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Original Research Article

PERFORMANCE ANALYSIS OF WIRELESS SENSOR NETWORKS USING OPNET

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Abstract: The increasing interest in wireless sensor networks (WSNs) can be promptly understood simply by thinking about what they essentially are: a large number of small sensing self-powered nodes which gather information or detect special events and communicate in a wireless fashion, with the end goal of handing their processed data to a base station. Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of applications.
The IEEE 802.15.4 protocol has been adopted as a communication standard for low data rate, low power consumption and low cost WSNs [1].
The ZigBee standard is close associated with the IEEE 802.15.4 protocol and specifies the network (including security services) and application (including objects and profiles) layers [2].
The Opnet Modeler is an industry leading discrete event network modeling and simulation environment [3]. Opnet Modeler was chosen due to its accuracy and to its sophisticated graphical user interface.
This paper presents simulation analysis of the IEEE 802.15.4/ZigBee model implemented in the Opnet modeler 17.5.. Firstly, three possible topologies star, mesh and tree are compared to each other. Secondly, more analysis is studied in mesh topology by changing number of nodes and find out effect of number of nodes for different parameters. simulation is performed with 10, 20, 30, 40, and 50 nodes. Thirdly, resiliency analysis is studied. Network resilience is the persistence of service delivery that can justifiably be trusted, when facing changes [4]. Changes are related to mutations in the topology, workload, and link quality etc. due to failure/recovery of nodes. In this paper a proposed method to measure resiliency is given by simulating WSN without failure and with different cases of failure (one failure to six failures).

Keywords: WSN, ZigBee, OPNET, Sensor Networks

1. Introduction

IEEE 802.15.4 standard and ZigBee specification stand as the leading communication technologies for large scale, low data rate, low cost and low power consumption Wireless Sensor Networks. The development environment in Opnet consists of three hierarchical modeling domains. Network domain describes network topology in terms of nodes and links. Internal architecture of a node is described in the node domain. Within the process domain, the behavior of a node is defined using state transition diagrams. Operations performed in each state or transitions are described in embedded C/C++ code blocks. Zigbee is supported only Non-Beacon mode & Beacon enabled mode is placeholder in this model.

There are three types of Zigbee devices. ZigBee Coordinator (ZC), ZigBee Router (ZR) and ZigBee End Device (ZED). ZC One for each ZigBee Network initiates and configures Network formation; Acts as an IEEE 802.15.4 Personal Area Network (PAN) Coordinator; Acts as ZR once the network is formed; a Full Functional Device (FFD) implements the full protocol stack.
ZR participates in multi-hop routing of messages in mesh and Cluster-Tree networks; implements the full protocol stack. ZED does not allow other devices to associate with it; does not participate in routing; It is just a sensor/actuator node. ZED acts as an IEEE 802.15.4 PAN end device. This is named a Reduced Functional Device (RFD).
Current and potential applications of the WSNs include: military sensing, physical security, air traffic control, traffic surveillance, video surveillance, industrial and manufacturing, automation, building and structures monitoring, environment monitoring, and distributed robotics [5]. Importance of ZigBee in the future of computer and communication technology from the points of protocol stacks size and power consumption has been discussed [6]. Different topologies for deploying WSNs in precision agriculture cluster-tree, mesh, and grid have been compared [7].
The performance parameters for the Zigbee star wireless network and mesh network have been compared by using Network Simulator-2 (NS-2) [8]. A measurement and analysis of the impact of failures in a ZigBee cluster-tree topology WSN has been presented [9].
A simulation study to analyze the effects of behavior of a mobile ZigBee node passing through the radius of multiple PANs has been analyzed [10]. The impact of number of nodes in throughput, end to end delay, and utilization has been analyzed [11]. Topology used is star topology. A number of performance measures of the IEEE 802.15.4 protocol have been discussed only for star topology using OMNeT++ simulator [12]. Performance of WPAN ZigBee IEEE 802.15.4 has been analyzed in detail with the help of three different topologies, namely; cluster-tree, mesh, and, star [13].
The rest of this paper is organized as follows; the next section presents examination of topological features of WSNs. Section 3 shows how the number of nodes impacts the different parameters. Resiliency assessment of WSNs is presented in section 4. Finally, conclusions are discussed in section 5.

2. Comparison of Star, Mesh and Cluster Tree Topologies

In this section, three possible topologies (Star, Mesh and Cluster Tree) are compared to each other. The focus of the study of this simulation is on the following values captured from global statistics (throughput, MAC Data traffic sent, and MAC Data traffic received).
The simulated network contains only one ZigBee Coordinator (ZC), Six ZigBee Routers (ZR) and nine ZigBee End Devises (ZED) as shown in figure 1. Three topologies are identical.

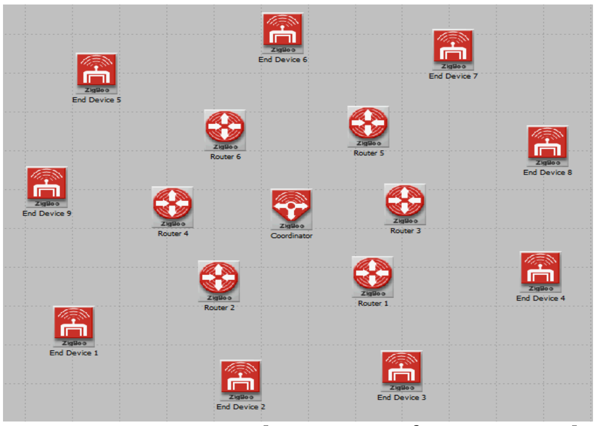

Figure 1: Network Structure for Star, Mesh and Cluster Tree Topologies

2.1 Simulation Parameters

The Physical layer parameters used are data rate = 250 Kbps, receiver sensitivity = -85 dB, transmission band at 2.4GHz and transmission power = 0.05 W. Table 1 shows application layer parameters used. Parameters used in this simulation are the same as the parameters used in [13].

Table 1: Application Traffic Parameters

Parameters	Application Traffic					
	Node	Packet Inter-arrival Time	Packet Size	Start time	Stop time	Destination
Cluster-Tree Network	PAN Coordinator	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	Router	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	End Device	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	ZRs
Mesh Network	PAN Coordinator	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	Router	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	End Device	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	Parent
Star Network	PAN Coordinator	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	Router	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	Coordinator
	End Device	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	Coordinator

In the following the previous work presented in [13] is examined.

2.2 Results of Previous Work

In this section the results obtained by the simulation of previous work is presented by using OPNET 17.5 simulator but the previous work was presented by using OPNET 14.5. However, Throughput, data traffic sent and data traffic received of the proposed networks in [13] as shown in figure 2, figure 3 and figure 4 respectively, from figures the results are the same.

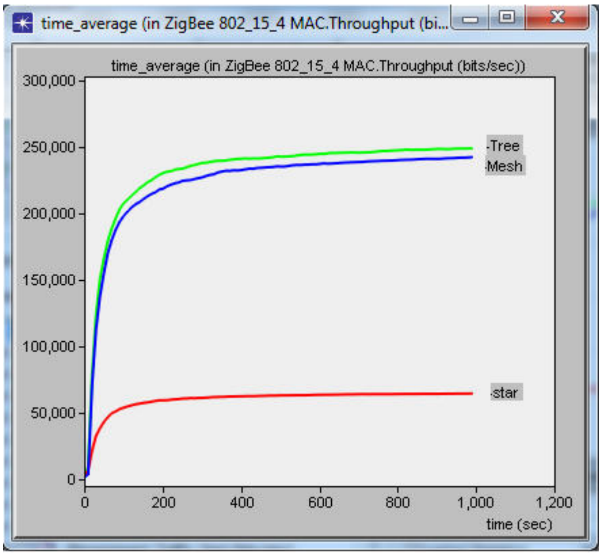

Figure 2: Throughput (bits/sec)

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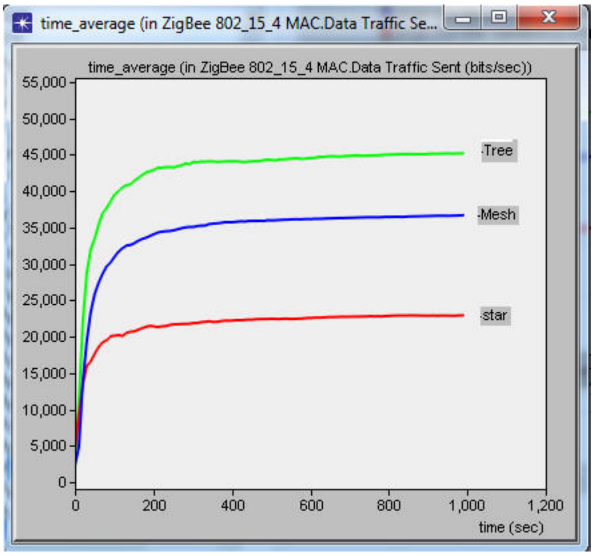

Figure 3: MAC. Data Traffic Sent (bits/sec)

The throughput data traffic sent and data traffic received is the maximum for cluster topology. Figures also show that throughput is the minimum in case of star topology.

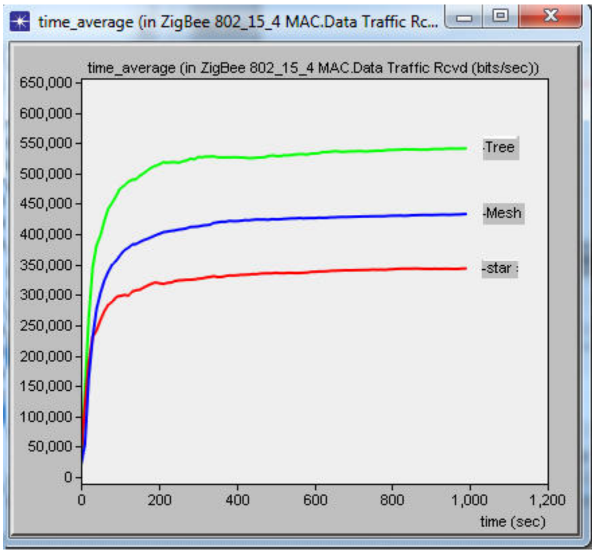

Figure 4: MAC. Data Traffic Received (bits/sec)

2.3 Results of Star, Mesh and Cluster Tree Topologies Simulation

It is stated that three topologies star, mesh and cluster tree have been constructed with equal number of ZCs, ZRs and ZEDs. Different parametric results (Throughput, Traffic sent, and Traffic received) have been explained here that show the impact of performance on different topologies.

2.3.1 Throughput

Represents the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to higher layers in all WPAN nodes of the network. Figure 5 shows that throughput in tree topology is more than mesh and star topologies. Because tree has seven fully functional devices where each cluster is managed separately by PAN routers and then joined with PAN coordinator which reduces the number of collisions and retransmissions.

2.3.2 Data Traffic Sent

Traffic transmitted by all the 802.15.4 MACs in the network in bits/sec. Figure 6 shows the traffic sent for all topologies. This results show that traffic sent is the maximum for cluster-tree topology. Because it uses ZC and ZRs which manages their own routing tables which are used in traffic generations. Lower collision and packet drop rate leads to high traffic sent for tree topology. This graph also shows that traffic sent for star is minimum due to one ZC there are more collision and retransmissions.

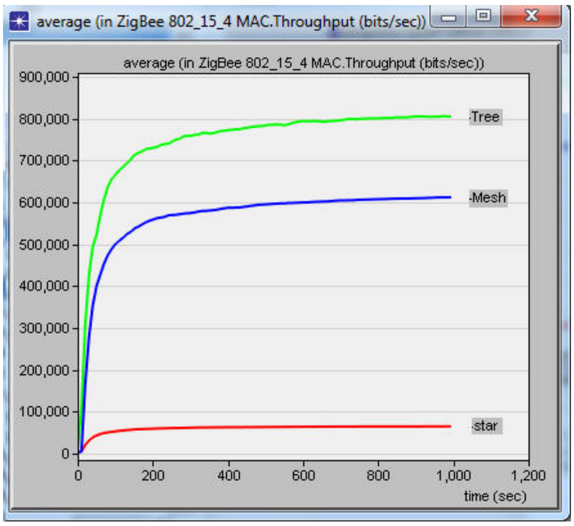

Figure 5: Throughput (bits/sec)

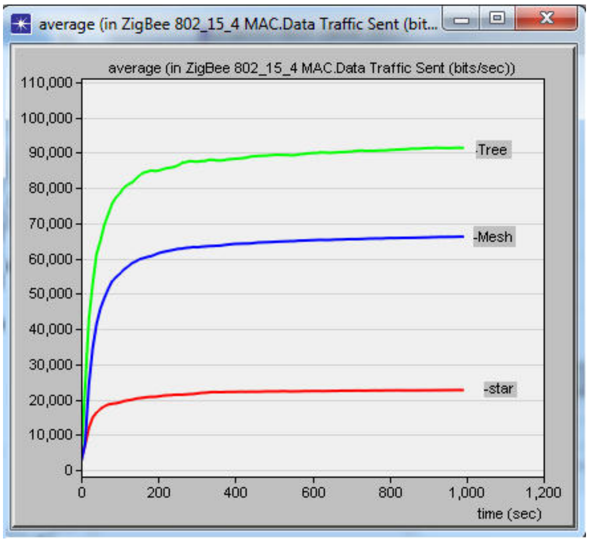

Figure 6: MAC. Data Traffic Sent (bits/sec)

2.3.3 Data Traffic Received

Represents the total traffic successfully received by the MAC from the physical layer in bits/sec. Figure 7 shows that the traffic received is maximum for Cluster-Tree topology because ZEDs communicate through ZCs and ZRs which leads to less collision and less packet drop and results to high traffic received.

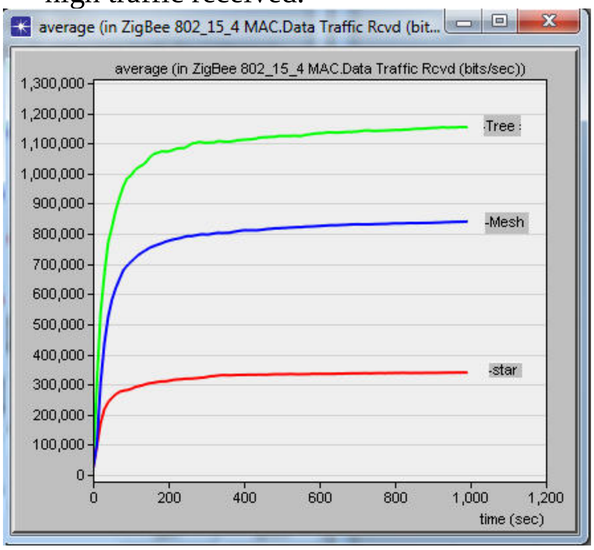

Figure 7: MAC. Data Traffic Received (bits/sec)

This figure also shows that traffic received is the minimum in case of star topology because it has only one PAN coordinator ZC and all other devices act as end devices ZEDs. Results show that the star topology may not be adequate for traditional WSNs for two reasons. First, the sensor node selected as a ZC will get its battery resources rapidly ruined. Second, the coverage of an IEEE 802.15.4/ZigBee cluster is very limited while addressing a large-scale WSN, leading to a scalability problem. The mesh topology enables enhanced networking flexibility, but it induces additional complexity for providing end-to-end connectivity between all nodes in the network. In contrast with the star topology, the mesh topology is more power-efficient and the battery resource usage is fairer, since the communication process does not rely on one particular node. The results show that throughput, data traffic received, and data traffic sent is more efficient and best suited in case of tree topology compares to mesh and star topologies. The summarized results are given in table 2.

2.4 Comparison Between Proposed Network and Previous Work

Number of nodes used in this paper is the same as number of nodes used in [13]. The network is formed by one ZigBee coordinator, six ZigBee routers and nine end device nodes, but in [13] the network is formed by one ZigBee coordinator, three ZigBee routers and twelve end device nodes. Results show that the number of routers increases, the throughput, data traffic sent and data traffic received also increased in the case of tree and mesh topology.

Table 2: Comparisons of Cluster-Tree, Mesh and Star Topologies

Comparisons	Reference [13]			Simulation Results		
	Cluster Tree	Mesh	Star	Cluster Tree	Mesh	Star
Throughput (Kbps)	295.632	287.046	87.046	818.971	624.417	66.141
Traffic Sent (Kbps)	51.083	40.732	28.186	92.744	67.407	22.979
Traffic Received (Kbps)	631.428	501.736	351.460	1171.183	855.659	344.687

Increasing number of fully function devices (routers) reduce the number of collisions and retransmissions. In the case of star topology all nodes work as RFD, So it is not affected by increasing of Routers.

3. Effect of Number of Nodes on Network Performance

Scalability is important issue in WSNs. Scalability to changes in size, density, and topology is important attributes, because sensor networks often operate in uncertain environments. Those changes in network size, node density, and topology should not affect the task and operation of the sensor network. Sensor network routing protocols should be scalable enough to respond to events in the environment. In this paper, number of nodes will be changed and find out effect of number of nodes in throughput, MAC data traffic sent, and MAC data traffic received. The simulations are performed with 10, 20, 30, 40, and 50 nodes in addition to coordinator. The topology used is mesh topology. Network structure is shown in figure 8.

3.1 Simulation Parameters for Mesh Topology

Physical layer parameters are similar to the parameters used in star, mesh and cluster-tree topologies. Table 3 shows application layer parameters used in this section.

Table 3: Application Traffic Parameters

Parameters	Application Traffic					
	Node	Packet Inter-arrival Time	Packet Size	Start time	Stop time	Destination
Mesh Network	PAN Coordinator	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	Router	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	End Device	Constant(1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs

The focus of the study of this simulation is on the following values captured from global statistics (throughput, MAC data traffic sent, and MAC data traffic received).

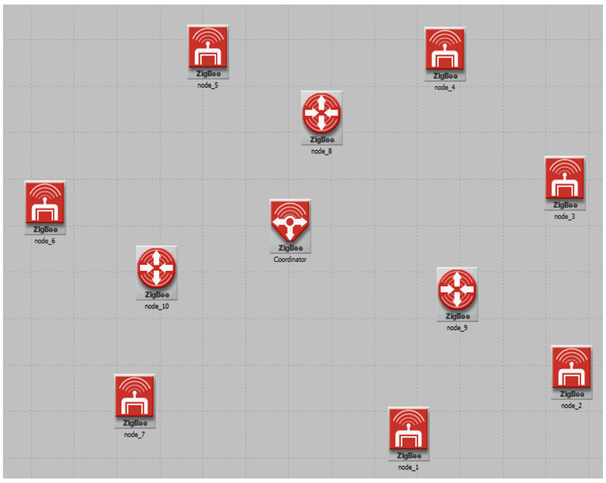

Figure 8: Network Structure for 10 Nodes Mesh Topology

3.2 Results of Mesh Topology

Impact of increasing number of nodes was analyzed in star network [11]. In this paper, the effect of increasing the number of nodes will be discussed for mesh topology.

At first, 10 nodes were placed around the coordinator then 20 nodes were placed and so on to 50 nodes.

Figures 9, 10 and 11 show the throughput, data traffic sent and data traffic received respectively of the simulated network. Results show that, when the number of nodes is increasing the throughput, data traffic sent and data traffic received are also increasing.

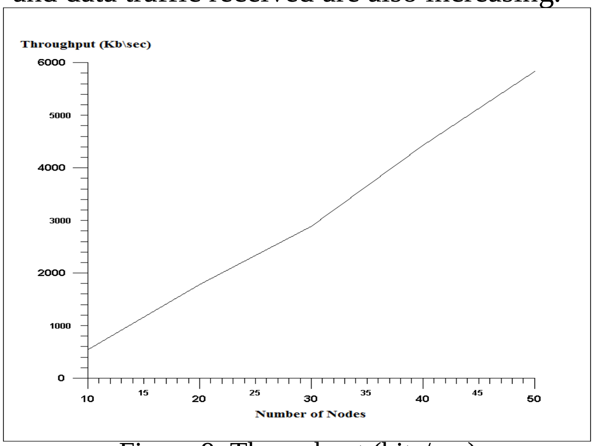

Figure 9: Throughput (bits/sec)

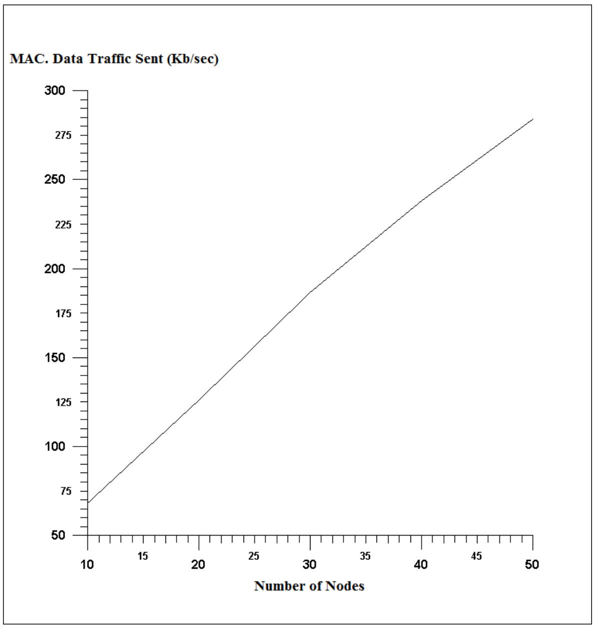

Figure 10: MAC. Data Traffic Sent (Kbits/sec)

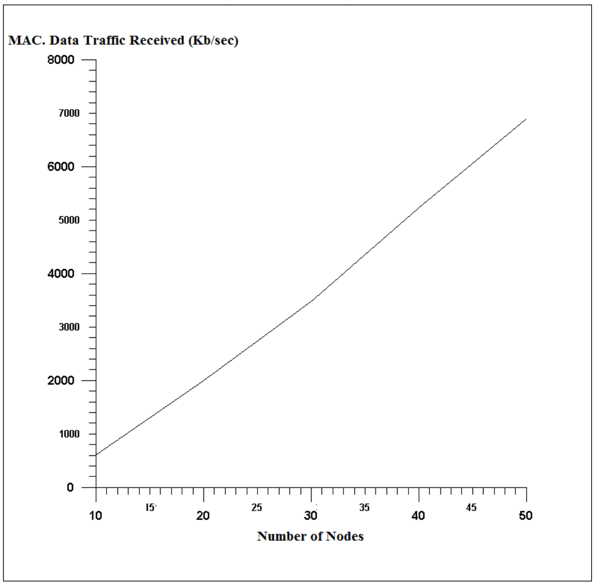

Figure 11: MAC. Data Traffic Received (Kbits/sec)

4. The Impact of ZigBee Device Failure on The Network Performance

Resiliency assessment of WSNs plays a central role in raising the level of trust of WSNs for critical applications. WSNs are exposed to several faults due to wireless medium, limited energy budget they are equipped with, harsh environment, and cheap adopted hardware.

Anode failure in a WSN has the effect of modifying the system topology by the removal of a communication node and its corresponding links. Since a real WSN configuration is not generally a fully connected graph, successive failures may result in a disconnection of the system, namely a disconnection failure, and therefore prevent a set of nodes from reaching the sink the concept of connection resiliency is related to the WSN topology, i.e. the degree of path redundancy in the network. However, the service delivered by the WSN does not encompass only the connection, but also the computation, i.e., even when sensor nodes are potentially connected (a path exists between nodes and sink node), data losses can still occur.

The variation in the amount of useful data received by the sink due to disconnection failures that can be tolerated by the WSN depends on the application required.

4.1. Proposed Method for Assessment Resiliency

A ZigBee coordinator is responsible for initializing, maintaining, and controlling the network. A star network has a coordinator with devices directly connecting to the coordinator so; all nodes consider RFD. For tree and mesh networks, devices can communicate with each other in a multi-hop fashion. The impact of ZigBee device failure on the performance factors in tree topology has been presented [9]. So, this simulation proposes measurements method of resilience by simulating all failure cases in mesh topology. The network is formed by one ZigBee coordinator, six ZigBee routers and eight end device nodes as shown in figure 12.

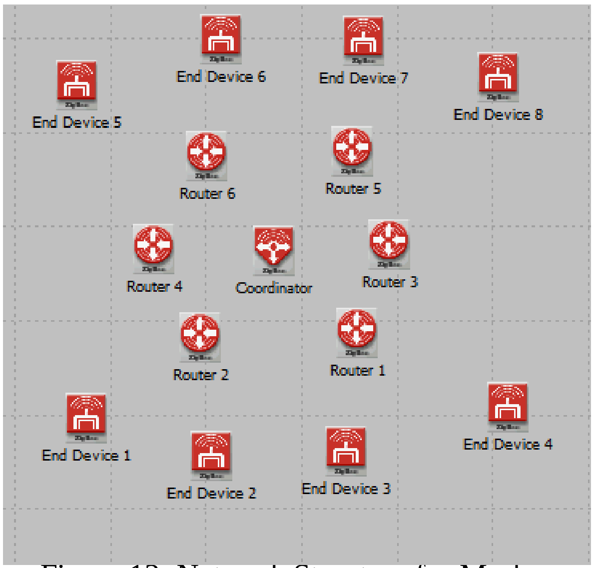

Figure 12: Network Structure for Mesh Topology

The focus of the study of this simulation is on data delivery resiliency by finding out application traffic received, i.e. worst case was considered. Coordinator node failures are not considered, coordinator failure prevents the whole network from communicating. Router failure may block a part of the network and thus may be less critical than the coordinator failure. However, end device failure usually is not critical.

As shown in table 4. If one router fails, there are six cases possible. May be router 1 or router 2 or one of others is the failed router so, six cases was simulated and worst case of those was considered i.e. worst case from the point of throughput at minimum throughput, from the point of data traffic received or data traffic sent at minimum also.

If two routers fail, there are fifteen cases possible ($^6C_2 = 15$).

If three routers fail there are twenty cases possible ($^6C_3 = 20$). And so on as shown in table 4.

All possible cases are sixty three cases have been simulated.

Table 4: Failure Cases

Number of failed routers	Number of possible cases
1	6
2	15
3	20
4	15
5	6
6	1

The parameters used in this simulation are the same as the parameters used in [9] except, in this paper topology used is mesh and end device application traffic is all coordinators and routers.

4.2. Simulation Results

In this section, the impact of router failure was measured by finding out application traffic received by the application layer in packets/sec. Application traffic received and application traffic received ratio are shown in figures 13,14.

To show impact of failure, measuring of packets received ratio from original case (without failure) to six failures (all routers failed). As the number of failed routers increases, the received traffic decreases. Results are summarized in table 5.

Table 5: The Impact of ZigBee Device Failure on the Network Performance Results

Number of failed routers	Traffic Received (Packets\sec)	Traffic Received ratio %
0	13.59	100 %
1	11.88	87.4 %
2	11.82	87 %
3	10.70	78.7 %
4	7.85	57.8 %
5	4.87	35.8 %
6	1.96	14.4 %

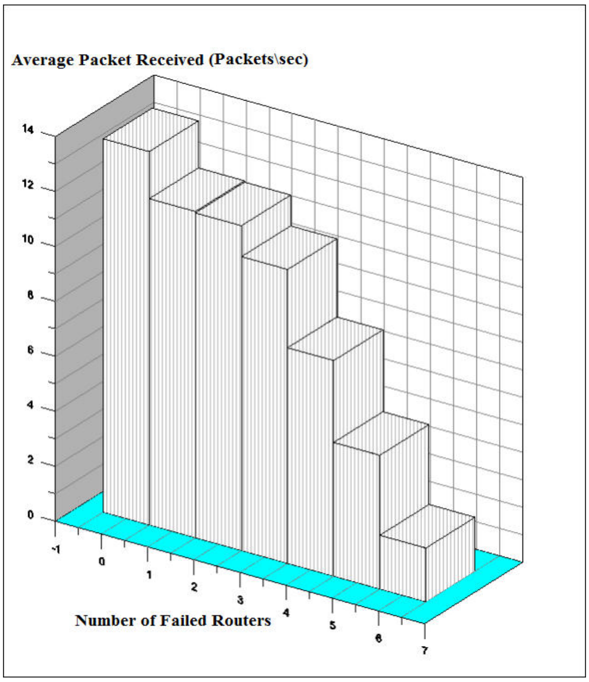

Figure 13: Average Packet Received

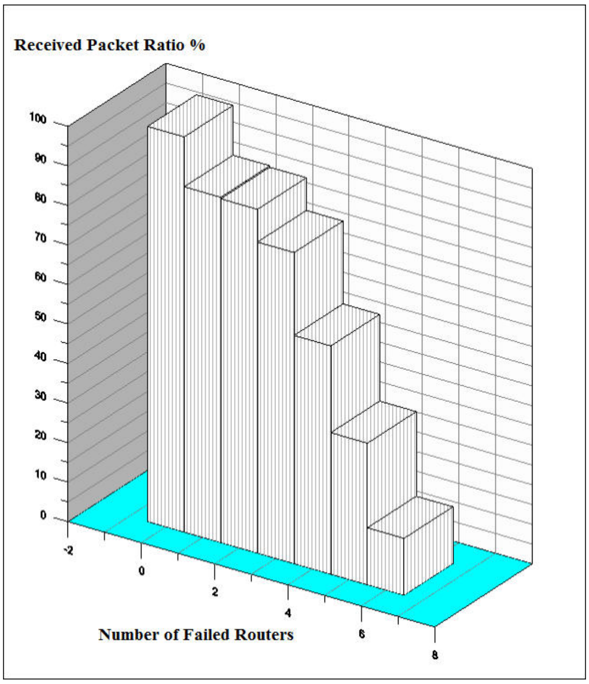

Figure 14: Received Packet Ratio

5. Conclusions

In this paper, three topologies (star, mesh and tree) are simulated. Each of them was contained identical networks. The results show that throughput, data traffic received and data traffic sent is more efficient and best suited in case of tree topology compares to mesh and star topologies for IEEE 802.15.4/ Zigbee standard.

A mesh topology offers multiple paths for massages within the network, so, mesh topology is more flexible than other topologies. This paper presents more analysis for mesh topology.

The results show that the number of nodes increases, the throughput, data traffic sent and data traffic received also increased. This results show that mesh topology is more scalable than star topology. The results also present relation between number of nodes and measured parameters so, may be used to expect the value of these parameters in different number of nodes from 10 nodes to 50 nodes.

Resilience assessment was studied. Sixty three possible cases were simulated and worst cases were considered. Acceptable packet ratio received is differentiated according to the application required. According to acceptable packet delivery threshold, user can decide acceptable number of failed routers by using proposed method of analysis.

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