughput; Delay; Riverbed.**

I. INTRODUCTION

There are several contemporary uses for Wireless Sensor Networks (WSNs) in data processing, analysis, mining and storage. Internet of Things (IoT), security monitoring and surveillance, threat identification, ambient noise level, patient monitoring in medical applications, and environmental control are but a few examples of WSN applications. Wireless sensors are tiny, low-cost nodes that can be used to represent WSNs. Within a network, these sensors communicate with one another by sending and receiving data packets. The nodes work as environmental sensors to report their results to a central unit called a "sink". The wireless sensors' primary drawback is their short battery life. As a result, the two primary issues in WSNs which need to be addressed are energy performance and network lifetime. In order to solve this issue, ZigBee techniques were established at a reasonable cost. By such means, the life of the wireless nodes in the network may be increased. The ZigBee uses the IEEE 802.15.4 standard to meet the key requirements of the WSN in terms of cost, complexity, flexibility, scalability and power [1].

A Riverbed (OPNET) Modeler Academic Edition 17.5 was used to study the throughput and delay for different scenarios of WSNs according to the IEEE 802.15.4 ZigBee standard. The study demonstrates the behaviour of throughput and delay when we increase the number of routers and/or coordinators in the WSNs.

II. THROUGHPUT IN WSN

Throughput is defined as the rate of messages served within a specific period of time forwarded from 802.15.4 MAC to the higher layers in all nodes of the network. The main problem with the sensors in WSNs is that when packets are sent from one sensor to another sensor (node), the throughput decreases as a result of high traffic and packet collisions [2]. To solve this problem, various methods were introduced. In this paper, we will discuss how the different network components can impact on throughput. Hence, it is envisaged that the optimum design would increase the throughput of a WSN in a way that that does not negatively affect delay or traffic. The arrangement of sensor nodes and the overall topology of the WSN play a significant role in determining throughput [1]. Efficient routing algorithms and topology management strategies can help optimize the network for better throughput. Throughput is usually measured in symbols or messages per second but in a WSN, it is more commonly measured in bits per second (bits/sec).

III. DELAY IN WSNS

The delay is defined as the time required to complete sending a single message in the MAC protocol. The estimated number of state transmissions, computed in relation to the worst-case or best-case bound, determines the delay. To make things as simple and low-tech as feasible, MAC protocol is needed. When designing a strategy, delay must be sufficiently low such

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that errors are minimized and both retransmissions and collisions are avoided [3].

Using the Riverbed modeler version (V17.5), in this paper we will consider the following three types of delay.

A. Delay It is the amount of time needed for a packet of data to access a WSN. It consists of a wide range of elements, including processing, propagation, transmission and queuing times [4].

B. End-to-End Delay

It is the time required for a data packet (or message) to travel from its source to its destination. It encompasses delays in switches, routers, coordinators and every other WSN component [5].

C. Media Access Delay

This delay is specific to the Zigbee WSN. It is associated with the time it takes for a node (or device) to access the channel. Media Access Delay consists of transmissions, backoff and contention times [6].

IV. RIVERBED MODELER VERSION (V17.5)

Riverbed Modeler Academic Edition 17.5, a tool for network modelling and simulation. It is used in communication network design, analysis and simulation. Network researchers and engineers can use the program as a platform to analyse protocol behaviour, evaluate performance and model different network scenarios.

Key features of the Riverbed Modeler typically include [7]:

Network Modelling: Users can build intricate models of network topologies, complete with routers, switches, connections, and end devices, using network modelling.

Protocol Simulation: With the help of a Riverbed Modeler, users may simulate different network protocols and examine how well they function in various scenarios.

Traffic Modelling: Users can evaluate how the network functions under various traffic patterns and model different types of traffic.

Wireless Network Simulation: The tool frequently includes wireless network simulation tools that used to like mobility, interference, and signal propagation.

Scenario Analysis: Users can assess network behaviour and performance by running simulations under various scenarios thanks to the scenario analysis capability.

Visualization: Users may observe and evaluate the outcomes of their simulations with the aid of the software's visualization capabilities.

Integration with other Tools: To provide a more thorough network study, a Riverbed Modeler can be integrated with additional platforms and technologies.

V. RELATED WORKS

Numerous works in the current literature have devoted their attention to throughput and delay found in WSNs. The ZigBee protocol gives less end-to-end delay for a tree network with a single coordinator and five sensors as seen in [8]. In [6], the delay was discussed in the context of a ZigBee WSN for different network scenarios according to the number of sensors, coordinators and routers using an OPNET modeler in a smart home.[9], [10] and [11] studied throughput and delay for single and multiple coordinators in tree, star and mesh ZigBee WSNs using an OPNET modeler. The performance parameters such as throughput for three system topology scenarios are presented using OPNET simulator of ZigBee WSN in [12]. The manner in which increasing the number of sensors in ZigBee based WSN would affect both delay and throughput is discussed, analyzed and tested using the Riverbed simulation program in [13]. Poisson conveyance shows superior performance as far as throughput, delay and quit-to-forestall put off are concerned using a Riverbed modeler as in [14]. Also, the throughput was tested and examined in different ZigBee-based WSNs of greenhouse environments as in [15].

This study will discuss ZigBee-based WSN performance without regard to the application that will be used. The functionality of the WSN will be examined in four scenarios for multiple settings. These different settings will be simulated using a Reiverbed modeler V17.5 for single and multiple coordinators and routers to study throughput and delay in IEEE 802.15.4 ZigBee-based WSNs.

VI. SIMULATION SCENARIOS

We conducted studies into four scenarios with 24 nodes (sensors) but with different numbers of coordinators (master nodes) and routers as follows: -

A. Scenario 1

In this scenario, 24 sensors are arranged in such a way that each sensor is represented by a ZigBee end device while the master node is represented by a ZigBee coordinator. The traffic should transverse from the end devices (sensors) to the coordinator (master node) as shown in Fig. 1.

Figure 1. Simulation Scenario 1.

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B. Scenario 2

In this scenario, the number of coordinators (master nodes) is increased to four. In this configuration, each coordinator is responsible for receiving traffic from only six sensors as shown in Fig. 2.

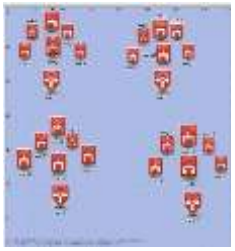

Figure 2. Simulation Scenario 2.

C. Scenario 3

In this scenario, we have added a single router to scenario 1. As such, we have 24 sensors with one coordinator and one router as shown in "Fig.3", below.

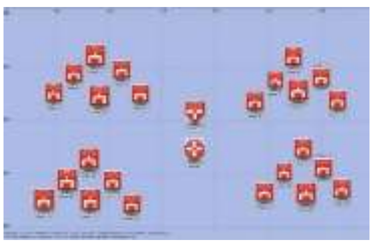

Figure 3. Simulation Scenario 3.

D. Scenario 4

The number of routers has been increased in this scenario. We now have 24 sensors, 4 routers and 1 coordinator as shown in Fig. 4 below.

Figure 4. Simulation Scenario 4.

VII. OUTCOMES AND DISCUSSION

Many statistics can be presented to study the performance of WSNs in terms of many parameters. In this paper, throughput and delay were considered for comparison between the different WSNs when the number of coordinators and/or routers were changed according to the scenarios mentioned previously. The simulation was run for one complete hour. The results are as follows:

A. *Throughput Result*

Fig. 5 shows the average throughput in bits per second for the four networks scenarios discussed in the previous section. The Riverbed modeler (V17.5) ran for one complete hour. It can be seen from the graphs that the throughput of the first three scenarios (scenario 1, 2 and 3) is identical. Comparing scenarios 1 and 2 (increasing the coordinators from 1 to 4) did not affect throughput. Meanwhile, when comparing scenarios 1 and 3 (adding a single router to the single coordinator), we see that the throughput has not been affected.
It can be seen from Fig. 5 that throughput in scenario 4 is much bigger than the throughput in the other three scenarios. The amount of the incremental throughput is 6,800 (bits/sec) in the steady state. Thus, increasing the number of routers from 1 to 4 causes an increase in the throughput of around 450%.

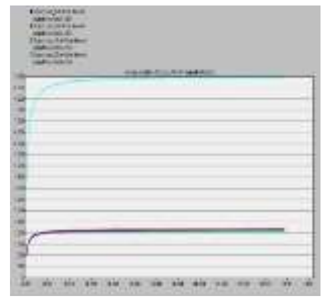

Figure 5. Throughput for the four scenarios.

B. Delay Results

1. End-to-End Delay

Fig. 6 shows the average End-to-End Delay for the four scenarios of the WSNs discussed previously. It can be seen that the End-to-End delay is identical for scenario 1 and 2. So increasing the number of coordinators from 1 to 4 does not affect delay. When a router is added to the WSN in scenario 3, the delay increased by about 0.01 sec in the steady state. Adding 4 routers in scenario 4 introduces extra delay (of about 0.0425 sec after running the modeler program for one hour) compared to the delay in scenarios 1 and 2. Accordingly, every router added to the WSN will introduce an extra End-to-End delay (of about 0.01 sec) at the steady state.

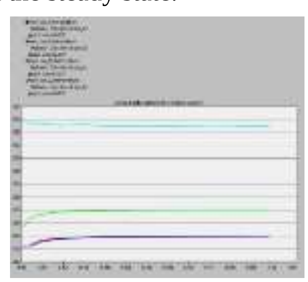

Figure 6. End-to-End Delay for the four scenarios.

2. Media Access Delay

In Fig. 7, the average Media Access Delay is presented for the four WSN scenarios. In the steady state, the Media Access Delays of the first three scenarios (scenarios 1, 2 and 3) are identical. Accordingly, increasing the number of coordinators does not affect this type of delay. In scenario 4 (4 routers), the Media Access Delay increased by about 0.00485 sec in the steady state. So, it is obvious that adding 4 routers increases the Media Access Delay in the steady state. While adding a single

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router introduces a small increment in the Media Access Delay in the transient state.

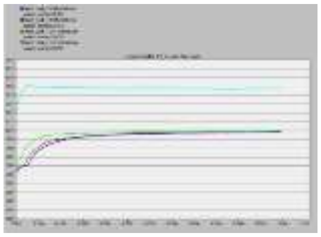

Figure7. Media Access Delay for the four scenarios.

3. Total Delay

Fig. 8 shows the average total Delay of the four WSNs. In the steady state, the four routers added to the WSN (as in scenario 4) introduce a Delay of about 0.0049 sec compared with the Delay in the other three scenarios. In the transient state, adding one router (as in scenario 3) produces an extra Delay that decreases with time.

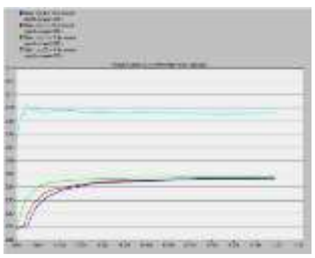

Figure8. Total Delay for the four scenarios.

Conclusion

As far as throughput is concerned, we may conclude that increasing the number of coordinators (master nodes) in the WSNs does not affect the throughput neither in the transient state nor in the steady state. In contrast, adding extra routers (4 routers in total, as indicated by the results) increases the throughput transmitted from 802.15.4 MAC to the upper layers. Each extra router added increases throughput by approximately 100%.

For all three types of delays (Media Access Delay, End-to-End Delay and total Delay), increasing the number of routers results in a corresponding increase in the delay. Each router added to the WSN adds an extra End-to-End delay of approximately 0.01 seconds.

Throughput and delay both increase with the addition of more routers. Therefore, depending on the application to be implemented in the WSN, it is highly advisable that network designers should aim to achieve a balance or a compromise between throughput and delay.

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