LR-WPAN Formation Topologies using IEEE 802.15.4

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Abstract

IEEE 802.15.4 protocols are gaining interests in both industrial and research fields as candidate technologies for (WPAN) Wireless Personal Area Networks, (WSN) Wireless Sensor Network and control Wireless Networks applications. This paper analyzes multiple topologies such as Cluster-Tree, Mesh and Star in various scenarios to compare different performance metrics (Throughput, traffic sent, traffic received, Load, End-to-end Delay and etc). In this analysis it is found that Cluster-Tree topology is best as compared to Mesh and Star topology because it take 20% and 45% load greater as compared to Mesh and Star Topology respectively. Similarly its throughput, Traffic Sent, Traffic Received and Delay is better than the other two topologies.

Keywords: LR- WPAN (Low Rate- Wireless Personal Area Network), ZC (ZigBee Coordinator), ZR (ZigBee Router), ZED (ZigBee End Device), Clu ster-Tree, Mesh, Star and IEEE 802.15.4

1 - Introduction

In the modern era we are getting benefit from different electronic appliances, it is compelling need to organize them in this way so that devices can communicate wirelessly. It is obviously preferable to establish wireless network. Wireless networks have changed our lives as the internet has revolutionized this universe. The future is of wireless network and WPAN, will be used in different embedded application like home appliances, military control system, medical, industry etc. These devices are battery operated and communicate in a specific range using wireless radio waves.

Latest standard of WPAN with low data rate and energy efficient protocol is IEEE 802.15.4 also called ZigBee [1]. ZigBee gets its name from the honeybee "*zig-zag* dancing of honeybees to give information to other bees for new food"[2]. It is an open standard for WPAN in monitoring and control fields and introduced by ZigBee Alliance (An organization of more than 150 companies [3].

A Network layout of proposed IEEE 802.15.4 WPAN based topologies is shown in Figure 1(a).

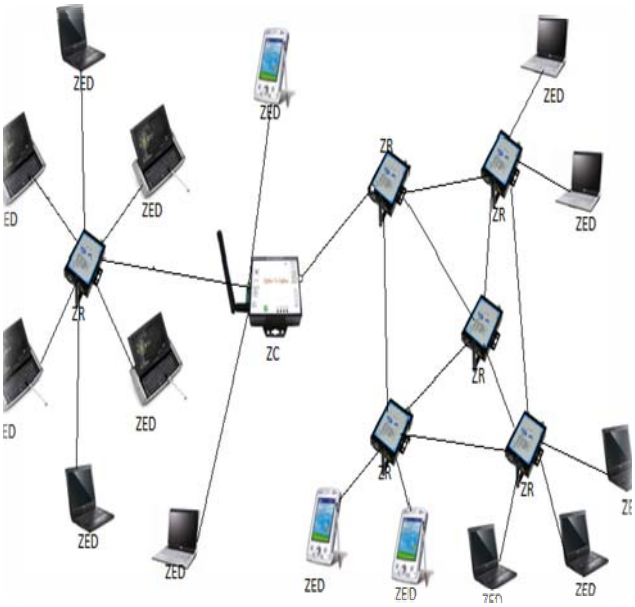


Figure 1(a): IEEE 802.15.4 Network Layout

In Europe and US 802.15.4 operate in the 2.4GHz band or the 868MHz and 915MHz ISM (industrial, scientific, and medical) bands @ 20,40 and 250 kbps by using CSMA/CA and slotted CSMA/CA.[4].

The IEEE 802.15.4 specifies the Physical Layer of (LR-WSNs) Low-Rate Wireless Sensor Networks and the (MAC) Medium Access control sub-layer [5]. ZigBee standard protocol introduces the cross platform communication independent of hardware and software. The protocol stack of 802.15.4 is shown here in diagram.[3]

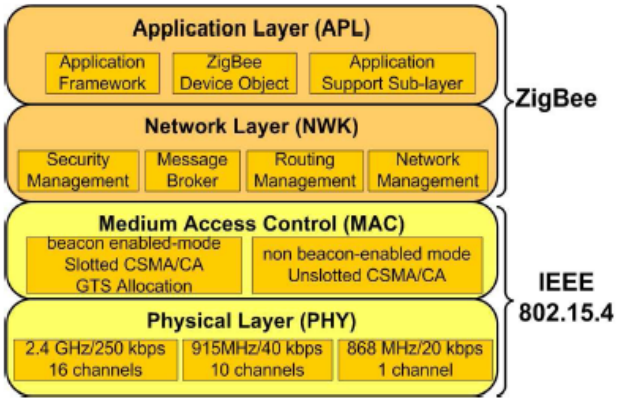


Figure 1(b): Protocol Stack of ZigBee

According to 802.15.4 standard there are three types of devices. 1) Coordinator, 2) Router, and 3) end device. Routers maintain the path to destinations and send data towards the desired device. The coordinator also performs the functionality of the router plus it creates, maintains and manages the network. Both router and coordinator are called (FFDs) *Fully Functional Devices.* Because they can implement all the functions of ZigBee standard. End devices also called (RFDs) *Reduced Functions Devices.* They receive data from devices called sensors arrange this data into packets and send to destination devices [6]. These devices operate in a short range of distance 10 to 20 meters.

In this paper we are analyzing three different topologies star mesh and cluster. The novelty of the work is in the performance of the parameters can be measured by different simulations. These results will be helpful to configure the ZigBee and to select a suitable topology according to situation.

This paper is organized in five parts. Part one describe the brief introduction of WPAN and 802.15.4 standard, in part two we describe the topologies w.r.t WPAN briefly, in part three there are proposed scenarios with multiple hybrid topologies, part four has detailed analysis and discussion of WPAN purposed topologies and part five has final conclusions based on our discussion.

2 - WPAN TOPOLOGIES

Topologies are the physical arrangements of the devices in the network, we discuss three different WPAN topologies in this paper. We use three type of devices in these topologies

(1) ZC ZigBee Coordinator, it is a FFD fully functional device, act as a PAN coordinator which configure and maintain the network[7]

(2) ZR ZigBee Router, it is also a FFD fully functional device, coordinate with ZC, and manages the multi-hope routing.[7]

(3) ZED ZigBee End Device, it is a RFD reduced functional device, it is an end device of ZigBee Network not perform routing, other devices cannot communicate through ZED[7]

2.1 - Star Topology

In case of star topology ZC is central device called ZigBee Coordinator ZC chooses the PAN ID which will not be used by other ZC in the range. It is a centralized network i.e all devices ZED in it cannot communicate directly but can communicate via ZC[7]. Star topology is shown in Figure 2(a)

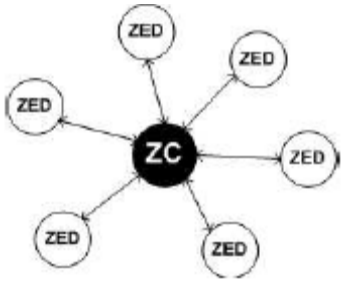


Figure2(a): Star Topology

2.2 - Mesh Topology

It is decentralized network all devices can communicate directly with each other in their radio range[7]. It is a robust and flexible topology. Figure 2(b) shows the mesh topology with ZC ZigBee Coordinator, ZR ZigBee Routers, and ZED ZigBee end devices.

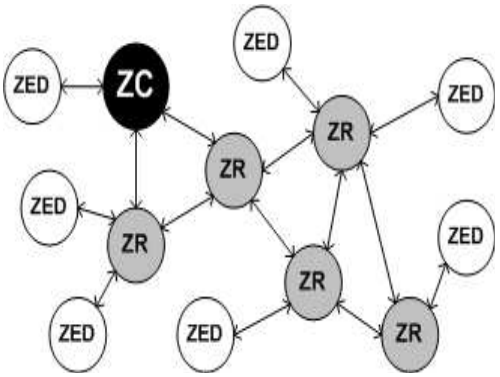


Figure 2(b): Mesh Topology

2.3 - Cluster-Tree Topology

Figure 2(c) shows the cluster topology which is just like the mesh network work with beacon-enabled mode having only one path between pair nodes[7]. In figure ZC

manages the whole network and coordinate with three clusters, these clusters are managed by ZRs.

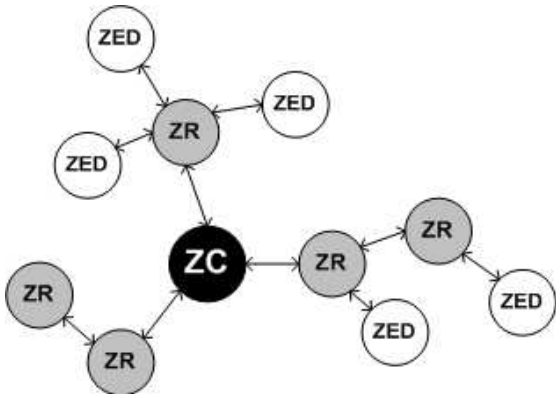


Figure 2(c): Cluster-Tree Topology

3 - Methodol ogy Overview, Network Design and Simulation.

Simulation modeling is the best approach to develop the system w.r.t time as well as cost[8]. The module ZigBee 80215.4 of OPNET Modeler 14.5 is used to develop the simulations. This version supports ring, star , cluster and mesh topologies[8]. Equal number of ZC,ZR and ZED are used in all topologies as briefly discussed here.

Star topology is shown in figure 3(a). A single PAN coordinator is the central device in the star and all end devices arranged around this PAN coordinator. No two end devices can communicate directly with each other without the help of PAN coordinator. End device first send data to PAN coordinator and then PAN coordinator send data to other particular end device.

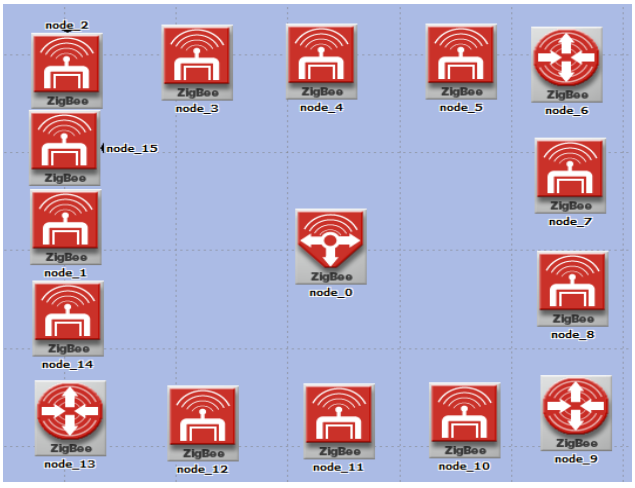


Figure 3(a) Purposed Star Topology

Structure of Mesh topology is shown in figure 3(b). One PAN coordinator to manage the PAN but any end device can send data to any other end device in its range.

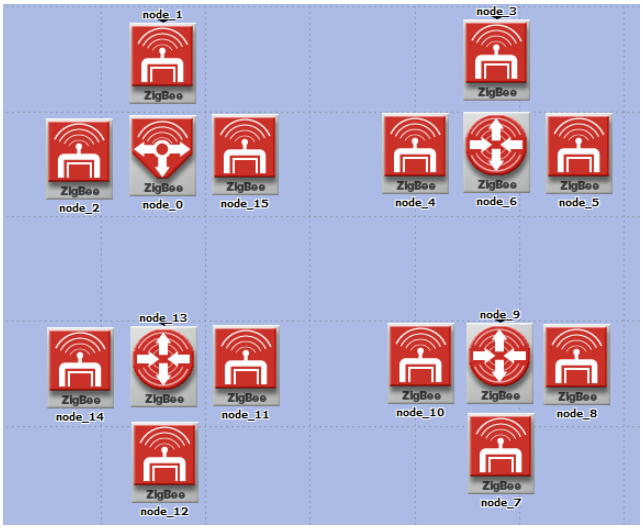


Figure 3(b) Purposed Mesh Topology

Cluster-Tree Topology is shown in the figure 3(c), having 3 Routers. Which manage each network locally and can communicate through PAN Coordinator. It is most popular topology due to its scalable nature w.r.t geographical area.

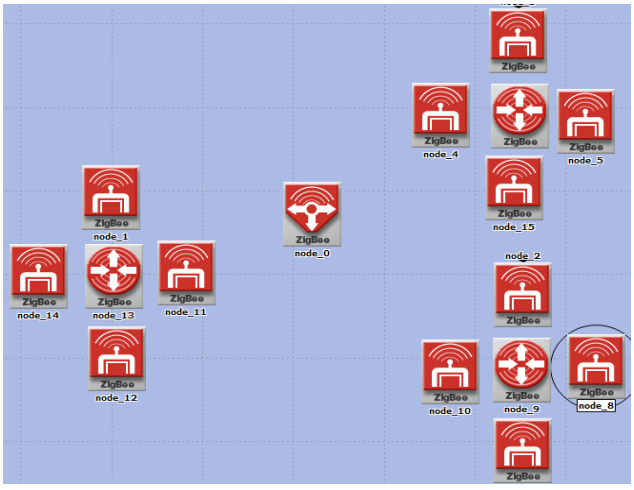


Figure 3(c) Purposed Cluster-Tree Topology

These are the three purposed topologies which are configured in OPNET according to different simulation parameters of Physical layer, media access control, carrier sense multiple access and Application traffic as shown in the following tables:

Table 3.1: Purposed Simulation Parameters of Physical Layer

Physical Layer	
Data rate	Data rate
Receiver Sensitivity	-85 dB
Transmission Band	2.4 GHz
Transmission Power	0.05 W

Table 3.2: Purposed Simulation Parameters of MAC and CSMA

MAC	
ACK wait time	0.05
Total Retransmissions	5
CSMA	
Exponent of minimum back off	3
Exponent of maximum back off	4
Carrier sense duration	0.1

Table 3.3: Purposed Application Traffic

Parameters	Application Traffic					
	Device Type	Inter-arrival time of Packet	Size of Packet	Start Time	Stop Time	Destination
Star Topology	ZC	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	ZR	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	ZC
	ZED	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	ZC
Mesh topology	ZC	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	ZR	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	ZED	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	Parents
Cluster-Topology	ZC	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	ZC and ZRs
	ZR	Constant (1.0)	Constant (1024)	Uniform (20,21)	Infinity	All ZCs and ZRs
	ZED	Exponential (1.0)	Exponential 1024	Exponential (1.0)	Infinity	ZRs

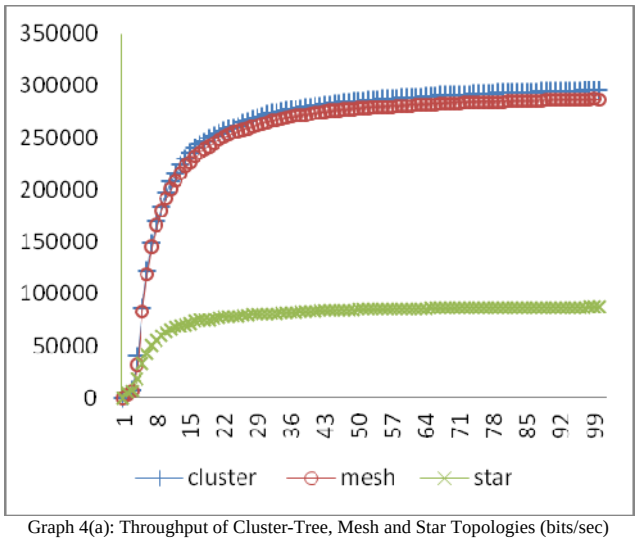
4 - Measurement Results

In this section we describe the results obtained by the simulations. As already it is stated that we have taken three topologies star, mesh and cluster tree with equal number of ZCs, ZRs and ZEDs. Different parametric results (Throughput, Traffic sent, Traffic received, Load, end-to-end Delay) have been explained here that show the impact of performance on different topologies.

4.1 – 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.

Graph 4(a) shows throughput of Cluster-Tree, Mesh and Star topology respectively.

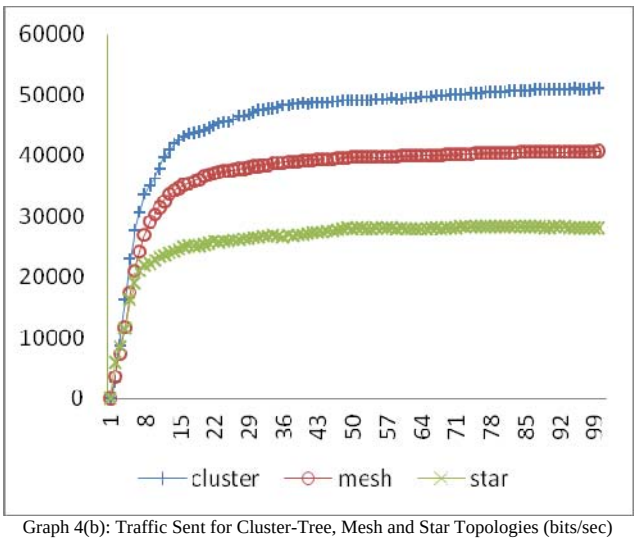


Graph 4(a): Throughput of Cluster-Tree, Mesh and Star Topologies (bits/sec)

Graph 4(a) shows that throughput of Cluster is 295.632 Kbps, 287.046 for mesh and 87.046 for star. This observation shows that throughput is maximum for cluster topology. Because Cluster has four fully functional devices and it is a beacon enabled topology where each cluster is managed separately by PAN routers and then joined with PAN coordinator which reduces the number of collisions and retransmissions. This graph also shows that throughput is minimum in case of star topology because it has only one PAN coordinator ZC and all other devices act as end devices ZEDs. All these ZEDs can communicate through a single ZC which leads to lower throughput. Moreover all nodes in Mesh communicate with each other, so the communication between ZEDs to ZEDs are not efficient than communication between ZEDs to ZC or ZR. Hence Mesh has fewer throughput than Cluster-Tree.

4.2 - Traffic Sent

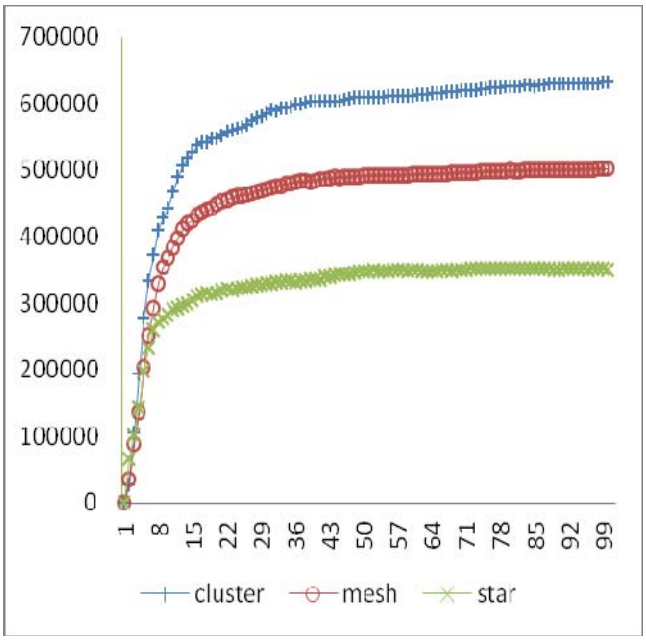
Traffic transmitted by all the 802.15.4 MACs in the network in bits/sec. While computing the size of the transmitted packets for this statistic, the physical layer and MAC headers of the packet are also included. This statistics include all the traffic that is sent by the MAC via CSMA-CA. It does not include any of the management or the control traffic, nor does it include ACKs. Graph 4(b) shows the traffic sent for all topologies. Traffic sent for cluster topology is 51.083 Kbps, 40.732Kbps for Mesh and 28.186 Kbps for Star. This observation shows that Traffic sent is 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 Cluster-Tree topology. This graph also shows that traffic sent for Star is minimum due to one ZC there are more collision and retransmissions



Graph 4(b): Traffic Sent for Cluster-Tree, Mesh and Star Topologies (bits/sec)

4.3 - Traffic Received

Represents the total traffic successfully received by the MAC from the physical layer in bits/sec. This includes retransmissions. Graph 4(c) shows the traffic received by all the topologies. Traffic received for Cluster-Tree Topology is 631.428 Kbps, 501.736 Kbps for Mesh and 351.460 Kbps for Star. This result 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

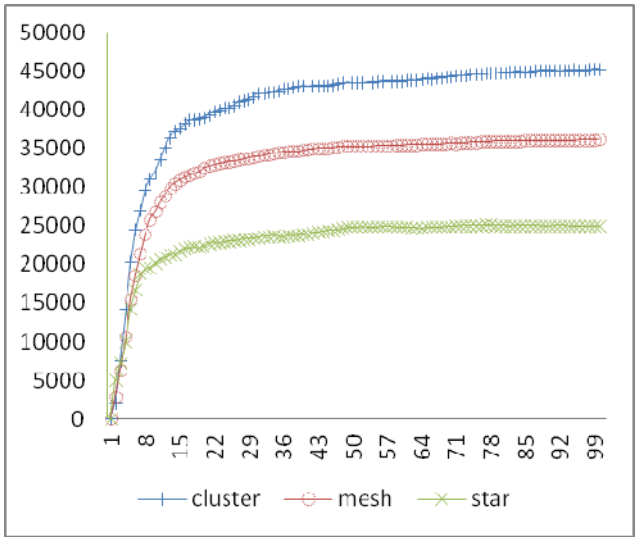


Graph 4(c): Traffic Received for Cluster-Tree, Mesh and Star (bits/sec)

This result also shows that the traffic received is minimum for Star Topology because there all devices communicate through a single ZC which causes high collision rate and high packet drop rate results to lower traffic rate. Same is the case with the Mesh topology but only a few ZEDs are in direct communication of ZCs

4.4 – Load

Represents the total load (in bits/sec) submitted to 802.15.4 MAC by all higher layers in all WPAN nodes of the network. Graph 4(d) shows the load of all topologies. Load for Cluster-Tree topology is 45.351 Kbps 36.218 Kbps for Mesh and 25.006 Kbps for Star. This results also shows that the load is maximum in case of Cluster-Tree topology.

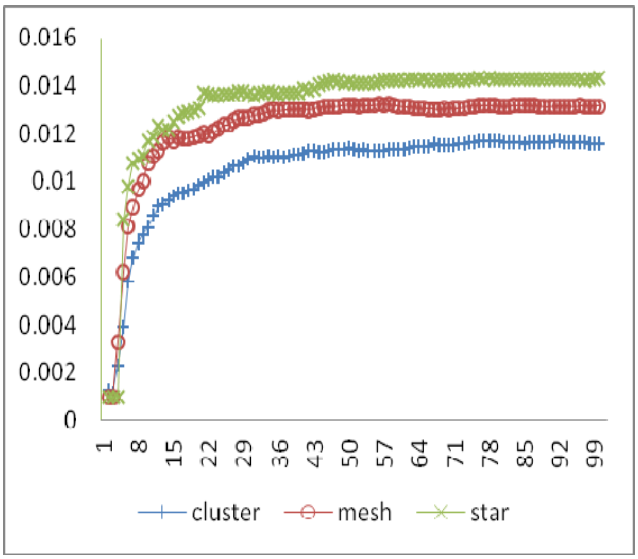


Graph 4(d): Load for Cluster-Tree, Mesh and Star Topologies (bits/sec).

4.5 - Media Access Delay

The total of queuing and contention delays of the data frames transmitted by the 802.15.4 MAC. For each frame, this delay is calculated as the duration from the time when it is inserted into the transmission queue, which is arrival time for higher layer data packets and creation time for all other frames types, until the time when the frame is sent to the physical layer for the first time.

Graph 4(e) shows the media access delay of all topologies Media access Delay for Cluster-Tree topology is 0.01159 sec, for Mesh 0.01313 Sec and for Star is 0.01433 Sec. This graph result shows that the minimum media access delay is for Cluster-Tree Topology and maximum for Star Topology.



Graph 4(e): Media Access Delay for Cluster-Tree, Mesh and Star (sec)

6 – Conclusions

Performance of WPAN ZigBee IEEE 802.15.4 has been analyzed in detail with the help of three different topologies Cluster-Tree, Mesh and Star. Performance of these WPAN Topologies has been analyzed with the help of different parameters like Throughput, Traffic Sent, Traffic Received, Load and Media access delay. This type of analysis is missing in literature which is helpful to understand and to implement 802.15.4 Network. The summarized results are given in the following table 6(a).

Table 6(a): Comparisons of Cluster-Tree, Mesh and Star Topologies

Comparisons	Cluster-Tree	Mesh	Star
Throughput (Kbps)	295.632	287.046	87.046
Traffic Sent (Kbps)	51.083	40.732	28.186
Traffic Received (Kbps)	631.428	501.736	351.460
Load(Kbps)	45.315	36.218	25.006
Media Access Delay (Sec)	0.01159	0.01313	0.01433

From the discussion in Section – 4 and summarized results as shown in Table 6(a) it is concluded that for WPAN ZigBee 802.15.4 the best and efficient topology is Cluster-Tree topology as compared Star and Mesh topology.

Acknowledgements

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