International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-6S, March 2019

Comparative Analysis of ZigBee Based Wireless Sensor Networks (WSNs)

Noman Shabbir, Syed R. Hassan, Muhammad N. Iqbal, Lauri Kutt, Arooj Unbreen

Abstract— This paper focuses on the comparative analysis of ZigBee Based Wireless Sensor Networks (WSNs) on network topologies basis. The topologies under consideration are Star, Tree and Mesh. The comparison is made against different network parameters like End to End (ETE) delay, No. of Hops, and throughput for small, medium and large scale sensor networks. Different parameters have their role in network performance. Simulation results in a table that consists of a comparison of different sizable networks on parameters and topological structure basis. From the results and conclusion it is feasible for us to select the topology according to the network size and parameter in consideration.

Keywords: ZigBee; WSNs; Network Topologies; ETE Delay; Throughput

1. INTRODUCTION

With the advancement in nanotechnology, microprocessor and communication systems, Wireless Sensor Networks (WSNs) have got significant importance.WSNs are a collection of hundreds and thousands of sensor nodes that have the capability to sense, process and communicate the surrounding events. The sensing nodes are referred to as motes. WSNs are an interesting application of ad-hocnetworks, eliminating the need for infrastructure and minimizing the expenditure of building the network. [1,2].

In most of the applications, the WSN nodes are placed at the points where it is least possible to access these nodes again. So battery life is a prominent factor in WSN applications. The data rate requirements of WSN applications are very low as compared to the WiFi (IEEE 802.11) which provide high data rate but it has a high power requirement. So keeping in regard the low data rate and long lifetime requirements of WSN's there is a need for a new standard that satisfies these requirements. So ZigBee standard is developed by IEEE to meet the low rate and low power requirements of low rate Wireless Personal Area Networks (WPANs).

The major research in this paper is focused on the comparison of ZigBee based WSN models, Star, tree, and mesh topologies for small, medium and large scale networks. The metrics under observation are End-to-End (ETE) delay, throughput, and number of hops.

Revised Version Manuscript Received on March 10, 2019.

Noman Shabbir, Deptartment of Electrical Power Engineering and Mechatronics, Tallinn University of Technology, Estonia.(E-mail: noshab@taltech.ee)

Syed R. Hassan, Departemnt of Electrical Engineering, GC University Lahore, Pakistan.(E-mail: syedrizwanhassan@gmail.com)

Muhammad N. Iqbal, Deptartment of Electrical Power Engineering and Mechatronics, Tallinn University of Technology, Estonia.(E-mail: miqbal@taltech.ee)

Lauri Kutt, Deptartment of Electrical Power Engineering and Mechatronics, Tallinn University of Technology, Estonia.(E-mail: lauri.kutt@taltech.ee)

Arooj Unbreen, Departemnt of Electrical Engineering, GC University Lahore, Pakistan.(E-mail: aroojunbreen786@gmail.com)

2. SURVEY OF PREVIOUS WORK

The applications of WSN's are growing day by day. There are many applications of WSN's with different priorities depending upon the requirement of the application. Some applications need high data rate and some applications are delay sensitive and have not much concern with the throughput [1]. Several research articles related to WSN's are studied to better understand the requirement of the parameters preference in a network according to the application. As to get the improved result of specific metrics the prior knowledge of these parameters is very mandatory [2].

In [3], comparison of the performance of networks based on mesh and tree based topologies is discussed with the result of the network in the case of failure of coordinator node. In [4,6], small, medium and large scale networks performance is compared with the metrics under consideration is End to End (ETE) delay, No. of Hopes and throughput. Networks based on tree topology with a single and double coordinator are analyzed and compared with other topologies [5,7].

3. RESEARCH PROBLEM & MAIN CONTRIBUTION

Effects of size of the network are a major factor influencing on the overall performance of the network so it is important to study this effect on all the topologies applicable in WSN's. For better implementation of the WSN's, it is mandatory to understand the basic difference between the basic structural differences between different network topologies.

The focus of this research is to design and implementation of star, tree, and mesh based WSN's of different sizes in OPNET simulator and then comparing these networks with respect to different metrics. The topological comparison is better to understand the effective use of specific topology for given requirements.

Computation of a table that provides information on the use of different topology according to the size of the network can help in designing, analyzing and predicting the performance of a network. Also, it can give an indication if someone has a particular priority towards a particular performance metric.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

4. PERFORMANCE METRICS AND TOPOLOGIES

In ZigBee based wireless networks there is three types of nodes based on functionality and they perform specific tasks in the network. The coordinator is a type of node which defined the network and routing of traffic take place through it. The coordinator is a mandatory part of every WSN to whom nodes are connected and it defines the name of the network. Among the types of nodes, the router nodes are the second one which is capable of message routing in a network and are not compulsory to be part of each sensor network. The routing capability is inactive when their nodes are used as end devices. Third, are the end devices that remain in active mode only while communicating with the other devices otherwise remain inactive to save battery [7, 8].

End to End delay, throughput, anda number of hopes are the major parameters upon which we will describe the performance of the topology. No. of hopes is the number of intermediate nodes a packet has to pass through while traveling from transmitter to the receiver. ETE delay accounts for the all the delays countered to the packet while transmission including medium access delays, route discovery time, retransmission delays and propagation delay. Throughput is the ratio of total data received by a receiver from a sender for a specific time. [9].

Star topology is a simple topology in which the end devices are directly connected to the coordinator and all traffic must pass through the coordinator which also acts as a router and major structural disadvantage of this topology is that upon failure of the coordinator the whole PAN failure will occur. In Tree topology, the clusters are connected to the coordinator and clusters are made up of end devices connected to a cluster head which is a router and this cluster head communicate between the cluster and coordinator. Every node has to pass through the node above in the tree from to route its message to the destination. Mesh topology is the same as Tree topology except that it provides multiple paths for a message to reach destination and failure of devices do not fail the whole communication system. This topology is very flexible and scalable.

5. SIMULATION MODELS

OPNET Modeler 14.5 network simulator is used to compare the behavior of ZigBee based wireless sensor networks on different scales with different topologies as depicted in figure 1. Here, different scenarios are compared on the basis of ETE delay, throughput and number of Hops. Several scenarios are modeled and implemented using a different type of topologies on a different number of nodes. Models and their specifications are given in table 1 and 2 and their results are drawn are in the next section.

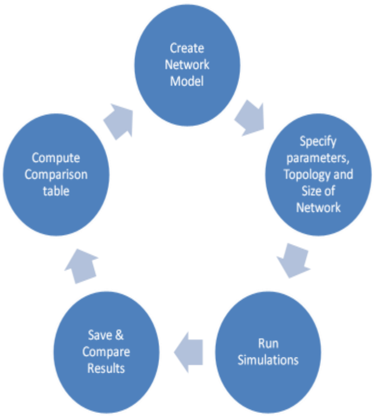

Figure 1: Simulation Model

5.1 Scenario I

In the scenario I, two different networks based on tree and mesh topologies are designed and compared with both having the same number of router and end devices. In a PAN, coordinator the main device defining the topology. Figure 2 shows both tree and mesh networks. In tree topology, router 1 will forward all the traffic to router 3 while all other devices will send data randomly but in case of Mesh, the data will be sent to the router 3 using the shortest path.

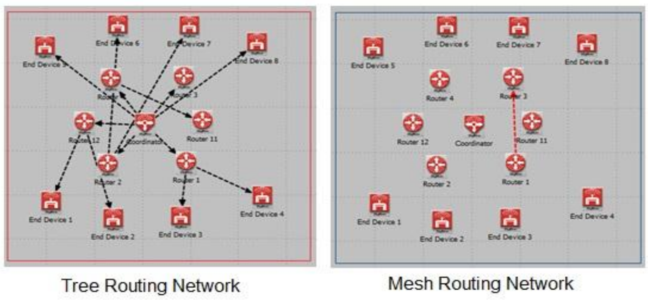

Figure 2: Tree & Mesh-based Networks

5.2 Scenario II

In this scenario, the special case of coordinator failure is discussed. The network has two coordinators, eight Routers and sixteen end-user devices. The coordinators are assigned PAN ID 1 and PAN ID 2, respectively. All other devices are free to join any one of the coordinators. A similar scenario is discussed in [3].

5.3 Scenario III

In this scenario, a comparison of star and mesh topologies is made while changing the size and number of nodes inside a network [4].To get better results of the simulations parameters are adopted given in table 1. All simulations are performed for 20 minutes.

5.4 Scenario IV

In this scenario, a comparison of all three topologies is made. All of them have one coordinator with six routers and six end-user devices. Mobility is added in this scenario by making one router and end user device mobile while all

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

others are kept stationary. Table 2 describes the simulation parameters for all the three topologies and with a simulation time of 1000 secs. All there topologies star, tree and mesh are shown in figure 3(a), figure 3(b) and figure 3(c), respectively. The projected movement of mobile node mobile nodes is shown as a white line. In the end, the Scenario in figure 3(b) is also compared with another scenario having tree topology with an extra coordinator.

Table 1: Physical Layer Parameters

Parameters	Small (10m x10m)		Medium (100m x100m)		Large (1000m x1000m)	
	Router	Devices	Router	Devices	Router	Devices
Star	- -	10 50	- -	10 50	- -	10 250
Mesh	2 7	8 43	2 7	8 43	2 7 27	8 43 223
Data Rate (kbps)	250		250		250	
Packet Rx Power (dbm)	-90		-90		-90	
Tx Band (MHz)	2450		2450		2450	
Tx Power (dB)	0.003		0.003		0.003	

6. SIMULATION RESULTS

In this section, results drawn from simulations perform on the models defined in the previous section are discussed.

6.1 Scenario I

Results of scenario I show, mesh topology-based network selecting the path having the shortest route i.e. a minimum number of nodes to its destination as shown in Figure 4.

Table 2: Simulation Parameters

ZigBee Parameters	Value		
	Star	Tree	Mesh
Max. Children	255	3	3
Max. routers	0	2	2
Max. depth	1	5	5
Achieved depth	1	3	3
Mesh routing	Disabled	Disabled	Disabled
Transmit power (W)	0.05	0.05	0.05
Transmission band (MHz)	2450	2450	2450

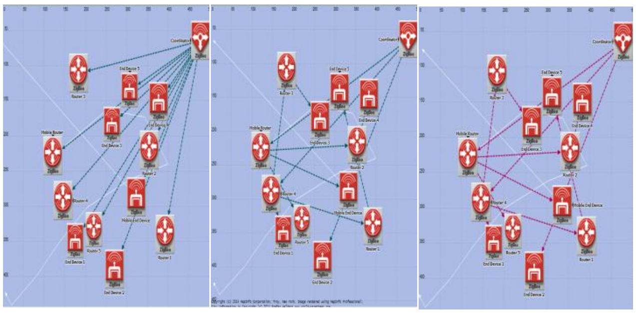

Figure 3(a): Star Network
Figure 3(b): Tree Network
Figure3(c): Mesh Network

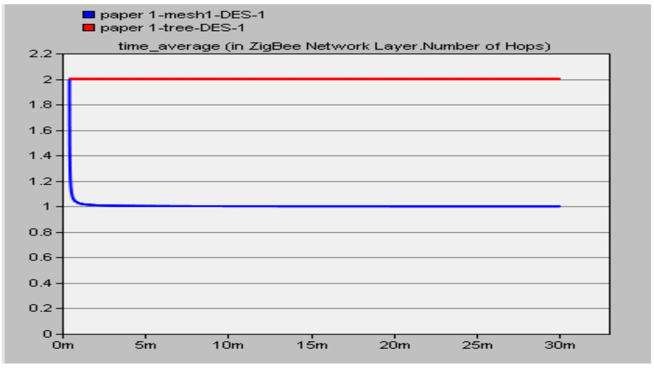

Figure 4: Number of Hops

The ETE delay of mesh and tree routing scenarios is 0.010 sec and 0.016 sec while the throughput is 13.4 Kbps and 3.41 Kbps respectively. Mesh has a lower ETE delay as it has the shortest path, but tree topology has the maximum throughput. The main reason is that in tree topology communication is based on coordinator and routers that are more efficient and the total network load is divided resulting in low packet losses and lesser collisions.

6.2 Scenario II

Figure 5 shows the PAN affiliation of both coordinators and the -1 value indicates the failure of the coordinator.

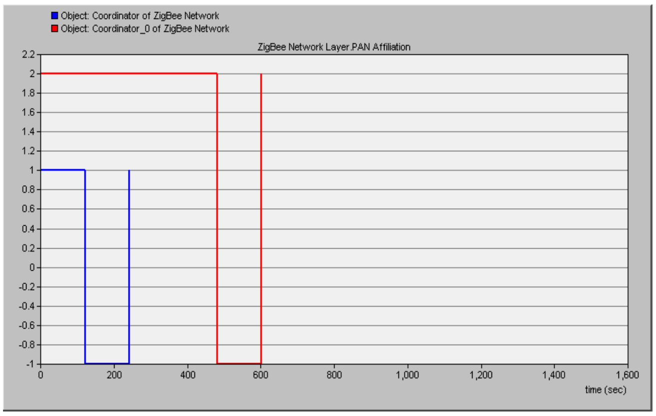

Figure 5: PAN Affiliation

6.3 Scenario III

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

ETE delay for small WSN scenarios is shown in table 3. ETE delay is directly proportional to the number of nodes while it increases significantly in case of mesh topology.

Table 3: Comparison of ETE delay for Small Scale Network

Network Topology	Number of Nodes	Small Scale ETE Delay (sec)	Medium Scale ETE Delay (sec)	Large Scale ETE Delay (sec)
Star	10	0.07	0.07	0.006
Star	50	0.010	0.011	-
Star	250	-	-	0.010
Mesh	10	0.015	0.016	0.010
Mesh	50	0.020	0.019	0.023
Mesh	250	-	-	0.018

There is no significant change in the result of the small and medium scale, the reason is the transmitting range of ZigBee. When the nodes are within range, there is not much difference in results. But in case of transition from star to the mesh network, there is a one hundred percent increase in ETE delay primarily due to the introduction of an extra hop as the message must pass through the ZigBee router.

In large scale network (1000m x 1000m), in star topology, some of the nodes are obviously out of range and as the number of devices is increased, the load increase on the coordinator thus an increase in ETE delay.

The ETE delay of the mesh is twice as compared to star topology with10 and if there is an increase in a number of nodes it does not increases but decreases. The results are shown in table 3. This is due to the presence of an additional router, thus an increase in more shortest paths.

Now in case of throughput, there is a decrease as some of the nodes are outside the transmission range, by increasing the transmission range for star and mesh topology, the comparison is made for nodes transmitting 1100 bps and the coordinator receiving between 500 bps to 1500 bps. The increase in the range is by adding extra routers as shown in figure 6. This increases the coordinator traffic around 3.5 times as compared to star topology. Figure 7 shows throughput at the coordinators of networks with single versus two coordinators. The result of throughput is:

$$(T * 1.25) = T0 + T1 \quad (1)$$

T: throughput with a single PAN
$T0$: throughput of PAN ID 0
$T1$: throughput of PAN ID 1

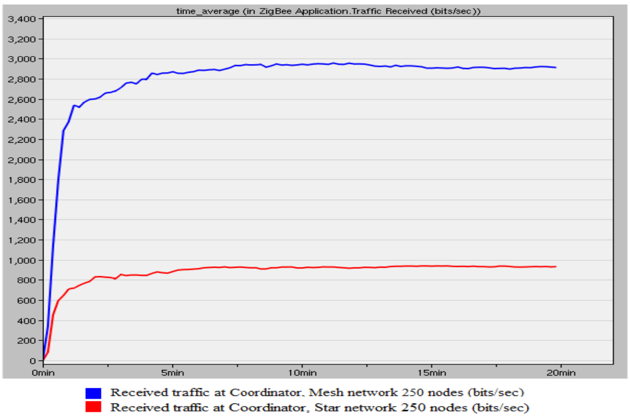

Figure 6: Traffic Received

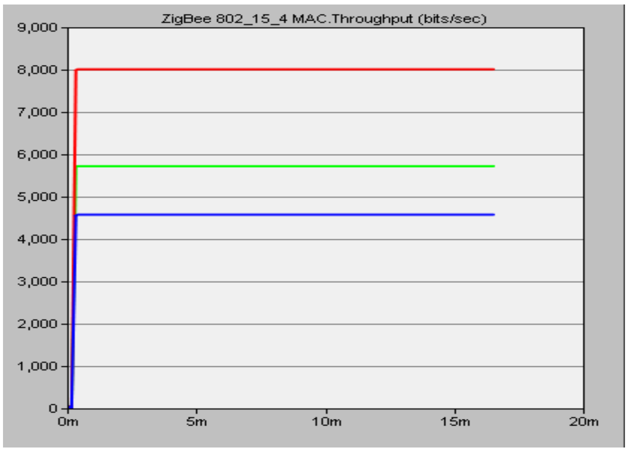

Figure 7: Comparison of Throughput

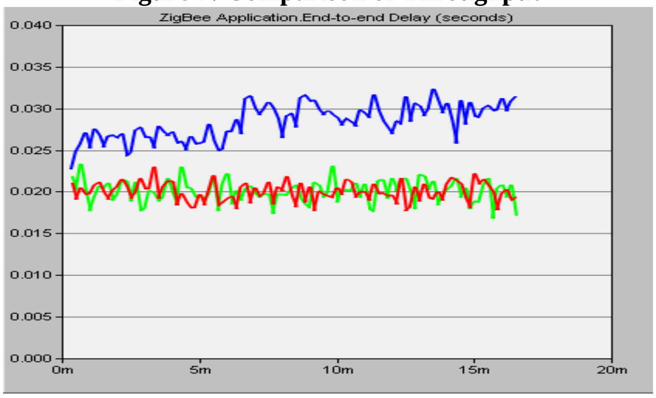

Figure 8a: ETE delay

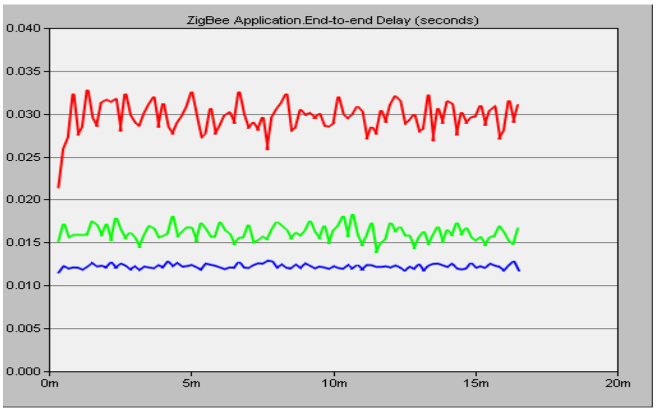

Figure 8b: ETE delay of Tree (1 & 2 coordinators)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The results indicates that at the coordinator, star topology has the maximum throughput of 12.6 Kbps followed by tree topology mesh topologies with the values of 10.2 Kbps and 3.3 kbps, respectively. As discussed earlier, the scenario with an extra coordinator is now compared with tree topology. The newly created scenario is compared with tree topology and its results ETE dealy are shown in figure 8b. Here, the ETE delay is defined as:

$$ET = EA + EB \quad (2)$$

E_T: ETE delay of the network with single PAN

E_A: ETE delay of PAN ID 0 and E_B: ETE delay of PAN ID 1

7. CONCLUSION

From simulations results, ZigBee based Wireless sensor networks can retain its stability on the failure of the coordinator by self-healing process and it supports the infrastructure free deployment of WSNs.

Table 4 is made from the result of all the simulations discussed above in the paper. The table guides us to use the most suitable topology according to size and metric preference basis. Improvement in throughput can be obtained by dividing the WSN and by inserting more coordinators without effecting ETE delay factor and ETE delay per coordinator is reduced but at the cost of coordinator price.

Table 4: Comparison Analysis of all Networks

		Small	Medium	Large
Star	*Throughput*	High	High	Low
	ETE Delay	Low	Low	High
	Performance	Excellent	Good	Bad
Tree	*Throughput*	High	High	High
	ETE Delay	Medium	Low	Medium
	Performance	Bad	Good	Good
Mesh	*Throughput*	Low	High	High
	ETE Delay	Low	Medium	Medium
	Performance	Good	Medium	High

ACKNOWLEDGMENTS

This work was supported by the Estonian Research Council grant PSG142

REFERENCES

1. A. Azim, M.M. Islam, "A dynamic round-time based fixed low energy adaptive clustering hierarchy for wireless sensor networks," IEEE 9th Malaysia Int. Conf., Malaysia (MICC), Dec. 15-17, 2009, pp. 922-926.
2. N. Shabbir et al, "Routing protocols for small scale WLAN based WSNs", 9th International Conference on Sensing Technology (ICST), pp. 412-415, New Zealand, 2015.
3. I.S. Hamoodi. et al, "Comprehensive Performance Study of OPNET Modeler for ZigBee Wireless Sensor Network," Third International Conference on Next Generation Mobile Applications, Services and Technologies, 2009, pp. 357-362.
4. P. Shah, K. Satish, "Analytical Approach for Performance of Wireless Sensor Networks", International Journal of Electronics and Computer Science Engineering, 2010.
5. M. Ferdowsi, "ENSC 427: COMMUNICATION NETWORKS", Final Report, 2012.
6. M. Boris, B. Mitko, "Overview and Analysis of the Performances of ZigBee based Wireless Sensor Networks", IJCA, Vol. 29, No. 12, September 2011, pp. 28-35.
7. A.A. Khan, "A survey of routing protocol in wireless sensor networks" [thesis]. Lahore: GCU; 2016. Available from: http://library.gcu.edu.pk/theses.htm
8. B.A. Bakr, L. Lilien, "LEACH-SM: A protocol for extending wireless sensor network lifetime by management of spare nodes", International Symposium on Modelling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt); IEEE; New Jersey, Princeton; 2011
9. Z. Zang, J.D. Qi, Y.J. Cao, "A robust routing protocol in wireless sensor networks." IET International Conference on Wireless Sensor Network, China: IET; 2010. pp. 276-279.
10. G. Yin, G. Yang, W. Yang, B. Zhang, W. Jin, "An energy-efficient routing algorithm for wireless", International Conference on Internet Computing in Science and Engineering (ICICSE'08), IEEE, China, 2008.