CHAPTER 5

THROUGHPUT, END-TO-END DELAY AND UTILIZATION ANALYSIS OF BEACON ENABLED AND NON-BEACON ENABLED WSN

5.1 INTRODUCTION

The simulation study in this chapter analyses the impact of the number of nodes on the reliability of data transmission and the end-to-end communication delay, based on the simulation model that was implemented in the OPNET Modeler. Network parameters Throughput, Utilization and End-to-End delay are analyzed in this chapter.

5.2 SIMULATION PARAMETERS

5.2.1 Throughput

Throughput is the average number of bits or packets successfully received or transmitted by the receiver or transmitter channel per second. The importance of analyzing this QoS parameter (Myung June Youn et al 2007) is because, the increased numbers of users of the wireless medium is the reason for increased possibility of interference. Throughput usually depends on many aspects of networks such as power control, scheduling strategies, routing schemes, packet collision, acknowledgment, obstructions between nodes and network topology.
Synchronization is a key for better throughput in the network. Every device in the network when ready to transmit data should compete for the channel. But to compete for the channel, the devices should know when the contention access periods start. Also this is what the superframe structure or truly, the beacon transmission does. This information is embedded into the beacon, and the device receiving the beacon can extract this information and get ready to compete for the channel. Same is the case when a device wants to exclusively transmit in the GTS mode. It is the coordinator that would assign a device access to the GTS (Anis Koubaa et al 2006).

5.2.2 **End-To-End Delay**

End-to-end delay is a measurement of the network delay on a packet and is measured by the time interval between a message is queued for transmission at the physical layer until the last bit is received at the receiving node. As the number of nodes in the WPANs increases, the delay obviously will increase. Minimum end-to-end delay is required for applications like the smoke detector, accident detector and carbon monoxide detector.

5.3 **ZIGBEE SIMULATION USING OPNET**

5.3.1 **Non-Beacon Mode Simulation Parameters**

The simulations analyzed in this section are performed on the OPNET Modeler ver. 14.5. ZigBee performs route discovery to determine the optimal path for messages to take to its destination. This section will discuss then analyze various cases simulated on OPNET. The network field is of size 100m X 100m. The simulations are performed with 10, 20, 30, 40, and 50 end-devices. The topology used is **Star Topology**. The simulation time is 1 minute. Network Simulation Parameters are shown in Table 5.1 and Network Layout is shown in Figure 5.1.
Table 5.1 Non-Beacon Network Parameters

<table>
<thead>
<tr>
<th>Network parameter</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission range</td>
<td>60 m</td>
</tr>
<tr>
<td>Packet size</td>
<td>1024 bits</td>
</tr>
<tr>
<td>GTS</td>
<td>Disabled</td>
</tr>
<tr>
<td>Acknowledge wait duration (sec)</td>
<td>0.05</td>
</tr>
<tr>
<td>Channel sensing Duration</td>
<td>0.01 sec</td>
</tr>
<tr>
<td>Beacon</td>
<td>Disabled</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>2.45 GHz</td>
</tr>
<tr>
<td>Packet Destination</td>
<td>Coordinator</td>
</tr>
</tbody>
</table>

Figure 5.1 Non-Beacon Network Layout
5.3.2 Number of Nodes

In this section, we change number of nodes and number of flows (keeping same flow/node ratio) and find out effect of number of nodes for different parameters with and without ACK. Number of nodes definitely affects PAN bridge performance. Bridge node should be the bottleneck node and performance degrades as the number of nodes increases. As number of nodes increases, number of flows also increases because flow/node ratio is fixed. More flows make more congestion, therefore delay increases.

5.3.3 Analysis of Simulation

In the analysis we will consider the Throughput, End-to-End delay and Utilization of the channel for different node density and the effect of ACK on above parameters in Star Topology.

Simulation without ACK

For simulation without ACK Scenario, ACK field is disabled. The static end devices are placed in a random manner around the static coordinator. Initially 10 nodes are placed. The effect of with 10 end devices without ACK is noted. In second scenario, 20 static end devices are randomly placed around the coordinator and then network parameter is noted and compared to the 10 nodes. Similarly 30 nodes, 40 nodes and 50 nodes are placed around the coordinator and simulated. The simulation results are compared for all the nodes i.e., 10 nodes, 20 nodes, 30 nodes, 40 nodes and 50 nodes.
Throughput

Figure 5.2 shows that comparison of the throughput for the various nodes (10, 20, 30, 40, 50 nodes). The Figure 5.2 clearly indicates that, when the number of nodes increased, throughput also increases.

End-to-End Delay

From Figure 5.3 it is inferred that End-to-End delay is high, when the network has 50 nodes and it is low, when the network has 10 nodes. From the Figure 5.3 we can conclude that, as the number of nodes increases it makes more congestion. Hence End-to-End delay is proportional to the number of nodes.
Utilization

In non-beacon enabled mode, all the nodes check the channel to transmit the packets. If the channel is idle, then only transmission is possible. Otherwise it will check again whether the channel is busy or idle.

From Figure 5.4 it explains that utilization of the channel is high, when the network has 50 nodes and it is low, when the network has 10 nodes. As the number of nodes increases, the utilization of the channel is more. Hence channel utilization is proportional to the number of nodes.
ACK has been enabled and ACK Parameters are defined. The simulation has been performed for the various static end devices (10, 20, 30, 40, 50 nodes) with coordinator. The simulation results captured for all the scenarios and all the scenario results are compared based on the network parameter.

**Effects of ACK on Throughput**

Throughput comparison for the various nodes (10, 20, 30, 40, 50 nodes) has been shown in Figure 5.5 for the Non Beacon Network without ACK scenario. As the number of nodes increases, irrespective of ACK enabled or ACK disabled, Number of packets transmission will be increased. Hence when the nodes are increased, throughput will also increase.
Effects of ACK on End-to-End Delay

From Figure 5.6 it is inferred that End-to-End delay is high, when the network has 50 nodes and it is low, when the network has 10 nodes. From the figure 5.6 we can conclude that, as the number of nodes increases it makes more congestion. Hence End-to-End delay is proportional to the number of nodes.

Effects of ACK on Utilization

Figure 5.7, explains that utilization of the channel is high, when the network has 50 nodes and it is low, when the network has 10 nodes. As the number of nodes increases the channel utilization is more. Hence channel utilization is proportional to the number of nodes.
Figure 5.6 End-to-End Delay with ACK

Figure 5.7 Utilization with ACK
5.3.4 Beacon Enabled Simulation Parameters

This section deals about beacon enabled mode. It is done by adding IEEE 802.15.4 simulation module. The network field is of size 100m X 100m. The simulations are performed with 10, 20, 30, 40 and 50 end-devices. The topology used is Star Topology. In this mode WPAN nodes are taken to construct the network. Beacon Network Layout is shown in Figure 5.8 and Simulation Parameters are specified in Table 5.2.

Table 5.2 Beacon Mode Parameters

<table>
<thead>
<tr>
<th>Network parameter</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time(Traffic Source)</td>
<td>0.0sec</td>
</tr>
<tr>
<td>Max backoff</td>
<td>4</td>
</tr>
<tr>
<td>Min backoff</td>
<td>3</td>
</tr>
<tr>
<td>Beacon order</td>
<td>1</td>
</tr>
<tr>
<td>Superframe order</td>
<td>1</td>
</tr>
<tr>
<td>Start time(GTS)</td>
<td>0.01sec</td>
</tr>
<tr>
<td>GTS length</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 5.8 Beacon Network Layout
5.3.5 Number of nodes

In this section, we change number of nodes and number of flows (keeping same flow/node ratio) and find out effect of number of nodes for load with and without ACK. Number of nodes definitely affects the PAN bridge performance. Bridge node should be the bottleneck node and performance degrades as the number of nodes increases. As number of nodes increases, number of flows also increases because flow/node ratio is fixed. More flows make more congestion, therefore delay increases.

5.3.6 Analysis of Simulation

In the analysis we will consider the throughput, End-to-End delay and utilization of the channel for different node density and the effect of ACK on above parameters in Star Topology.

Simulation without ACK

For without ACK scenario, ACK has been disabled. The static end devices are placed in a random manner around the static coordinator. Initially 10 nodes are placed. The effect of with 10 end devices without ACK is noted. In second scenario, 20 static end devices are randomly placed around the coordinator and then network parameter is noted and compared to the 10 nodes. Similarly 30 nodes, 40 nodes and 50 nodes are placed around the coordinator and simulated. The simulation results are compared for all the nodes i.e., 10 nodes, 20 nodes, 30 nodes, 40 nodes and 50 nodes.

Throughput

In beacon enabled mode, throughput is maximum, when the superframe and beacon order is low. For throughput considerations, we have chosen superframe order and beacon order as 1.
Figure 5.9 clearly indicates that when the number of nodes increases, throughput also increases.

![Figure 5.9 Throughput without ACK](image)

**Figure 5.9 Throughput without ACK**

**End-to-End Delay**

From Figure 5.10 it is inferred that End-to-End delay is high, when the network has 50 nodes and it is low, when the network has 10 nodes. From the Figure 5.10 we can conclude that, as the number of nodes increases it makes more congestion. Hence End-to-End delay is proportional to the number of nodes.
Figure 5.10 End-to-End Delay without ACK

Utilization

In beacon enabled mode, coordinator sends a beacon signal to the entire node. Hence it uses the channel only to transmit/receive packets into the particular nodes at a time. Remaining nodes doesn’t use the channel to transmit the packets in the same time due to nodes in sleep state.

From Figure 5.11 it explains that utilization of the channel is high, when the network has 50 nodes and it is low, when the network has 10 nodes. As the number of nodes increases, utilization of the channel is more. Hence channel utilization is proportional to the number of nodes.
Figure 5.11 Utilization without ACK

Simulation with ACK

ACK has been enabled and ACK Parameters are defined. The simulation has been performed for the various static end devices (10, 20, 30, 40, 50 nodes) with Coordinator. The simulation results captured for all the scenarios and all the scenario result compared based on the network parameter.

Effects of ACK on Throughput

Throughput comparison for the various nodes (10, 20, 30, 40, 50 nodes) has been shown in Figure 5.12 for the Beacon Enabled Network without ACK scenario. As the number of nodes increases, irrespective of ACK enabled or ACK disabled, number of packets transmitted will be increased. Hence when the nodes are increased, throughput will also increase.
From Figure 5.13 it is inferred that End-to-End delay is high, when the network has 50 nodes and it is low, when the network has 10 nodes. From the Figure 5.13 we can conclude that, as the number of nodes increases it makes more congestion. Hence End-to-End delay is proportional to the number of nodes.
Figure 5.13 End-to-End Delay with ACK

Effects of ACK on Utilization

From Figure 5.14 it explains that utilization of the channel is high, when the network has 50 nodes and it is low, when the network has 10 nodes. As the number of nodes increases it utilize the channel more. Hence channel utilization is proportional to the number of nodes.
5.3.7 Comparison of Beacon Enabled and Non-Beacon Modes

Throughput

Figure 5.15 shows that comparison of the 10 nodes, beacon enabled with and without ACK scenarios and non-beacon enabled mode with and without ACK scenario. By interpreting the above 4 scenarios, non-beacon without ACK has maximum throughput and beacon mode with ACK has minimum throughput whereas in beacon mode throughput is almost constant and hence beacon mode is suitable whenever the constant throughput is required. Figures 5.16 to 5.19 show that Throughput comparison of 20 nodes to 50 nodes.
Figure 5.15 10 Nodes Throughput

Figure 5.16 20 Nodes Throughput
Figure 5.17 30 Nodes Throughput

Figure 5.18 40 Nodes Throughput
End-to-End Delay

Figures 5.20 and 5.21 indicates that End-to-End delay comparison of four scenarios for 10 nodes and 20 nodes respectively. For a good network, End-to-End delay should be very low. By comparing the four scenarios Beacon enabled mode with ACK provides minimum delay rather than remaining scenarios and non-beacon mode provides maximum delay. Thus Beacon enabled mode is suitable for minimum delay applications. Figure 5.22 to 5.24 indicates that End-to-End delay comparison of four scenarios for 30 nodes to 50 nodes respectively.
Figure 5.20 10 Nodes End-to-End Delay

Figure 5.21 20 Nodes End-to-End Delay
Figure 5.22 30 Nodes End-to-End Delay

Figure 5.23 40 Nodes End-to-End Delay
Figure 5.24 50 Nodes End-to-End Delay

Table 5.3 End-to-End Delay Comparison for 5 Set of Nodes

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Non Beacon ACK Disabled (ms)</th>
<th>Non Beacon ACK Enabled (ms)</th>
<th>Beacon ACK Disabled (ms)</th>
<th>Beacon ACK Enabled (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nodes</td>
<td>18.7096</td>
<td>82.0454</td>
<td>8.91485</td>
<td>5.53004</td>
</tr>
<tr>
<td>20 nodes</td>
<td>19.8848</td>
<td>486.211</td>
<td>13.2783</td>
<td>6.41157</td>
</tr>
<tr>
<td>30 nodes</td>
<td>31.1341</td>
<td>1058.55</td>
<td>15.1755</td>
<td>12.5972</td>
</tr>
<tr>
<td>40 nodes</td>
<td>24.2598</td>
<td>1940.1</td>
<td>15.4083</td>
<td>12.6108</td>
</tr>
<tr>
<td>50 nodes</td>
<td>33.4044</td>
<td>2157.18</td>
<td>18.6721</td>
<td>18.4348</td>
</tr>
</tbody>
</table>
Table 5.3 explains that End-to-End Delay comparison for 5 set of nodes in Beacon ACK Enabled and Disabled and Non-Beacon ACK Enabled and Disabled Scenario.

**Utilization**

Comparison of four scenarios utilization is shown in Figures from 5.25 to 5.29 (nodes 10 to nodes 50 respectively). In Beacon Enabled mode the utilization of the channel is lower than the Non-Beacon mode.

Figure 5.25 10 Nodes Utilization
Figure 5.26 20 Nodes Utilization

Figure 5.27 30 Nodes Utilization
Figure 5.28 40 Nodes Utilization

Figure 5.29 50 Nodes Utilization
Table 5.4 describes that utilization comparison for 5 set of nodes in Beacon ACK Enabled and Disabled and Non-Beacon ACK Enabled and Disabled scenario.

### Table 5.4 Utilization Comparison for 5 Set of Nodes

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Non Beacon ACK Disabled</th>
<th>Non Beacon ACK Enabled</th>
<th>Beacon ACK Disabled</th>
<th>Beacon ACK Enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nodes</td>
<td>10.2575</td>
<td>7.28672</td>
<td>0.570695</td>
<td>0.4093</td>
</tr>
<tr>
<td>20 nodes</td>
<td>19.6541</td>
<td>13.8773</td>
<td>0.7787</td>
<td>0.744038</td>
</tr>
<tr>
<td>30 nodes</td>
<td>25.371</td>
<td>19.7839</td>
<td>0.848051</td>
<td>0.778716</td>
</tr>
<tr>
<td>40 nodes</td>
<td>33.3193</td>
<td>28.0835</td>
<td>0.778727</td>
<td>0.77872</td>
</tr>
<tr>
<td>50 nodes</td>
<td>35.0119</td>
<td>34.5535</td>
<td>0.84804</td>
<td>0.778742</td>
</tr>
</tbody>
</table>

### 5.4 SUMMARY

Simulation is a flexible means for assessment of the performance offered by a telecommunication system. However, identifying the correct simulation parameters is a key for a successful and nearly realistic analysis of any study. A brief overview of simulation parameters are presented in this chapter and simulation is done for the IEEE 802.15.4 with modes Beacon Enabled and Non Beacon Enabled.

From the above simulation results, it’s clear that as the number of nodes increases, the Throughput, End-to-End delay and Utilization of the channel also increased. In both beacon enabled and non beacon enabled modes, unacknowledgment enabled scenarios have maximum throughput compared to the acknowledgment scenarios. Comparing the beacon enabled and non-beacon enabled mode, Beacon mode provides constant Throughput and minimum End-to-End delay.