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Zigbee Based Wireless Sensor Networks for Smart Campus

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Abstract: *A network which connects a bunch of distributed low-power sensor nodes together, with each node dedicated to a predefined operation can be visualized as a Wireless Sensor Network (WSN). The network must have the capability of gathering and transferring the data generated by end nodes efficiently. The major parts of Zigbee based LR-WPAN (Low Range-Wireless Personal Area Network) are- coordinator, routers and end devices. In this paper the authors concentrated on Zigbee based LR-WPAN and analyzed the effect of static and dynamic state of Zigbee PAN Coordinator on the performance of the network. Here the analysis is made on 3 topologies namely- star, mesh and tree with the help of OPNET modeler simulations. Authors suggested that instead of making the end devices dynamic, the coordinator can roam around the network area more easily, giving better global network performance over static coordinator network in terms of throughput and end-to-end delay. For different topologies, different impacts on network parameters are obtained. The main aim of this work is to evaluate, through simulations, the effect of coordinator mobility in a ZigBee/IEEE 802.15.4 based wireless personal area network and allow the people to mould the network topology as per the requirement and performance obtained here.*

Keywords: *WSN, mobile coordinator, star, mesh and tree topologies, Throughput, End to End delay.*

I. INTRODUCTION

Nowadays wireless sensor technology is becoming a popular way to create wireless personal area network (WPAN) due to its low cost, low power consumption applications, convenience of using wireless signals in open areas such as office space or home rather than having to lay out wires and scalability but energy-saving stays a critical design issue. [1] It has applications in environment monitoring, military operation, intelligent home, medical and health and other commercial field. [2], [3], [4].Devices in a LR-WPAN (Low-range wireless personal area network) can be classified as full function devices (FFDs) and reduced function devices (RFDs). [5] One device is designated as the PAN coordinator (FFD) which is responsible for monitoring the network activities and its devices, it guides and instructs the data flow across the network; others are routers and end nodes (RFDs). A FFD monitors the whole network via control packets and handles security/failure cases. It has the capability of becoming a PAN coordinator or associating with an existing PAN coordinator. A RFD can only relay the data but cannot change the task on its own assigned to it.

Zigbee and IEEE 802.15.4 are not the same. [6],[7] It is a standard base network protocol, widely used for LR-WPAN and supported solely by Zigbee alliance using the transported services of IEEE 802.15.4 network specifications. Zigbee protocol stack has basically 4 layers- application, network and security, MAC layer and physical layer. IEEE defined only latter two for LR-WPAN while former two are provided by Zigbee Alliance. Network and security layer also includes the application framework necessary for application processing.

Zigbee networks can support a large number of nodes; approx. 64,000 with dynamic routing and single coordinator. Every node can be configured as a multifunction device with at most 240 applications running at a time. [8] The performance of the network depends on the topology employed which is highly application specific. Here authors tried to simulate via OPNET modeler the impact of various topologies on the global MAC statistics like throughput, global application statistics like end-to-end delay and global network statistics like number of hops which represents average number of hops travelled by application traffic in PAN. Most of the advanced applications of Zigbee Networks like remote location event sensing deploy mobility of the nodes rather than static structure.[9],[10] Authors think that the mobility of the prime node (PAN coordinator) greatly affects the performance of the system.

In section II, authors threw light on the Zigbee specification and its conjunction with IEEE 802.15.4, its protocol architecture and the parameters of each layer that we needed and configured in the study presented. In section III, the three major components of Zigbee based LR-WPAN are briefed and a detailed discussion about each topology of this network is carried out. Section IV demonstrates the simulation scenarios we have taken along with an example of its application. In section V simulation results in terms of throughput and end-to-end delay are given along with the interpretations.

II. ZIGBEE-802.15.4- OVERVIEW

The growth in wireless technology has lead to an emergence of many standards specifically in the ISM radio band with frequencies**:** 868 MHz, 915 MHz and 2.4 GHz. The 868 MHz frequency band is used mainly in Europe, the 915 MHz mainly in North America while the 2.4 GHz is used worldwide. There was always a need for a standard communication between sensors with low data rate and low power consumption. As an answer to this plight, many companies forged an alliance to create a standard which could be accepted worldwide. It was the Zigbee Alliance which created **Zigbee. [**11]

ZigBee is a specification based on IEEE 802.15-2006 standard used for high level communication protocols, creating a personal area networks from small and low-powered digital radio system. ZigBee's are capable of transmitting data over long distances by passing data through intermediate devices, reaching more distant ones, thus creating a network. The key components of a Zigbee network are- PAN coordinator, routers and end devices. All of them can be configured to deal with multiple applications as large as 124 simultaneously. ZigBee's are employed in applications which require a lower data rate, longer battery life, and secured networking. It has a defined data rate of 250kb/s. The technologies determined in the ZigBee specification are designed to be simpler and less expensive than other (WPANs) technology.[6]

ZigBee consists of four layers. The top two (Application and Network & security) layer's specifications are provided by the ZigBee Alliance to provide manufacturing standards. The bottom two (MAC and PHY) layer's specifications are provided by the IEEE 802.15.4-2006 standard to ensure coexistence without interference with other wireless protocols, such as Wi-Fi. [12]

2.1 Zigbee stack protocol

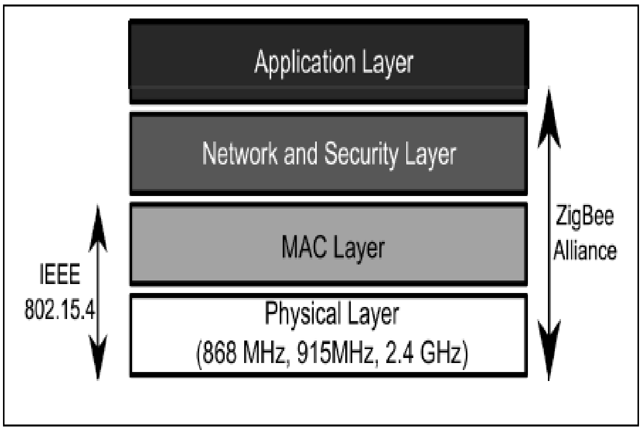

Fig 1: Zigbee Stack Protocol Layers

2.1.1 Physical Layer

Zigbee uses three frequency bands for transmission of data-

- 868 MHz band with a single channel having a data rate of 20 kb/s.
- The 915MHz band with 10 channels, and each channel having a central frequency separated from the adjacent band by 2 MHz and data rate of 40 kb/s. BPSK modulation technique are used in which symbols are transmitted at 1 bit per symbol.
- The 2.4 GHz ISM band having 16 channels, 5 MHz wide offers 250 kb/s of data rate. It uses O-QPSK modulation with 4 bits/symbol transmitted using DSSS with 32 Bit chips. [12]

In our work we took 2.4 GHz transmission band with 0.05 W transmission power.

2.1.2 MAC layer-

The transmission Channel is accessed primarily through Carrier Sense Multiple Access- Collision Avoidance (CSMA-CA) protocol. The MAC layer can take care of transmitting data. The MAC layer decides whether to use slotted or unslotted CSMA-CA. It also takes care of scanning the channel, starting PANs, detecting and resolving PAN ID conflicts, performing device discovery etc [12].In our scenarios we kept channel sensing duration as 0.1 seconds in order to optimize the power consumption with acknowledgements enabled.

2.1.3 Network and Security layer-

The network layer takes control of network startup, device configuration, topology specific routing, and providing security. On each node, the network layer is the part of the stack that does the route calculations, neighbor discovery and reception control. [12] In our work the route discovery time-out is kept as 20 seconds, sufficient for network area of 100 meters range.

2.1.4 Application Support Sub Layer-

It interfaces the network layer and application layer providing a general set of services through two entities, the APS Data Entity and APS Management Entity. These provide services like making application level PDU, group filtering, and managing Object database. [12]

III. ZIGBEE NETWORK TOPOLOGIES-OVERVIEW

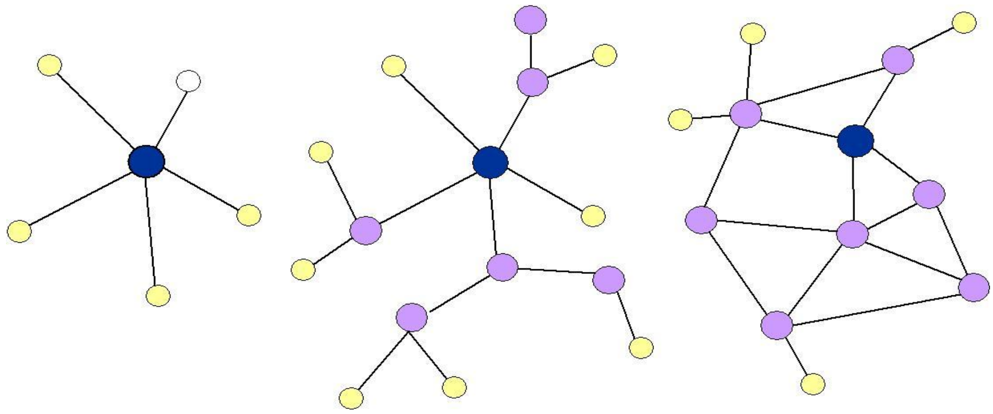

Fig 2 ***STAR*** ***TREE*** ***MESH***

3.1 Zigbee Network Devices:

3.1.1 Zigbee Coordinator (ZC): It is the most capable device which forms the root of the network tree and might bridge to other networks. It collects and stores information about the network.

A **coordinator** has the following characteristics: It

- Allows routers and end devices to join the network
- Assists in routing of the data
- cannot sleep- always on device.

3.1.2 Zigbee Router (ZR): A Zigbee Router can act as an intermediate device, passing on data from other devices as well as running an application function.

3.1.3 Zigbee End devices (ZED): Its job is to communicate with the parent node (either the Coordinator or a Router).It cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life. A ZED requires the least amount of memory, and so it is cheaper as compared to ZC or ZR.

3.2 Zigbee Network Topologies:

3.2.1 Star Topology: In star, a coordinator is the prime node and all other devices are directly connected to it. Every data exchange between 2 end devices must pass through the coordinator first. This topology is very much vulnerable to collapses since the whole network goes down if the prime node fails. Employing routers is a waste of energy here as their functionality is never actually used. [13]

3.2.2 Tree Topology: In tree, the prime node would be the root node of the network with hierarchical body. There is a point to point connection between any 2 nodes i.e. a single path exists for reaching a node. Due to the self healing capability of dynamic routing employed, in case of collapses the backup would be prepared from the vicinity instantly(if available).[13]

3.2.3 Mesh Topology: In mesh, data packets can be directly relayed between the routers and then to nodes. They need not pass through the prime node. Such a network has multiple paths for reaching a node and hence a backup can be made easily in failure situations e.g. if a router stops working then any nearby router will tackle the traffic of that router in a very finite time without affecting the performance much.[13]

	Pros	Cons
Star	1. Easy to synchronize 2. Support low power operation 3. Low latency	1. Small scale
Tree	1. Low routing cost 2. Allow multihop communication	1. Route reconstruction is costly 2. Latency may be quite long
Mesh	1. Robust multihop communication 2. Network is more flexible 3. Lower latency	1. Routes discovery is costly 2. Needs storage for routing table

Table 1: Pros and Cons of Topologies

In mesh and tree, if 1 node sends data and in the path if both coordinator and router are available for forwarding the traffic then both will do and the destination will receive from both the same traffic but with some noise and quality degrades slightly. While in star, for such a situation only coordinator will forward the traffic, router won't. Hence the traffic will reach the destination with accuracy.

IV. OPNET- BASED SIMULATION SCENARIOS FOR CAMPUS ENVIRONMENT

OPNET or Optimized Network Engineering Tools is robust tool used to model and simulate sensor networks. The current version support simulation of heterogeneous networks which can be used in various communications protocols. OPNET supports simulation of the network at packet-level to analyze fixed, mobile and satellite networks. The OPNET simulation environment favours the simulation of Zigbee based sensor networks by providing three components.[14],[15],[16].

We have taken a very practical situation of a campus having a dimension of 100m x 100m.The results are then simulated. This practical situation can be used to link various Departments such as in Hospitals, Schools and College etc. Consider a College having six departments and each department is connected to central coordinator. These departments are linked with 3 different network topologies namely star, mesh and tree. Efficiency of each network is evaluated .In the second scenario we have considered mobile Zigbee coordinators. These mobile coordinators are very useful for an industry run application process or may be in battlefield to keep track of enemies.

We are considering two scenarios. First, authors are comparing the three possible topologies (Star, Mesh and Tree) to each other using only *one* ZigBee Coordinator (ZC), *six* ZigBee routers (ZR) and *six* ZigBee End devices (ZED) in each topology. The comparison includes end-to-end delay and global throughput. For the second scenario, we are taking the same three topologies and same Zigbee devices but ZC as mobile.

4.1 Simulation Scenarios

4.1.1 Dynamic Zigbee Coordinator-Star Topology

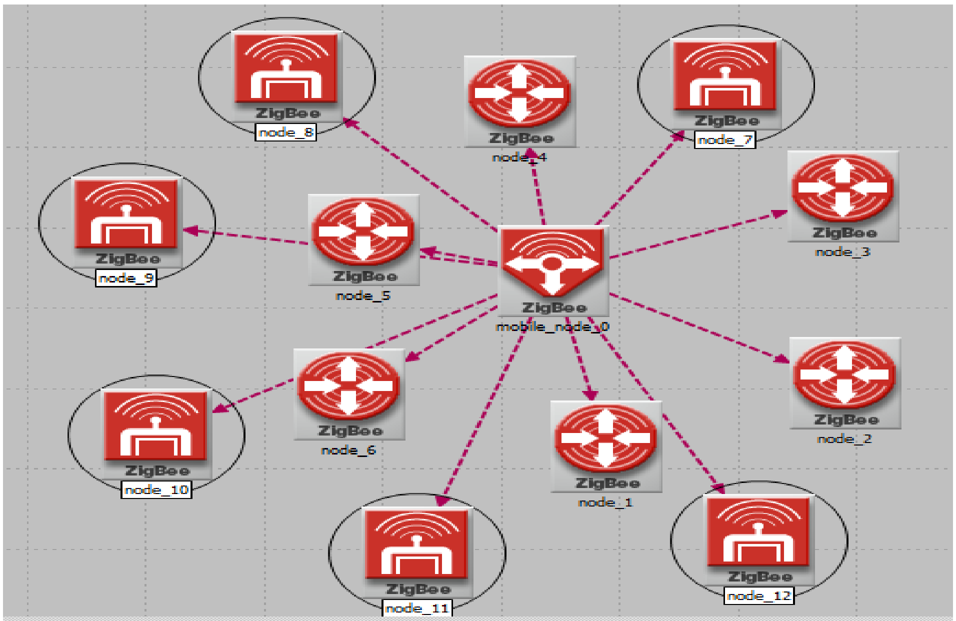

Fig-3

4.1.2 Dynamic Zigbee Coordinator-Mesh Topology

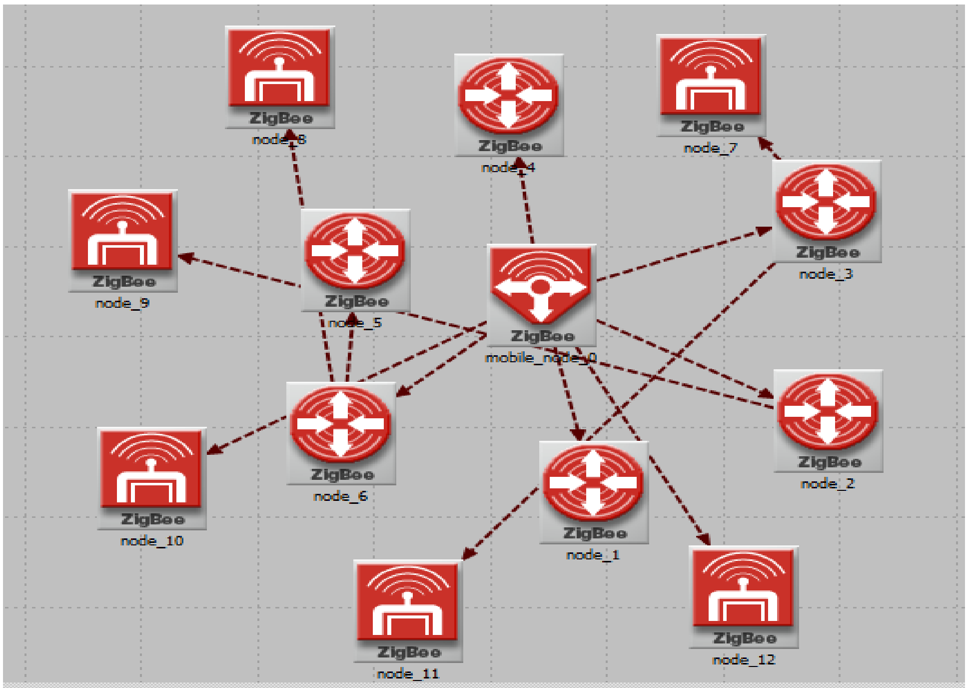

Fig-4

4.1.3 Dynamic Zigbee Coordinator-Tree Topology

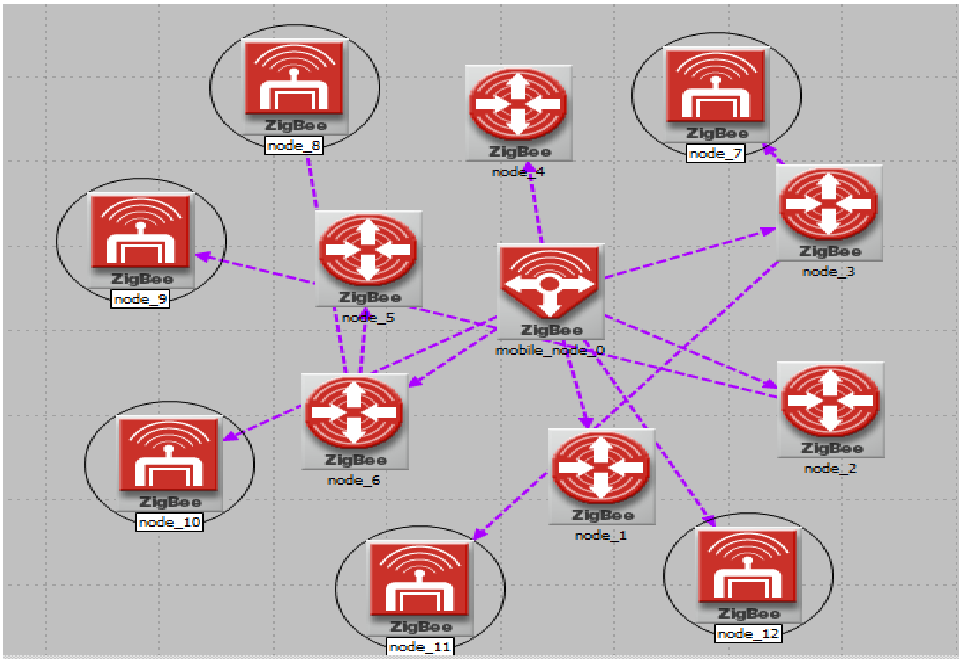

Fig-5

V. SIMULATION RESULTS

We have considered Throughput and End to End delay as the key parameters for comparing efficiency between Star, Mesh and Tree topologies.

5.1 Throughput:

The Throughput or Network throughput is the rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. It is usually measured in bits per second bit/s or bps. During the simulation throughput as a global statistics has been taken so any object could contribute to its value as it gives a general idea of the overall throughput of the system.[17]

5.1.1 Throughput: Static Zigbee Coordinator

For ZC as Static, throughput is better in the case of Tree Topology with average value of 35500bits/s

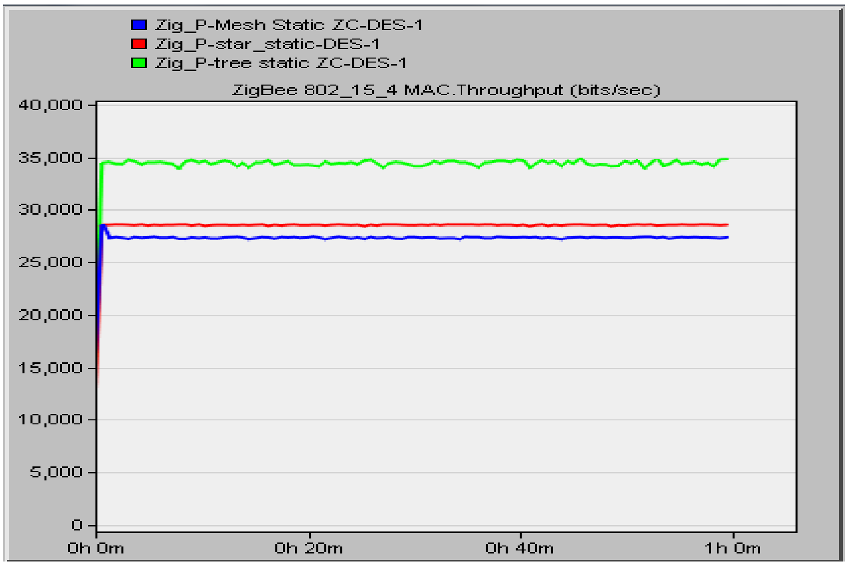

Fig 6

5.1.2 Throughput: Dynamic Zigbee Coordinator

For ZC as Dynamic, Tree topology performs better as compared to Static ZC with throughput slightly more than the former by 1500bits/s.

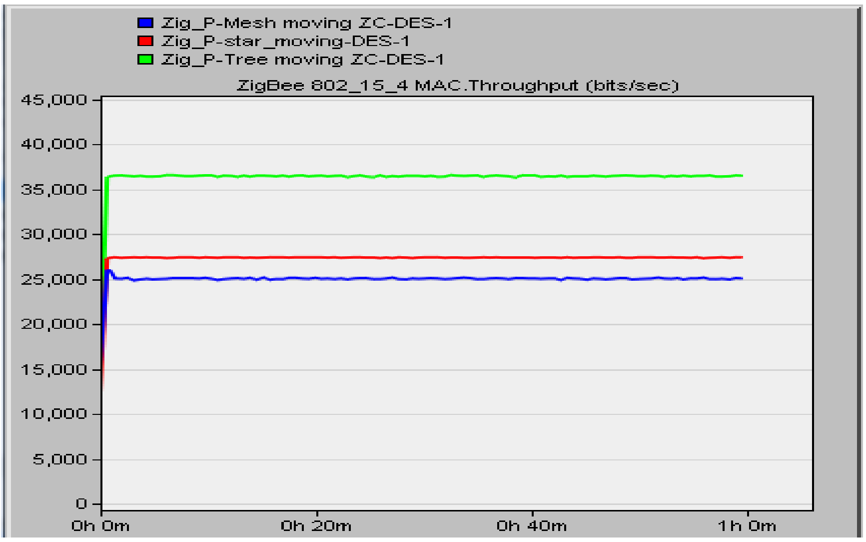

Fig 7

5.2 End To End Delay:

End-to-end delay refers to the time taken for a packet to reach from source to destination in a network.

5.2.1 End to End delay: Static Zigbee Coordinator:

ZC as Static Mesh topology is having least End to End delay of 0.0132s.

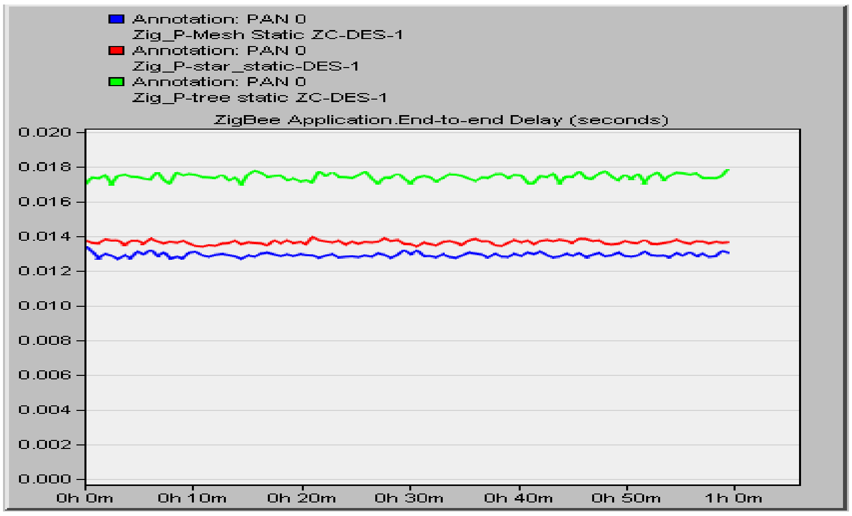

Fig 8

5.2.2 End to End delay: Dynamic Zigbee Coordinator:

ZC as Dynamic, Mesh topology is having least End to End and has a better performance as compared to Static ZC.

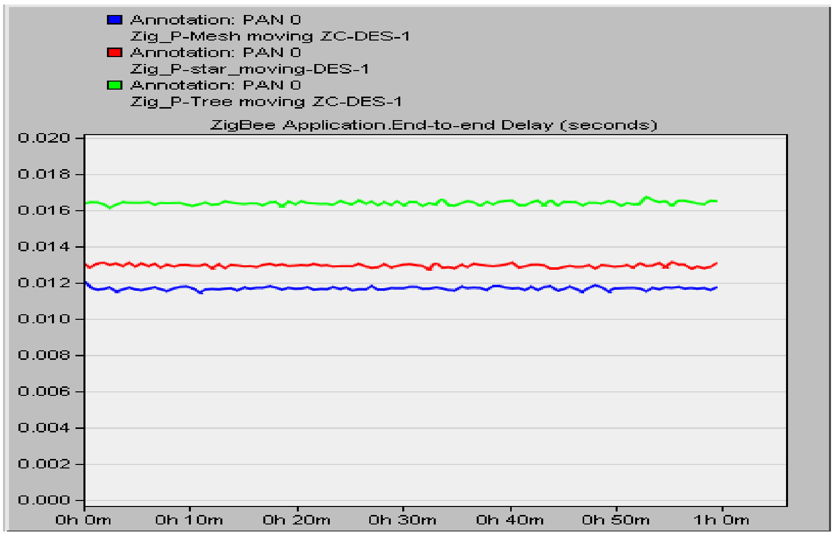

Fig 9

Network Topologies	Throughput	End-End delay
Star	Static ZC-29000bits/s Dym ZC- 28000bits/s	Static ZC- 0.0142 sec Dym ZC- 0.0135 sec
Mesh	Static ZC-28000bits/s Dym ZC- 27500bits/s	Static ZC- 0.0132 sec Dym ZC- 0.0122 sec
Tree	Static ZC-35500bits/s Dym ZC- 37000bits/s	Static ZC- 0.0178 sec Dym ZC- 0.0168 sec

Table 2: Simulation Table

Parameters	Value		
	Star(Default)	**Tree**(Default)	**Mesh**(Default)
Max. Children	255	7	7
Max. Routers	0	5	5
Max. Depth	1	5	5
Transmit Band	2.4GHz	2.4GHz	2.4GHz
Transmitted Power	0.05	0.05	0.05
ACK mechanism	Enabled	Enabled	Enabled

Table 3: Zigbee Parameters

Network Size (Campus)	100m*100m
Number of End Devices	6
Number of Routers	6
Number of Coordinators	1
Mobility Model	Random walk-20m/s
Simulation Duration	3600 s

Table 4: Simulation Parameters

VI. CONCLUSION

In this paper we have gone through several analysis for achieving optimum end to end delay and throughput for smart campus. By making the coordinator as dynamic in Zigbee based LR-WPAN, throughput of tree topology increases considerably as compared to mesh and star topologies. Our OPNET results say that by using dynamic coordinator minimum end-to-end delay is achieved. In dynamic coordinator end to end delay reduces when compared to static, hence when end to end delay reduces automatically energy consumption also reduces . We conclude that our analysis achieved good performance in terms of throughput and end-to-end delay for dynamic tree topology as compared to any other. Further this work can be extended for large scale WSNs.

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