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# On the Selection of Optimum Topology for QoS aware ZigBee-WiMAX Based Healthcare Monitoring System

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***Abstract— in this work I have proposed different network architectures using OPNET which consists of combination of ZigBee and WiMAX topologies. ZigBee is used to sense the data from the human body whereas WiMAX is used as a backbone to deliver the data at the distant location using microwave links. The nee of using WiMAX with ZigBee arises as ZigBee network's coverage area is limited to few meters. This paper provides the layout architecture on the healthcare monitoring system developed using different combination of topologies of WiMAX and ZigBee in OPNET. The successful implementation of ZigBee-WiMAX based healthcare network depends upon the performance of the different proposed networks. In this paper the performance comparison is done between six different ZigBee-WiMAX topology combinations which include ZigBee mesh WiMAX mesh, ZigBee star WiMAX mesh, ZigBee tree WiMAX mesh, ZigBee mesh WiMAX Point to Multipoint (P2MP), ZigBee star WiMAX P2MP and ZigBee tree WiMAX P2MP topologies. Through simulations performed in OPNET, QoS parameters like throughput, load and delay have been evaluated to obtain the optimal performance of the proposed system based and to select best suitable topology combination out of the proposed network architectures.***

***Keywords: OPNET; ZigBee; WiMAX; Microwave; Coverage; Healthcare; Monitoring; Mesh; Star; Tree; P2MP.***

## I. INTRODUCTION

### A. *Introduction to ZigBee*

ZigBee belongs to the IEEE family of standards as IEEE 802.15.4. ZigBee is used to implement the network which requires low data transfer rate, low power consumption and secure networking. It is used in number of applications like weather monitoring and forecasting, healthcare monitoring, home and office automation [1]. In the healthcare applications ZigBee sensors are installed in the patient's body. These ZigBee sensors sense the data related to the various health issues from the patient's body and send appropriate report to the person/doctor who monitors this data. These ZigBee sensors send the report by connecting with the existing WLAN or LAN architecture because the coverage area of ZigBee network is limited from 10 meters to 100 meters. The existing network architecture acts as a backbone for the ZigBee network which enables it to communicate over a larger distance than its coverage area.

 

The basic elements of a ZigBee network include end devices, routers and a coordinator [2]. The end devices are used to sense the data from the environment. The routers are optional to use if required according to the demands of the network. The coordinator acts as a central device to the whole network. It is also called as root of the network and acts as a bridge to connect the network to the outside networks. ZigBee coordinator is also said as the starting point of the network. The arrangement of these devices leads to the formation of ZigBee topologies. There are three ZigBee topologies. In ZigBee mesh topology all our nodes can communicate with each other and can pass their own data traffic through another node [3]. In ZigBee star topology the use of routers is optional and all the end devices directly interact with the ZigBee coordinator. Unlike ZigBee mesh topology no two end devices can communicate with each other. The end devices transfer the sensed data directly to the ZigBee coordinator [4]. ZigBee star topology is heavily dependent on the coordinator due to which it can face certain problems. ZigBee tree topology makes the use of a tree like hierarchical structure to implement the network. The network consists of three layers of nodes. The ZigBee coordinator acts as the root of the tree and is present at the first layer. The second layer comprises of the routers. The third layer consists of the end devices which sense the data from the external environment. The ZigBee end devices act as leaf nodes of the tree and send the sensed data to their corresponding routers. The routers then transfers the traffic received from the end devices to the ZigBee coordinator [5].

B. *Use of ZigBee in Healthcare Systems*

ZigBee Healthcare offers a global standard for interoperable devices enabling reliable and secure monitoring and management of non-critical, low-acuity healthcare services. The principal application areas of ZigBee devices in healthcare monitoring and management are:

- Disease Management (DM)
- Personal Fitness Monitoring (PFM)
- Personal Wellness Monitoring (PWM)

ZigBee plays an important role in the modern healthcare services. ZigBee sensors can be wearable or can be installed in the patient's body via surgery. ZigBee sensors senses the abnormal health related data from patient's body such as increased heart rate, increased or decreased blood pressure level, increased or decreased blood sugar level, ECG, body temperature and many other health related issues [6]. ZigBee devices compare the sensed data with the pre specified data which defines the normal condition. If any type of discrepancy is found in the sensed data then the ZigBee devices sends the data over a longer distance to the operators or doctors which takes particular decision according to the seriousness of the condition of the patient. It also enables the doctors to regularly monitor the patient's activities [7]. Another benefit of using this technology is that the patient need not to visit the doctors regularly as the doctor is already in touch with the medical condition of the patient.

C. *Introduction to WiMAX*

In today's world the demand of mobile broadband access is increasing day by day. The conventional wired broadband techniques are unable to completely fulfill that demands. The conventional broadband technologies include DSL, Dial-up etc. But this type of internet services can't be provided at distant rural areas and it does not provide any kind of mobility to the devices connected with the network [8]. For the solution of this problem the concept of WiMAX was introduced by WiMAX Forum which was formed in June 2001. WiMAX provides high speed wireless broadband access to fixed as well as mobile systems. WiMAX follows IEEE 802.16 family of standards also called as WMAN (Wireless Metropolitan Area Network). WiMAX is used to replace the conventional wired broadband. WiMAX consists of flexible channel sizes and can support hundreds or thousands of users. The channels sizes from 1.5 Hz to 20 Hz accordingly. WiMAX also provides some level of Quality of Service (QoS). WiMAX can also be operated in combination with the existing infrastructure so that lesser or no wastage of the resources should be made. The original version of WiMAX specified a physical layer operating in the 10GHz to 66 GHz range. WiMAX 802.16a added specifications for 2GHz to 11 GHz frequency band. The various features provided by WiMAX are Scalable bandwidth and data rate support, Link-layer retransmissions, Adaptive modulation and coding (AMC) etc.

WiMAX consists of two topologies. First one is Mesh topology in which it is not compulsory for all the subscriber stations (SSs) to communicate with the base station (BS). The communication can take place between two SSs only or the data can be passed through other SSs until it reaches the BS. The Mesh topology is also used to increase the coverage area of the BS as nodes present outside the coverage area of a BS can also connect with the network by using intermediate SSs as a temporary BS. The intermediate SS helps in extending the coverage area of the BS. Second WiMAX topology is Point to Multipoint (P2MP) topology which is similar to the cellular network. In WiMAX P2MP topology all the SSs only communicate with the help of the BSs under whom coverage area they are being operated. No two SSs can communicate directly with each other. If one SS has to communicate with another SS then the sender SS will send the data to the BS which

 

locates the position of the receiver SS and transfers the data to the receiver. If the receiver node is under the coverage area of another BS, then firstly the communication path between the two BSs is established by agreeing on certain rules and protocols. The BS can directly send data to all or selected number of its SSs.

## II. SIMULATION METHODOLOGY AND ENVIRONMENT

The architectures I have proposed contains the combination of three different ZigBee topologies: Mesh topology, Star topology and Tree topology in combination with two topologies of WiMAX: Mesh topology and P2MP topology. Six different combinations of networks are proposed using these topologies of ZigBee and WiMAX in OPNET.

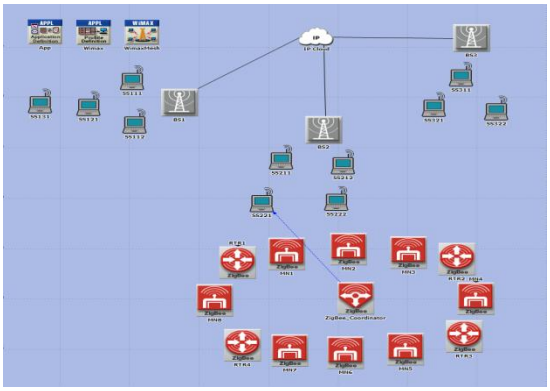

Fig. 1 – ZigBee Mesh WiMAX Mesh Topology

The simulation of these topologies is being carried out to find out the combination of best suitable topologies to implement an efficient QoS aware healthcare system. The following figure 1 to figure 6 shows the different proposed architectures using different combinations of ZigBee and WiMAX networks in OPNET.

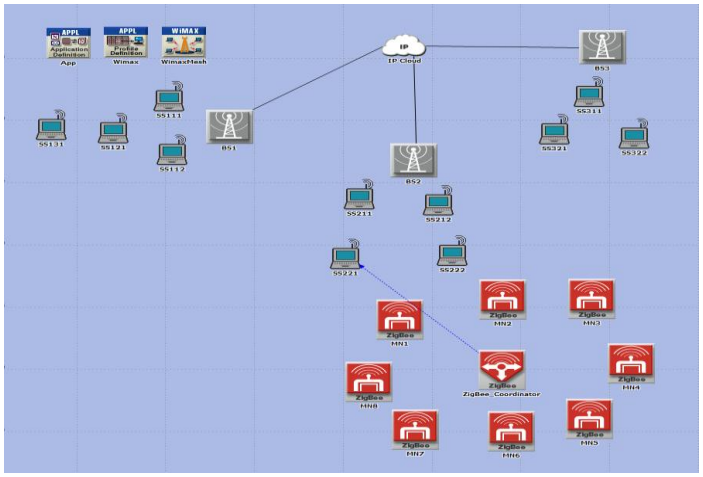

Fig. 2 – ZigBee Star WiMAX Mesh Topology

 

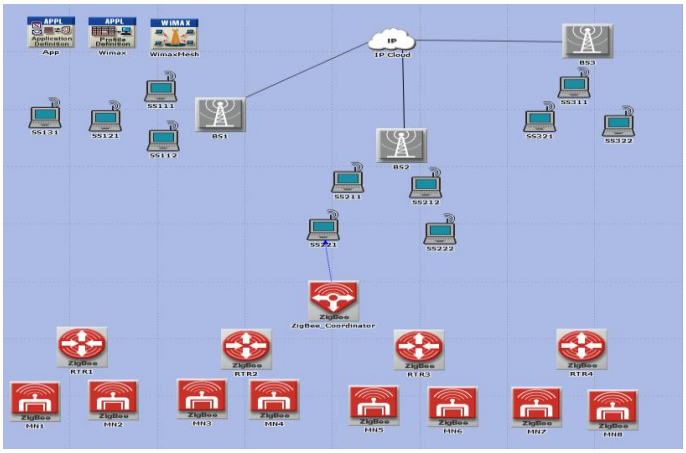

Fig. 3 – ZigBee Tree WiMAX Mesh Topology

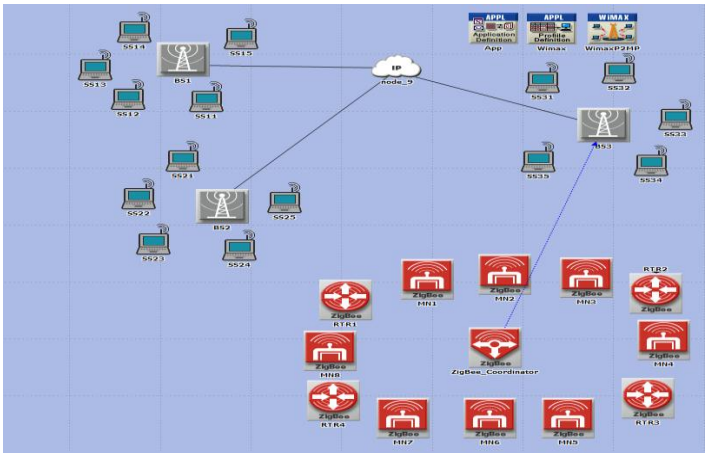

Fig. 4 – ZigBee Mesh WiMAX P2MP Topology

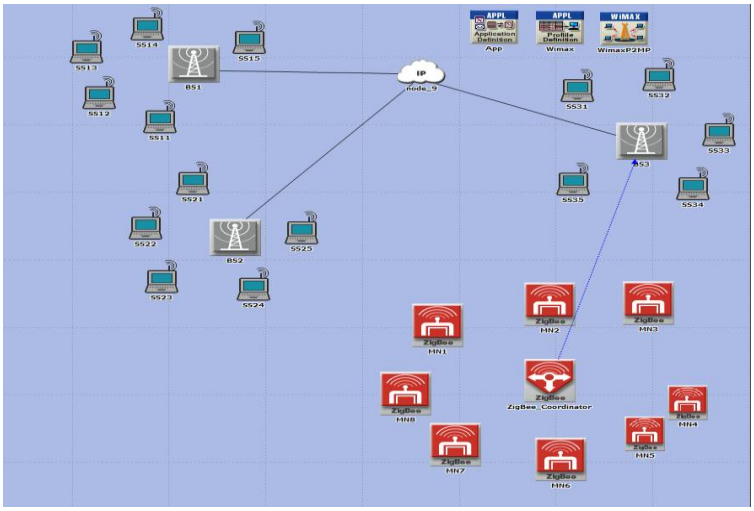

Fig. 5 – ZigBee Star WiMAX P2MP Topology

 

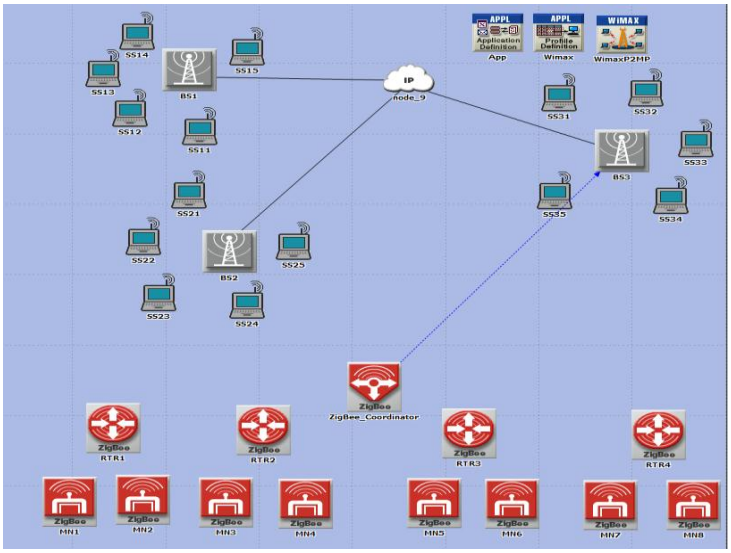


Fig. 6 – ZigBee Tree WiMAX P2MP Topology

WiMAX topology is connected to ZigBee topology via ZigBee coordinator. In WiMAX, the mesh topology includes 3 BS and 15 SSs in which each BS is surrounded by 5 SSs. In P2MP architecture consists of 3 BSs and 11 SSs. In both the WiMAX architectures, the BSs are connected using IP Cloud which offers the functionality of data sharing between these BSs. In ZigBee, for implementing 9 nodes network in star topology, the ZigBee coordinator is surrounded by 8 end devices. In mesh and tree topologies 1 ZigBee coordinator, 4 routers and 8 end devices have been set up. Table 1 shows the value of ZigBee Network parameters that have been used to perform the simulation. Table 2 and 3 shows the values of parameters used in WiMAX SS and BS respectively used to carry out the simulation.

Table 1 – ZigBee Simulation Parameters

| **Parameters** | **Value** |
|---|---|
| Area | 40*40 Kilometers |
| **MAC Layer Parameters** | |
| ACK | Enabled |
| ACK wait Duration | 0.05 seconds |
| No. of retransmission | 5 |
| CSMA | Enabled |
| Minimum Back-off Exponent | 3 |
| Maximum number of Back-offs | 4 |
| Channel Sense Duration | 0.1 seconds |
| **PHY Layer Parameters** | |
| Data rate | Auto Calculate |
| Frequency band | 2450 MHz |
| Packet reception power threshold | -85dBm |
| Transmit Power | 0.05 W |
| **Application Layer Parameters** | |
| Destination | Random, All Coordinators and Routers, RTR1, RTR2, RTR3, RTR4, ZigBee_Coordinator |
| Packet Inter-arrival time | Uniform(2,10) |
| Packet Size | Constant(1024) |
| Start Time | Uniform (10,25) |
| Stop Time | infinity |

Table 2 – WiMAX Subscriber Station (SS) Simulation Parameters

| | |
|---|---|
| Antenna Gain (dBi) | -1 dBi |

 

| | |
|---|---|
| Max Power Transfer (W) | 0.5 |
| PHY Profile | Wireless OFDMA 20 MHz |
| PHY Profile Type | OFDM |
| Modulation and coding | Adaptive |
| Pathloss Model | Free Space |
| Buffer Size | 64 KB |
| Terrain Type | Terrain Type A |

Table 3 – WiMAX Base Station (BS) Simulation Parameters

| | |
|---|---|
| Antenna Gain (dBi) | 15dBi |
| Maximum Number of SS nodes | 100 |
| Maximum Power density (dBm/subchannel) | -110 |
| Ranging Backoff Start | 2 |
| Ranging Backoff End | 4 |
| PHY Profile | Wireless OFDM 20 MHz |
| PHY Profile Type | OFDM |

## III. SIMULATION RESULTS AND DISCUSSION

Based on simulation scenario proposed earlier in this paper, extensive simulation has been conducted and the results are obtained. In this section the relative performance of ZigBee mesh, star and tree topologies have been discussed in terms of throughput, load and delay. Results obtained have been categorized based on the performance of different ZigBee topologies in combination WiMAX topologies. Firstly the comparison between the different topologies of ZigBee portion with respect to WiMAX topologies is carried out. Then the effect of different ZigBee topologies on WiMAX topologies will be discussed after the performance evaluation of ZigBee network.

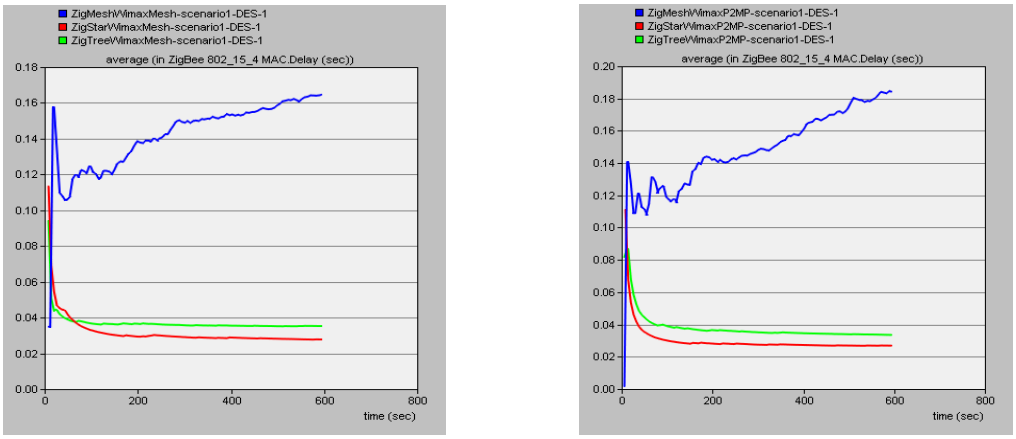


Fig. 7 – ZigBee Delay (with WiAMAX Mesh Topology and P2MP Topology )

Delay is highest in ZigBee mesh topology (0.165 sec), medium in ZigBee tree topology (0.035 sec) and least in ZigBee star topology (0.027 sec) when implemented with WiMAX mesh topology. When ZigBee topologies are implemented with WiMAX P2MP topology, the delay is increased in ZigBee mesh topology (0.184 sec). Delay remains same in the ZigBee star topology (0.27 sec) and is slightly reduced in the ZigBee tree topology (0.34 sec).

 

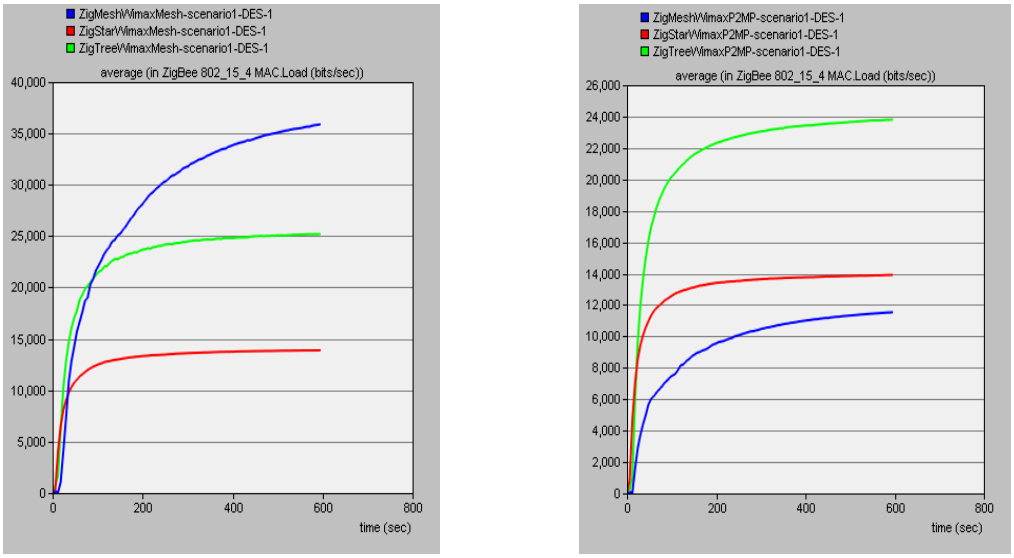


Fig. 8 – ZigBee Load (with WiAMAX Mesh Topology and P2MP Topology )

Load is highest in ZigBee mesh topology (35880 bits/sec). Load of ZigBee tree topology (25200 bits/sec) is more than the load of ZigBee star topology (13890 bits/sec) which is least in ZigBee topologies implemented alongside WiMAX mesh topology. When WiMAX P2MP topology is used load is reduced heavily in the ZigBee mesh topology (11540 bits/sec), which is least in all of the topologies. ZigBee tree topology (23810 bits/sec) has the highest load but is still reduced from the previous scenario. There is slight improvement in the load of ZigBee star topology (13920 bits/sec) but it is still lesser than that of ZigBee tree topology.

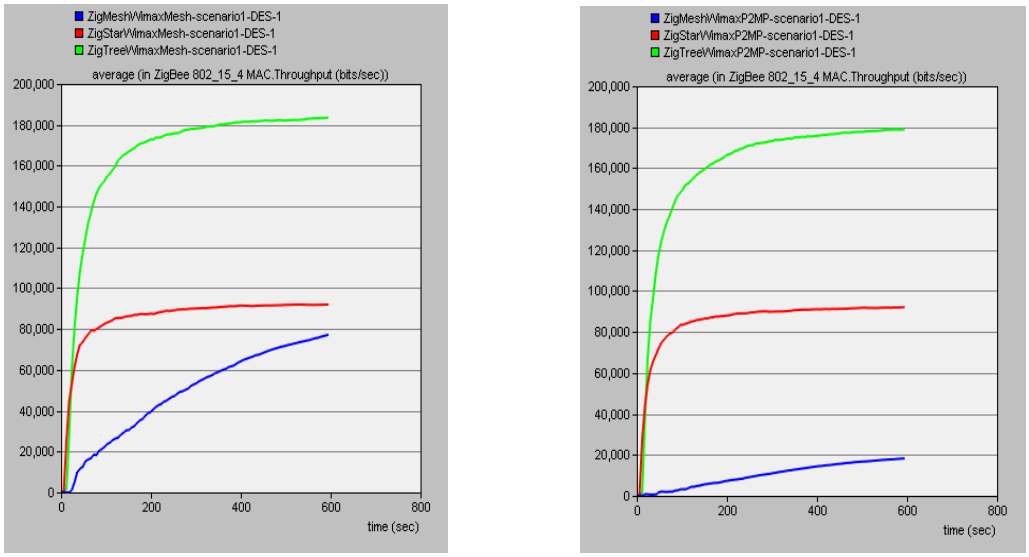


Fig. 9 – ZigBee Throughput (with WiAMAX Mesh Topology and P2MP Topology )

When implemented with WiMAX mesh topology, the throughput of ZigBee star topology(91980 bits/sec) is more than that of ZigBee mesh topology (77210 bits/sec). But ZigBee tree topology(183580 bits/sec) has the highest throughput. When the WiMAX topology is switched to P2MP topology, throughput of ZigBee tree topology (178930 bits/sec) is reduced by a little margin. Throughput is improved in ZigBee star topology (92110 bits/sec) but is still less than throughput of tree topology. ZigBee mesh topology is heavily affected by the change in WiMAX topology as its throughput is reduced (18320 bits/sec) by a large margin.

All the results show that by change from the WiMAX mesh topology to the P2MP topology, there is slight degradation in results obtained from ZigBee tree topology and little improvement in ZigBee star topology. But still ZigBee tree topology provides the best results as compared to other two topologies. ZigBee mesh topology is greatly affected by the change in WiMAX topologies. ZigBee mesh topology's results

 

obtained are better when implemented with WiMAX mesh topology. But when the implemented with WiMAX P2MP topology, the results of ZigBee mesh topology degrades gradually including throughput, network load and increase in network delay. All results have been summarized in Table 4.

Table 4 - Performance of ZigBee topologies with different WiMAX topologies

| **Resulted Parameters (Maximum Average)** | **WiMAX Mesh topology** | | | **WiMAX P2MP topology** | | |
|---|---|---|---|---|---|---|
| | **ZigBee Mesh topology** | **ZigBee Star topology** | **ZigBee Tree topology** | **ZigBee Mesh topology** | **ZigBee Star topology** | **ZigBee Tree topology** |
| **Delay (Sec)** | 0.165 | 0.027 | 0.035 | 0.184 | 0.027 | 0.034 |
| **Load (bits/sec)** | 35880 | 13890 | 25200 | 11540 | 13920 | 23810 |
| **Throughput (bits/sec)** | 77210 | 91980 | 183580 | 18320 | 92110 | 178930 |

Fig. 11 shows that in WiMAX mesh topology, delay is highest when used with ZigBee mesh topology (2.503 sec). Delay is intermediate in WiMAX mesh topology when implemented alongside ZigBee star topology is (1.587 sec) and is least with ZigBee tree topology (1.004 sec). But when WiMAX P2MP topology is used with ZigBee topologies, the delay in WiMAX topology is reduced by some factor when used with ZigBee mesh topology (2.243 sec) and increased when implemented with ZigBee star topology (2.960 sec) and ZigBee tree topology (1.854 sec).

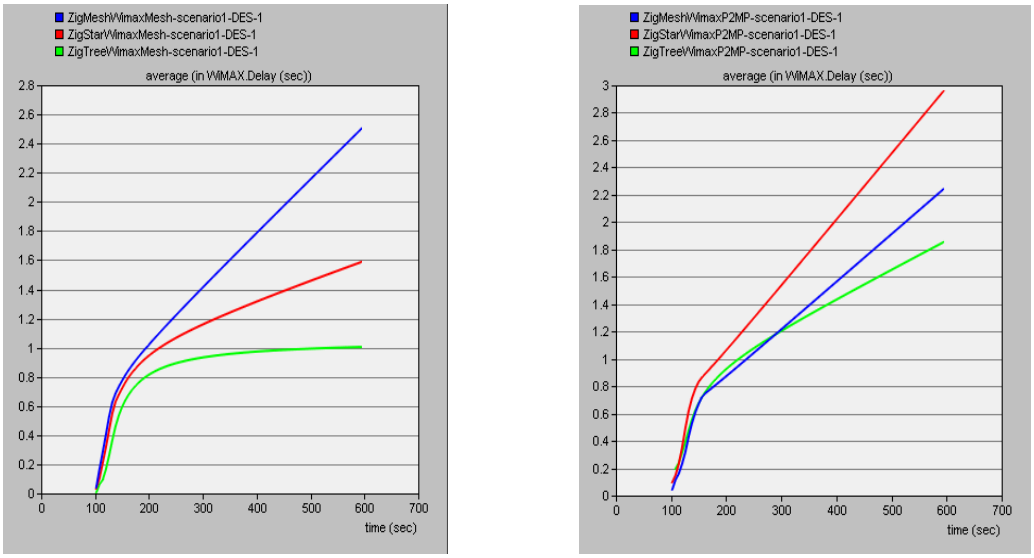


Fig. 10 – WiMAX Mesh and P2MP topology Delay (with ZigBee topologies)

 

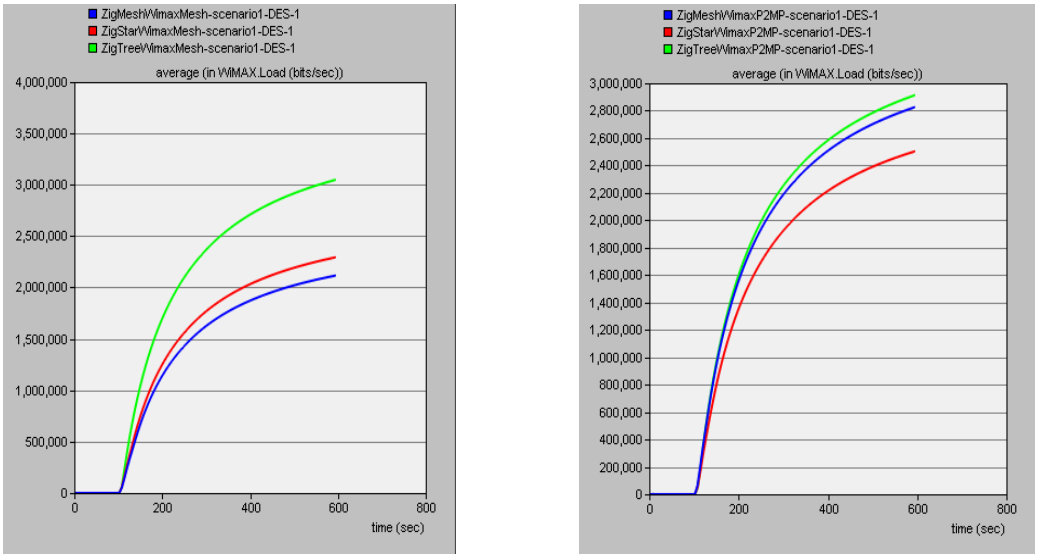


Fig. 11 – WiMAX Mesh and P2MP topology Load (with ZigBee topologies)

Network load of WiMAX mesh topology is least with ZigBee mesh topology (2116800 bits/sec), intermediate with ZigBee star topology (2294390 bits/sec) and highest with ZigBee tree topology (3049210 bits/sec). When WiMAX P2MP topology is used, the load of WiMAX network is least with ZigBee star topology (2503200 bits/sec), increased with ZigBee mesh topology (2825850 bits/sec) and highest with ZigBee tree topology (2913180 bits/sec) but decreased from WiMAX mesh topology.

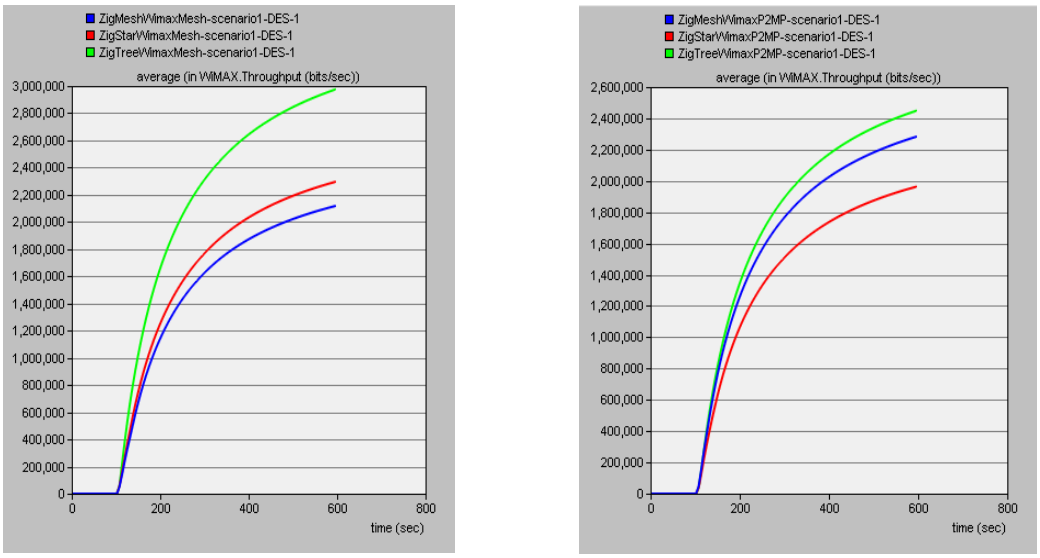


Fig. 12 – WiMAX Mesh and P2MP topology Throughput (with ZigBee topologies)

Throughput of WiMAX mesh topology is highest with ZigBee tree topology (2974270 bits/sec) and least with ZigBee mesh topology (2116780 bits/sec). WiMAX throughput is intermediate with ZigBee star topology (2294370 bits/sec). When WiMAX P2MP topology is used, the throughput of WiMAX network is decreased with Zigbee tree and star topologies but increased with ZigBee mesh toplogy. WiMAX throughput is least with ZigBee star topology (1962090 bits/sec), moderate with ZigBee mesh topology (2281820 bits/sec) and highest with ZigBee tree topology (2447470 bits/sec).

The results of the simulations show that the performance of WiMAX mesh topology is better than WiMAX P2MP topology in combination with different ZigBee topologies. When we switch from WiMAX mesh topology to WiMAX P2MP topology there is degradation in the performance of ZigBee tree topology and ZigBee star topology and slight improvement in the performance of ZigBee Mesh topology. All results have been summarized in Table 5.

 

Table 5 - Performance of WiMAX topologies with different ZigBee topologies

| **Resulted Parameters (Maximum Average)** | **WiMAX Mesh topology** | | | **WiMAX P2MP topology** | | |
|---|---|---|---|---|---|---|
| | **ZigBee Mesh topology** | **ZigBee Star topology** | **ZigBee Tree topology** | **ZigBee Mesh topology** | **ZigBee Star topology** | **ZigBee Tree topology** |
| **Delay (Sec)** | 2.503 | 1.587 | 1.004 | 2.243 | 2.960 | 1.854 |
| **Load (bits/sec)** | 2116800 | 2294390 | 3049210 | 2825850 | 2503200 | 2913180 |
| **Throughput (bits/sec)** | 2116780 | 2294370 | 2974240 | 2281820 | 1962090 | 2447470 |

## IV. CONCLUSION

In order to identify the best suitable topologies of WiMAX and ZigBee to operate together for implementing healthcare monitoring system with respect to their performance, work has been done in this paper. For doing so the simulation scenarios have been created for mesh, tree and star topologies of ZigBee with mesh and P2MP topologies of WiMAX using OPNET modeler. Performance evaluation has been done in terms of delay, load and throughput. It is observed that ZigBee tree topology outperforms other ZigBee topologies in term of throughput when used with both WiMAX topologies. However it is observed that ZigBee tree and ZigBee mesh topologies performs better when used with WiMAX mesh topology whereas ZigBee star topology performs slightly better when implemented with WiMAX P2MP topology as compared to when implemented with WiMAX mesh topology. WiMAX mesh topology performs better than WiMAX P2MP topology in terms of QoS parameters like delay, load and throughput when implemented with different ZigBee topologies. Overall ZigBee tree topology's performance is best when implemented with WiMAX mesh topology than all other implemented combinations of WiMAX and ZigBee topologies. Thus the results obtained here, can be used as ready reference for the design engineering implementing ZigBee and WiMAX network based healthcare monitoring system prototypes.

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