Simulation and Performance Analysis of Wireless Sensor Network (WSN) for Smart Home Automation

Final Project Report

ENSC 833: PERFORMANCE OF COMMUNICATION NETWORKS, Spring 2019

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Abstract

Smart home automation is becoming popular day by day. Rapid implementation of a wireless sensor network (WSN) has made it possible. Smart home automation is the direct result of the gradual increment of usage of smart devices in our daily life. By thinking of smart devices, it will be a mistake to consider only mobile phones and laptops because nowadays home appliances are also becoming smart and remote controlled. For an effective smart home automation system, the implementation of the wireless sensor network (WSN) for our daily home appliances and smart devices should be cost-effective and efficient. In this project, a wireless sensor network (WSN) system will be simulated by implementing the Wi-Fi and ZigBee network scenarios. The riverbed modeler (OPNET) has been used to simulate and analyze the network performance of the wireless sensor networks.

Keywords: WiFi; ZigBee; WSN;

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List of Acronyms

WSN	Wireless Sensor Network
WPAN	Wireless Personal Area Network
PHY	Physical Layer
MAC	Medium Access Control
NWK	Network Layer
APL	Application Layer
ZDO	ZigBee Device Object
APS	Application Support Sub Layer
CSMA	Carrier Sense Multiple Access Collision Avoidance
UPB	Universal Powerline Bus
PAN	Personal Area Network
ETED	End-To-End Delay

Chapter 1.

Introduction

1.1. Motivation

The motivation for smart home automation has come from its endless benefits. The benefits of smart home automation can be divided into few sections. The benefits of smart home automation start with the savings of the consumer's money. Consumers can save energy, cutting utility costs over time. Some home automation technologies monitor water usage, too, helping to prevent exorbitant water bills. Certain devices even offer rebates. Ensuring home security is one of the perks of smart home automation. Security cameras, automated lighting and motion sensors have provided the extra security for consumer's home and offices. Because home automation technology performs regular repetitive tasks automatically, end users experience great convenience. These type of control gives the consumers the peace of mind and comfort.

For home automation, the goal is to build a wireless sensor network where different devices can co-exist using different network protocols. The proposed wireless sensor network for our Project is the combination of ZigBee and Wi-Fi protocol. In this project, different scenarios of a typical wireless sensor network for home automation have been simulated in order to observe and analyze the performance and several features of WiFi and ZigBee protocol. Additionally, we also shed light on the interference which occurs due to the coexistence of WiFi and ZigBee in the same wireless network system.

1.2. Related Works

Previous years ENSC projects provide insights and required assistances regarding home automation, ZigBee and WiFi network in order to build our current project, which include:

- Sophia Calzada, Curtis Rietchel and Tomasz Szajner, “Performance Analysis of a Wireless Home Network”, 2014 ENSC 427 Communication Networks.

- George Liao, Ahmed Saleh and Aqib Haque, “Characteristics of WiFi”, 2010 ENSC 427 Communication Networks.

- Cathy Zhang, Ricky Chau and Wenqi Sun, “Wi-Fi NETWORK SIMULATION OPNET”, 2009 ENSC 427 Communication Networks.

- J. Angelov, S. Valentionov Petrov, and L. Zhao, “Evaluation of ZigBee Remote Sensor Networks,” 2012 ENSC 427 Communication Networks.

- S. Teng, “Simulation of the ZigBee PAN Protocol in OPNET as a Basis for the Comparison of Competing Sensor Network Technologies,” 2010 ENSC 427 Communication Networks.

Chapter 2.

Literature Review

2.1. Home Automation

Nowadays, smart home automation is growing rapidly in many fields, and many applications based on home automation provide a lot of conveniences and reduce the consumption of human resources. A smart home automation equipment is usually an electronic device that was can be remotely controlled. Actually, anything which can be connected to a network can be automated and controlled remotely can be regarded as a part of smart home automation, thus a powerful and efficient communication is very important.

One major reason for the popularity of smart home automation is the development of wireless technologies. For example, people can easily use their smartphones to communicate with microcontrollers using wireless communication techniques such as ZigBee and WiFi.

Figure 1: Smart Home Automation [1]

The benefits of smart home automation

Smart home automation can provide many benefits because of its unique characteristics:

- *Savings Resources*
  Smart light and smart heat can save electricity and smart water faucets can save the water, people can utilize different resources more reasonable and save their money by increasing the use ratio of the energy.

- *Security*
  People can use some high-tech smart devices such as a ring video doorbell with Wi-Fi camera to watch out their house even if they are not at home, and automation means people don't need to worry about ignoring some important operation and make the whole home device system more reliable.

- *Convenience*
  Users can experience great convenience because most of the operations of devices are totally automatic.

- *Control*
  The better control function within the home is another advantage of smart home automation, users can control their devices at anywhere they can access the network.

Technologies driving connectivity in the smart home automation

There are many kinds of platforms and protocols have been applied in building a smart home system such as UPB, INSTEON, Z-WAVE, ZIGBEE, Wi-Fi, BLUETOOTH and THREAD. Different platforms or protocols have their own characteristics and each characteristic of the various devices instruct them to perform a function.

Figure 2: Different Platforms and Protocols [2]

Choosing a suitable platform or protocol is a very essential step for the build of a smart home system. However, among all other protocols Wi-Fi and ZIGBEE are two very popular technologies for establishing a wireless sensor network:

- *WiFi*

  WiFi is a very mature technology and becomes very popular in many fields, and for home automation field, many manufacturers have applied Wi-Fi technology in making smart home devices. But for some battery-operated smart devices and sensors, they will run out of their powers much sooner than in other wireless environment.

- *ZigBee*

  ZigBee is a wireless home automation protocol. Although its full acceptance is limited by the lack of interoperability between ZigBee devices, it is a low-cost, low power technology and devices can run a long time with this wireless network environment.

Both of these two protocols are the key technologies in this project and a more particular introduce of these technologies will be showed in the next two sections.

2.2. WiFi Technology

WiFi is technology for radio wireless local area network of devices based on the IEEE 802.11 standards. WiFi stands for “wireless fidelity” and it’s a very mature technology and has been applied in many fields. WiFi technology is executing by a remote supervising structure like as security and medicine. A WiFi network makes use of radio waves to transmit information across a network.

Figure 3: WiFi Logo

Compared with traditional wired networks, WiFi has many advantages which make it become so popular:

- Convenience: Users can access to network sources from a very convenient location and not be limited by the wiring.
- Productivity: Users can maintain the status of a network connection when he moves from a place to another place.
- Deployment: Compared with a wired network, it’s easier to initialize the setup of a wireless network.
- Expandability: A wireless network can serve many clients with existing equipment.
- Cost: Users can establish a wireless network with a lower price compared to a wired network.

WiFi Standards

IEEE developed a family of specifications for WiFi named 802.11 and it specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. There are several standards for WiFi:

802.11 Wireless Standards					
IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac (Draft)
Year Released	1999	1999	2003	2009	2011 (Draft)
Frequency	5 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz	5 GHz
Max. Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps	>1 Gbps
Typical Range Indoors*	100 ft.	100 ft.	125 ft.	225 ft.	TBD
Typical Range Outdoors*	400 ft.	450 ft.	450 ft.	825 ft.	TBD

Figure 4: WiFi Standards [3]

The figure above shows five kinds of WiFi standards, the “Max. Data Rate” means how much data can be transmitted and the “Frequency” means what radio frequency the network is carried on. The basic rule is the higher the letter, the faster the speed of the network, another rule is the network type can be named by a combination of numbers, like 802.11ac.

- 802.11a: This type is one of the oldest standards and can’t compatible with b or g network, but still in use by many devices today.
- 802.11b: This type can compatible with g network.
- 802.11g: The most popular network type and its combination of speed and backwards compatibility make it a good match for today’s network.

- 802.11n: The fastest type of network. 100Mbps is common, though speeds of up to 600 Mbps is possible under perfect conditions. It does this by using multiple frequencies at once and joining that speed together.

- 802.11 ac: The router can support a and c networks.

WiFi Applications

Nowadays, WiFi technology has been widely deployed in many applications.

- *Mobile applications:*
  A mobile application is mostly referred to as a software application based on the web, and at most of the time, users can get access to the network in a WiFi wireless network environment. The advantages of mobile applications are high productivity, increased security and better remote access.

- *Business applications:*
  WiFi can be used in the business meeting and telecommuting. The advantages of WiFi are mobility with the office, increased collaboration and simpler infrastructure.

- *Home applications:*
  WiFi can be used for controlling home devices remotely such as heating and cooling system.

Not only the applications we mentioned above, but also some special fields such as agriculture and military, some application can be run more efficient because of the WiFi technology.

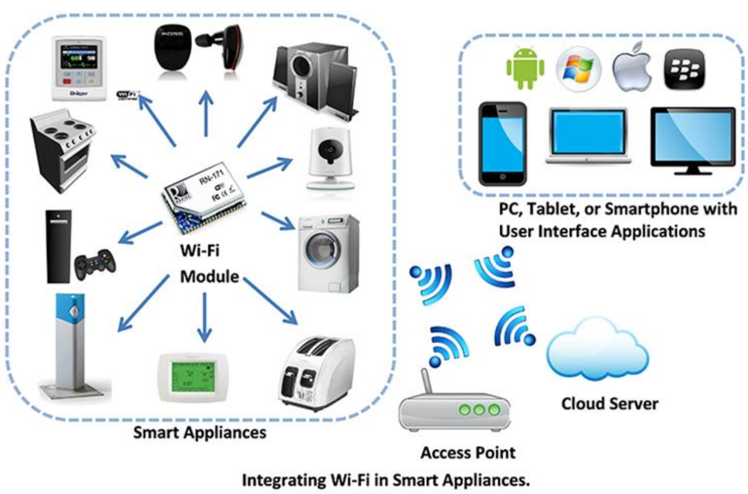


Figure 5: Application of WiFi [4]

2.3. ZigBee Technology

ZigBee is a wireless network protocol invented by ZigBee alliance for remote control and sensor applications. ZigBee is based on IEEE 802.15.4 which is a low data-rate standard for wireless personal area networks (WPANs). The benefits of ZigBee including low-cost and low-power consumption targets the application such as medical monitoring and low-power sensors. Moreover, benefiting from the attribute of enabling interoperability among the devices, ZigBee can provide multi-vendor consumer electronic solutions to the application including home and office automation.

Figure 6: ZigBee Logo [11]

In general, as the most popular industry wireless network protocol, ZigBee has few distinctive advantages than other wireless sensor networks like Bluetooth and Wi-Fi which are:

- Low cost: it means low device cost, low installation cost and low maintenance.
- High-density level of the network: the IEEE 802.15.4 standard defines the physical and MAC layer to handle any number of devices.
- Simple and easy to implement: the protocol code stack of ZigBee is about a quarter of Bluetooth’s and WIFI’s. So, ZigBee can be deployed globally.

ZigBee Architecture

ZigBee System Architecture:

ZigBee system structure consists of three types of devices which are coordinators, Routers and end devices. As the essential element in the network, coordinators act as root and bridge of the network. Routers act as an intermediary device to allow data to pass through them from source to destination. End devices have limited access to communicate with their parent node only.

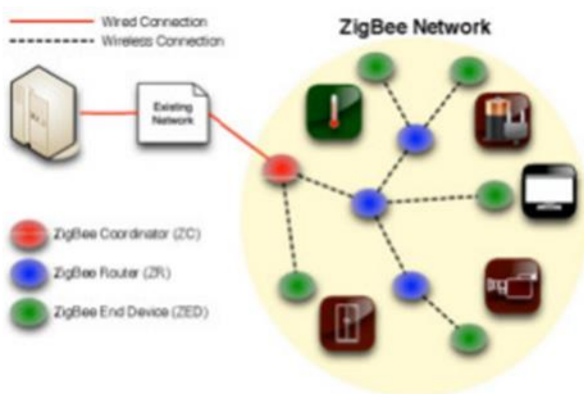


Figure 7: ZigBee Protocol Architecture [11]

ZigBee Protocol Architecture:

ZigBee protocol architecture consists of a stack of major four layers which are:

<u>Application layer (APL)</u>

APL consists of several sublayers which are ZigBee Device Object (ZDO), Application Framework and Application Support Sub Layer (APS). As the interface between application objects and the APS layer in ZigBee devices, ZDO is responsible for overall device management including detecting, initiating and binding other devices to the network. Application Framework is an environment for application objects to transfer data. APS consists of Application Support Data Entity and Application Support Management Entity. They provide services to the Application and the Network layers through a service access point.

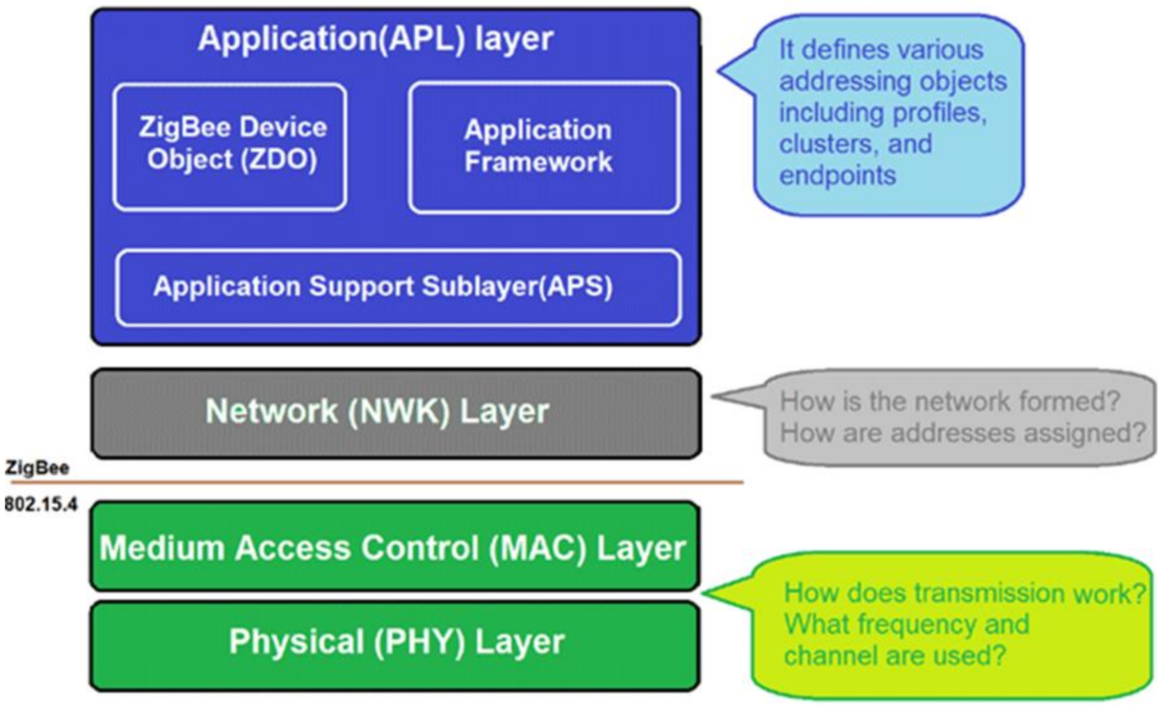


Figure 8: ZigBee Protocol Architecture [12]

Network Layer (NWK)

NWK is the connection between the Application and MAC layers. It is responsible for network formation and routing including network setup, end device connection and disconnection to the network. Also, it provides security to ZigBee networks for ensuring both the authenticity and confidentiality of a transmission.

Medium Access Control Layer (MAC)

MAC layer acts as the interface between the PHY and NWK layers. It is responsible for reliable data transmission by implementing the carrier sense multiple access collision avoidances (CSMA). It is also responsible for transmitting beacon frames for synchronizing communication.

Physical Layer (PHY)

PHY is closest to the hardware. And it defines how devices are connected to make a network including the output power, number of channels and transmission rate. It is also responsible for controlling and communicating with the ZigBee radio such as modulation and demodulation operations on transmitting and receiving signals.

The PHY and MAC layers are specified by the IEEE 802.15.4 standard. And ZigBee Alliance provides the required standards for NWK and APL layers.

ZigBee Topologies

ZigBee supports star and peer-to-peer topologies and there are two types of peer-to-peer topologies which are mesh and cluster tree.

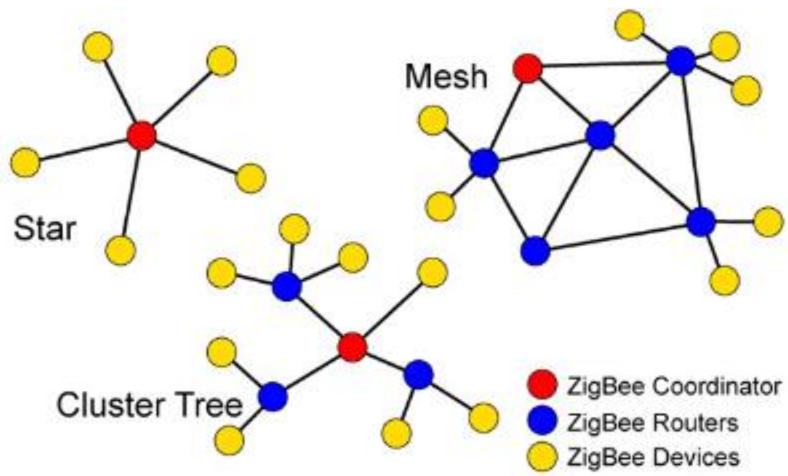


Figure 9: ZigBee Network Topologies [11]

In a star topology, there is only one coordinator connected to any number of end devices. This coordinator act as a root to initiate and manage the devices over the network. And end devices are separated from each other both physically and electrically. Therefore, there is no direct communication between end devices. In mesh and tree topologies, the ZigBee network is extended with many routers, which allows devices to communicate with any other neighbour nodes. Furthermore, in mesh and tree topologies, the failure on any node can be solved by routing the information to another router device of the topology automatically.

ZigBee Data Transmission

For data transmission in ZigBee, the combination of hardware and software is required to send data from one end to another. Hardware is responsible for carrying data from one point to another. Then software is responsible for setting the instructions on how to make it work well. In general, ZigBee can transmit data in two ways: unicast and broadcast transmission.

Unicast Transmission:

Unicast transmission can be described that ZigBee routes data from one device (Source) to another device (Destination). Moreover, the distance between the two end devices could be different. Because the destination device might be an immediate neighbour, or the data might need to perform several hops to reach the desired destination.

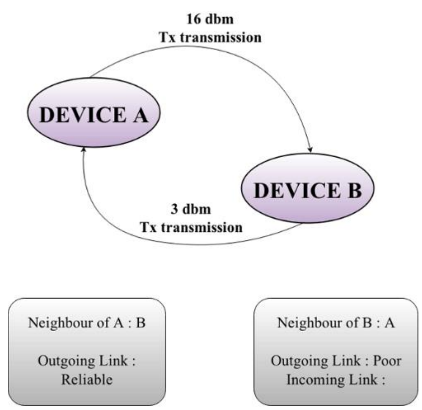


Figure 10: Unicast Transmission [12]

Broadcast Transmission:

Broadcast transmission means data can be sent to many or all devices in the network. Moreover, the coordinator and all routers receiving a broadcast transmission will retransmit the packet three times to help ZigBee protocol to be propagated throughout the entire network.

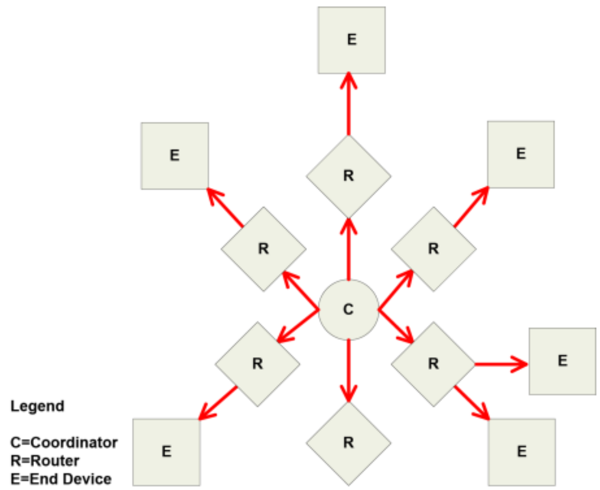


Figure 11: Broadcast Transmission [13]

ZigBee Applications

Nowadays, ZigBee technology has been widely deployed in many applications including Home and Industrial Automation, Smart Metering and Grid monitoring.

- Home Automation: ZigBee is commonly used for controlling home devices remotely such as lighting system control, heating and cooling system control.
- Industrial Automation: In manufacturing and production industries, ZigBee can lower the communication cost and improve the control process for better reliability.
- Smart Metering: Applications in smart metering include energy consumption response, pricing support and security over power theft.
- Smart Grid monitoring: Applications in Smart Grid monitoring include remote temperature monitoring, fault locating and reactive power management.

Chapter 3.

WSN Simulation and Results for Smart Home Automation

For the WSN simulation, five typical WiFi and ZigBee network scenarios are presented to analyse the performance of the wireless network for smart home automation. Three out of four scenarios are represented to observe the performance of the WiFi and ZigBee network separately. The fourth scenario is about the coexistence of ZigBee and WiFi network to find out the impact of interference in terms of network performance because many devices can be connected to the network wirelessly using different wireless communication technologies.

In this project, the smart home automation consists of two sub-networks such as WiFi sub-network and ZigBee sub-network. Workstations such as desktop PCs, laptops, mobile phone, smart TV and etc. under the WiFi sub-network are mobile and tends to have high data rate applications. We are using a WLAN server to provide various application services for the WiFi sub-network. However, the ZigBee sub-network is having applications which are using various types of sensors and consume low power. This type of home appliances can be fixed in a certain position or be mobile such as smart door locks, smart bulbs, thermostats, wireless mopping devices, different types of tracking device or self-controlled drone etc. In ZigBee sub-network, these devices are considered as mobile end devices and there is a fixed node which is considered as ZigBee coordinator according to our simulation context. This ZigBee coordinator is integrated into a control terminal to control the mobile end devices.

To implement the WSN simulation scenarios, the Riverbed Modeler 17.5 academic edition is being used. This simulator has the ability to model and simulate the scenarios in order to observe the behaviour of the system.

The list of four network scenarios is:

1. Performance based on different distances of workstations and home appliances
2. Performance based on the number of workstations and home appliances
3. Performance based on the mobility of workstations and home appliances
4. Performance during the coexistence between WiFi and ZigBee network

3.1. Performance based on different distances of workstations and home appliances

<u>WiFi Sub-network</u>

Here, we are considering two workstations to simulate the performance of the network depending on their distance from the WLAN server. The distances of the two workstations from the WLAN server are different. Work_Station_0 is inside the range of the WLAN server and the Work_Station_1 is outside the range of the WLAN server, as shown in Figure 12.

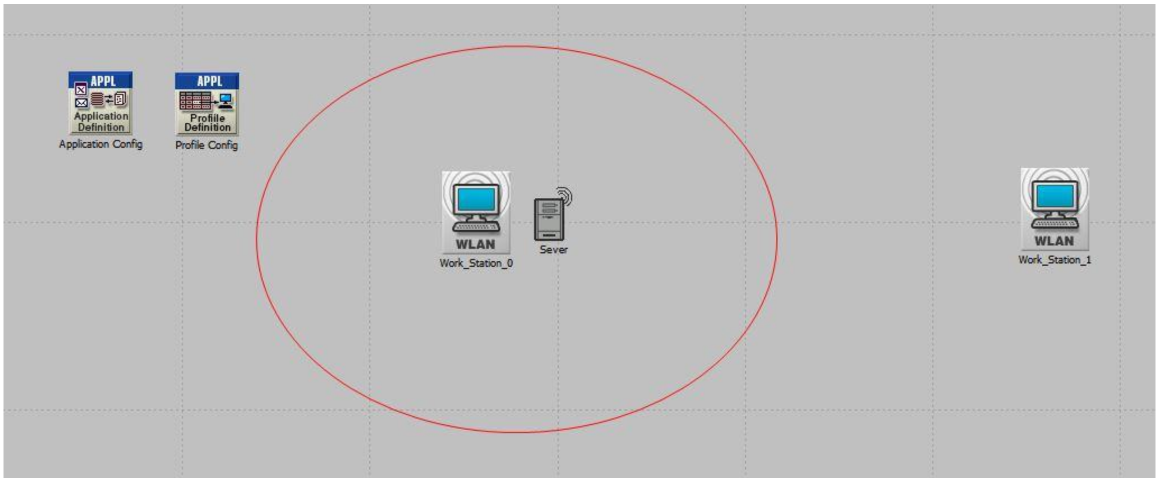


Figure 12: Position of Work_Station_0 and Work_Station_1 in terms of WLAN server

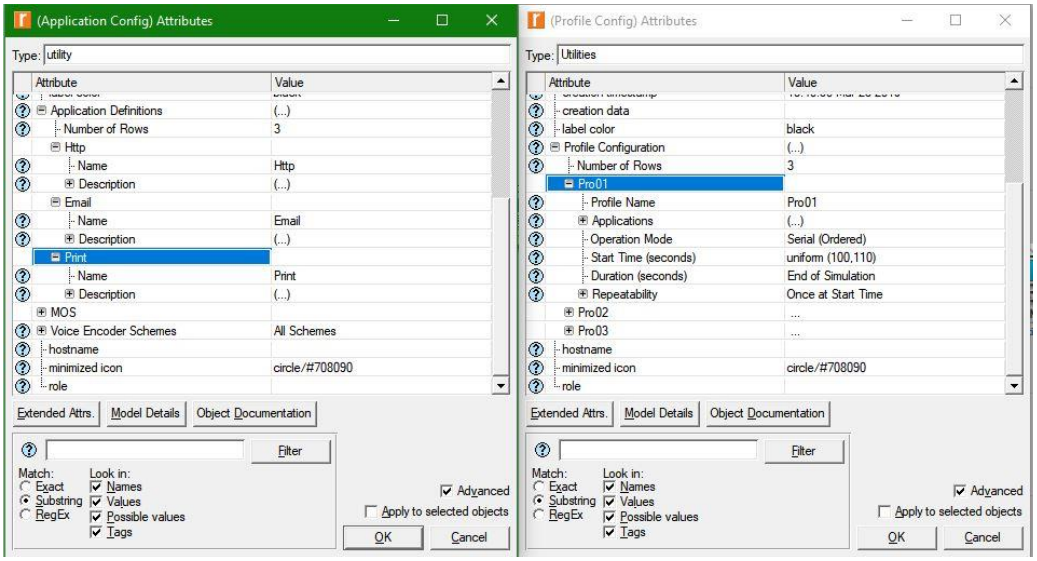


Figure 13: Application and Profile Configurations

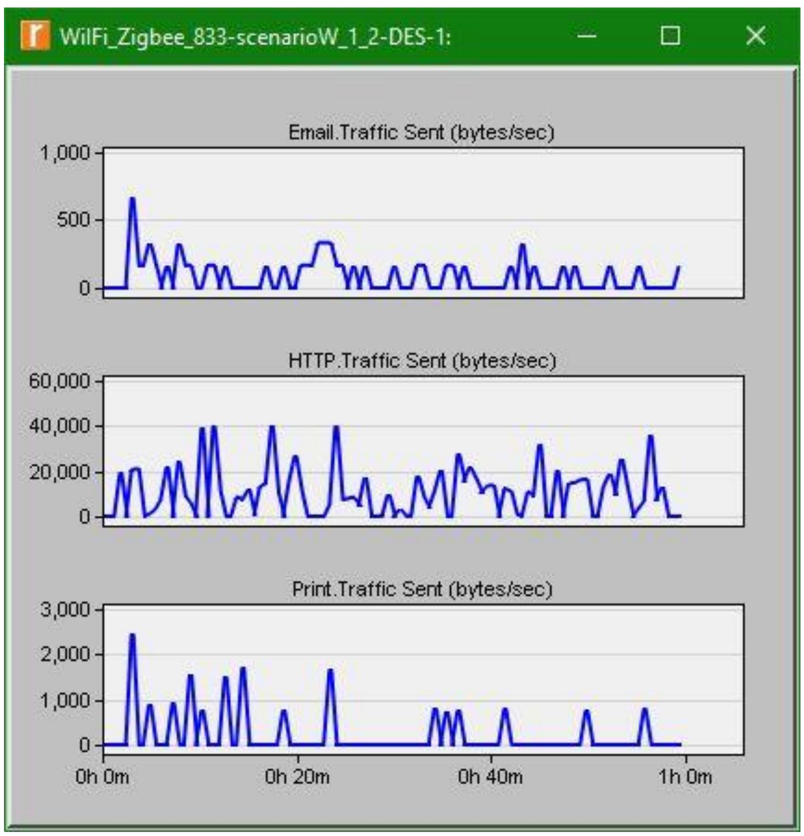


Figure 14:Throughput for Each Application

Figure 14 shows that we are using three applications for application configuration, and they are: Http (Heavy Browsing), Email (High Load) and Print (Color Prints). As far as profile configuration concerns, we create three separate profiles and keep their parameters as default settings.

After running the simulation for 1 hour, we get the simulation result regarding the traffic data sent for different applications from figure 14 and figure 15 provides us with the performance of wireless Lan throughput of the network. From figure 15, we can observe that the distance of the workstations from the WLAN server has played a significant role in the performance of the network.

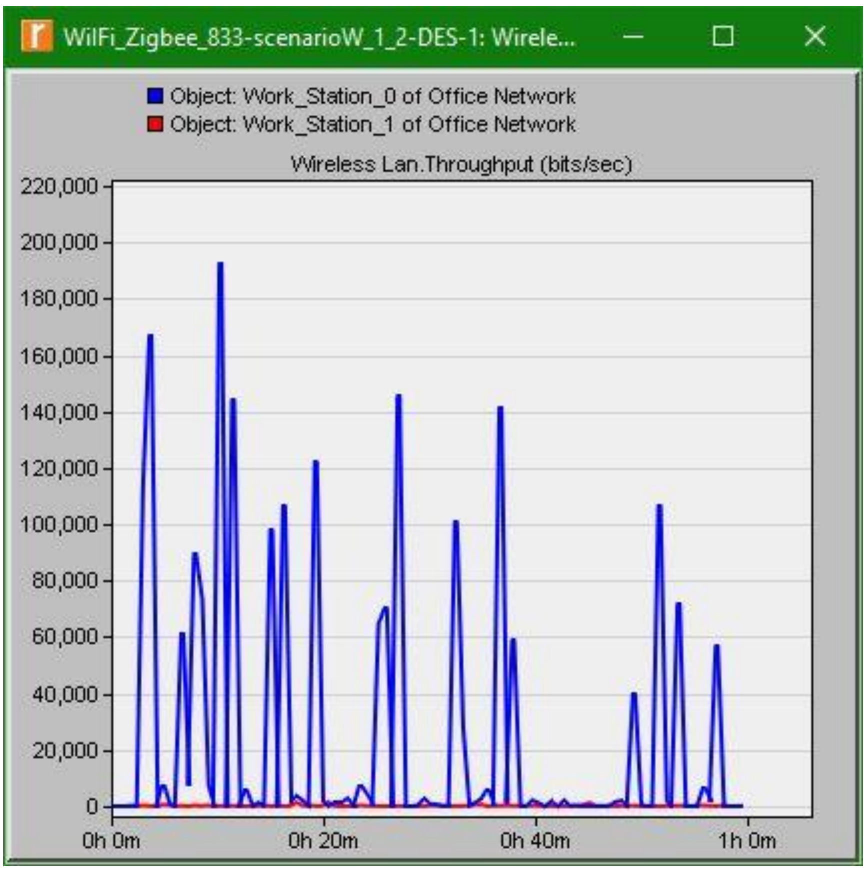


Figure 15: Wireless LAN Throughput of the network

Results: Throughput for each application is satisfactory and the performance of the network depends on the distance of the workstation from the WLAN server. The performance of the network is decreased with an increment of the distance between the WLAN server and workstations.

ZigBee Sub-network

To observe the effect of distance differences between the mobile end device and ZigBee coordinator, we simulate the following scenario using default settings for coordinator and mobile end device, as shown in figure 16.

Figure 17: Different distances between coordinator and mobile end devices

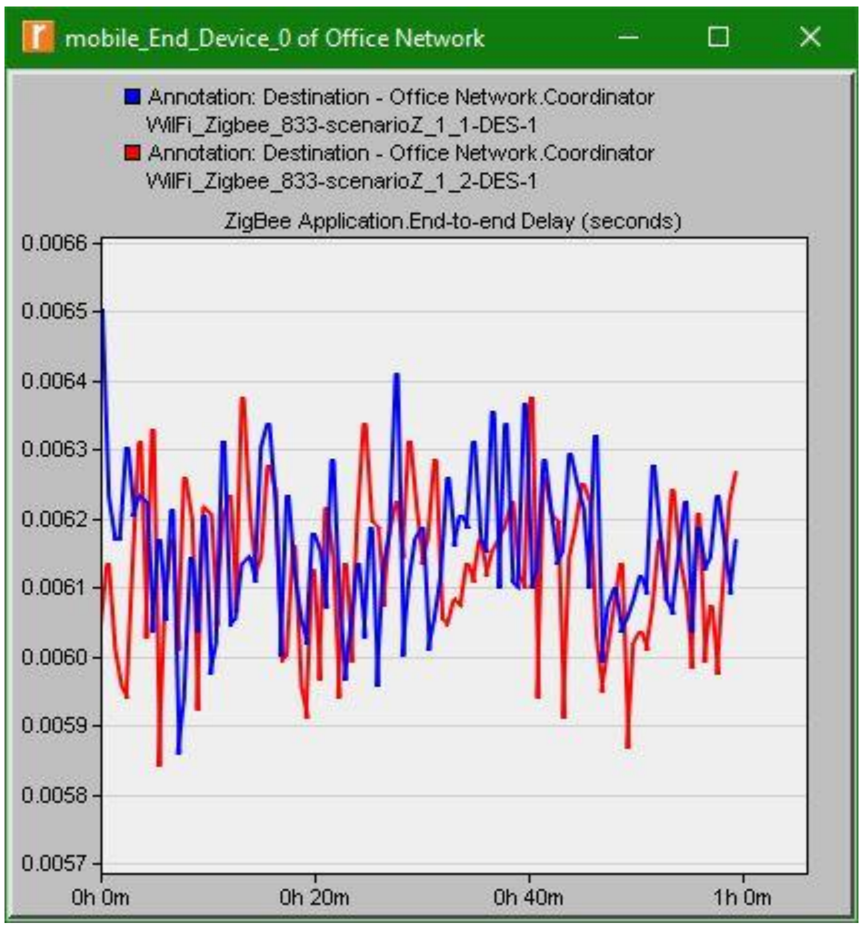


Figure 16: End to end Delay for Both Distances from the Coordinator

From our simulation results shown in figure 17, it is evident that the distance of the coordinator and the mobile end device (Home Appliance) does not change the end-to-end delay drastically.

Results: The performance of the ZigBee sub-network is not changing significantly due to the distance differences between the coordinator and mobile end device for our home automation scenario.

3.2. Performance based on the number of workstations and home appliances

<u>WiFi Sub-network</u>

Under WiFi sub-network, we are going to analyze the performance of different no. of workstations in a wireless network. For this simulation, we are using three applications such as Email, Http and Print. The simulation run time is 1 hour.

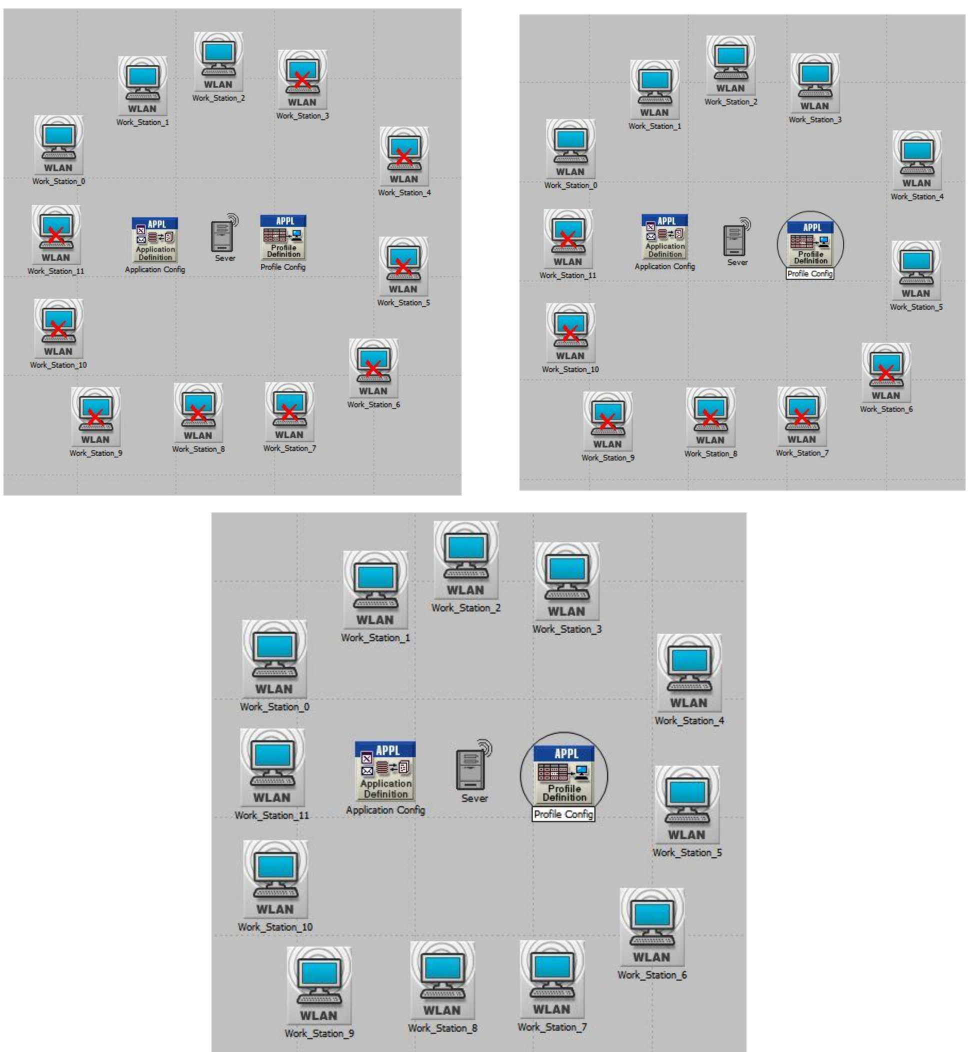
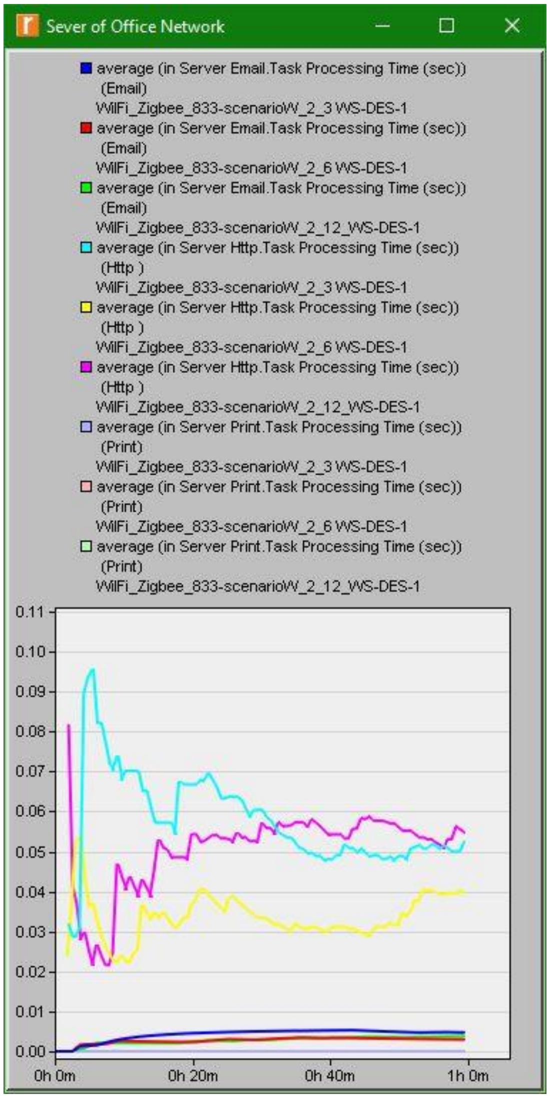


Figure 18: Home network with 3, 6 and 12 active workstations separately

From the simulation results we get from the figure 19, it shows that the no. of the workstations connected to the network has affected the results of task processing time and throughput.



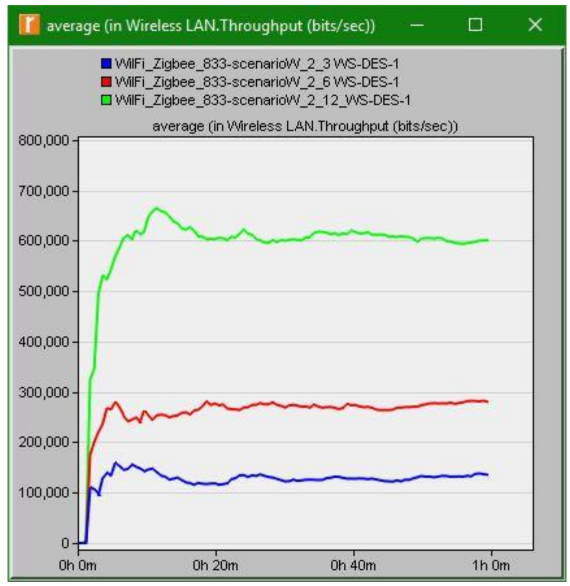


Figure 19: Task processing time and throughput for 3, 6 and 12 workstations

Results: Maximum no. of workstations in a network has achieved maximum throughput because 12 workstations are responsible to use more data traffic than the less no. of workstations. For task processing time, the network with 12 workstations has shown a higher value than others for Http application (Heavy Browsing).

ZigBee Sub-network

A complex ZigBee sub-network is build using 1 coordinator, 6 routers and 6 mobile end devices (Home Appliances). Three types of topology such as star, mesh and tree are being implemented using these 13 nodes in figure 20, 21 and 22. The simulation run time is 4 hours. The goal of this simulation is to determine the performance of different ZigBee topologies for our home automation system. Moreover, we are also going to analyze how ZigBee end devices cope with the failure and recovery of a router in a complex network. The ZigBee parameters will remain default such as random destination, 1024 bytes of packet size, constant (1.0) packet inter-arrival time, uniform (20,21) start time and etc. However, the network parameter will change according to the topology.

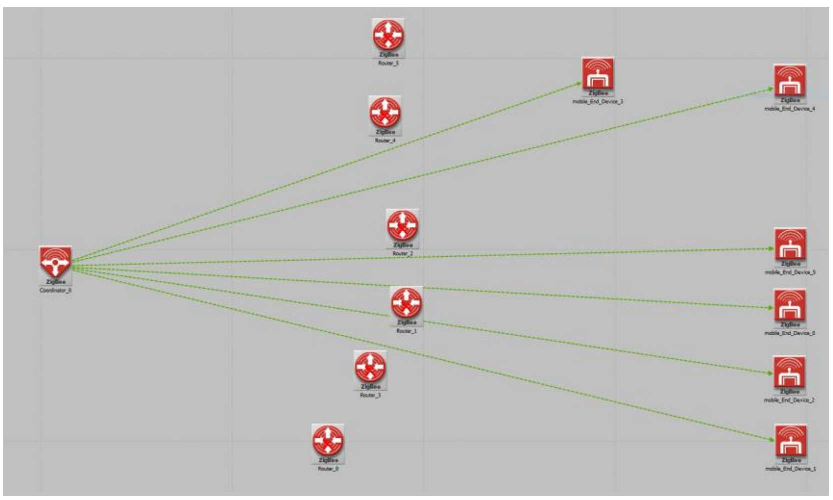


Figure 21: Star Topology

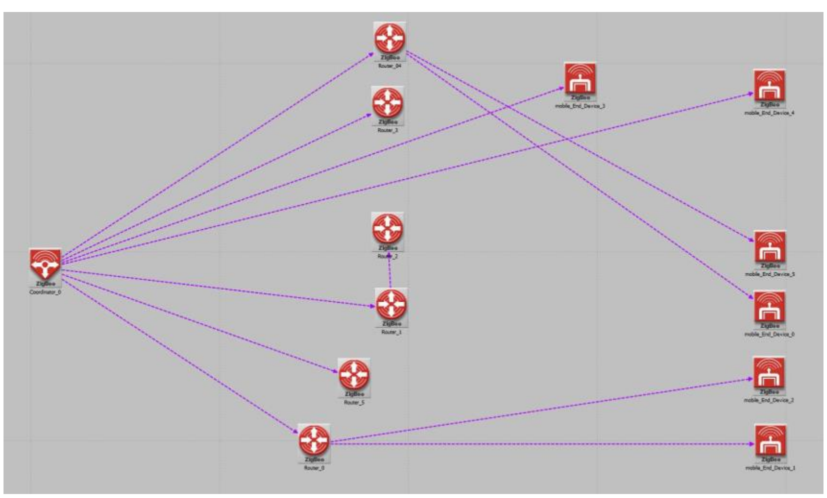


Figure 20: Mesh Topology

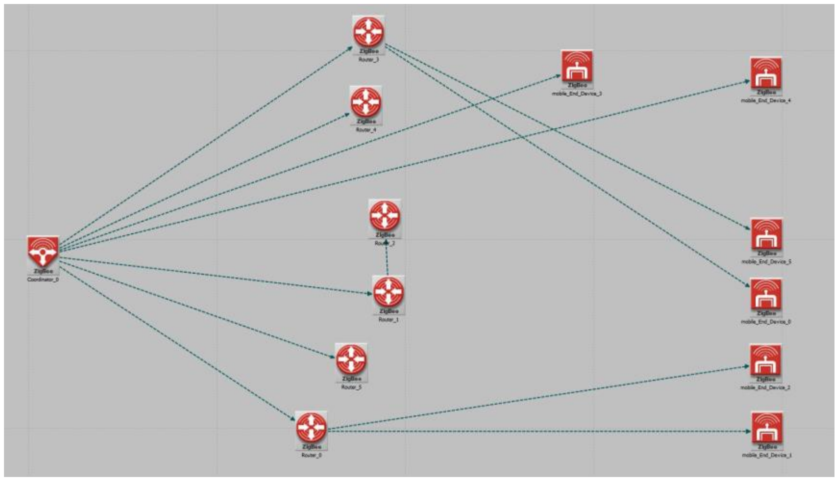


Figure 22: Tree Topology

From the simulation results in figure 23, the ZigBee tree topology possesses the highest value for ZigBee application end to end delay and control traffic rcvd in the mac layer.

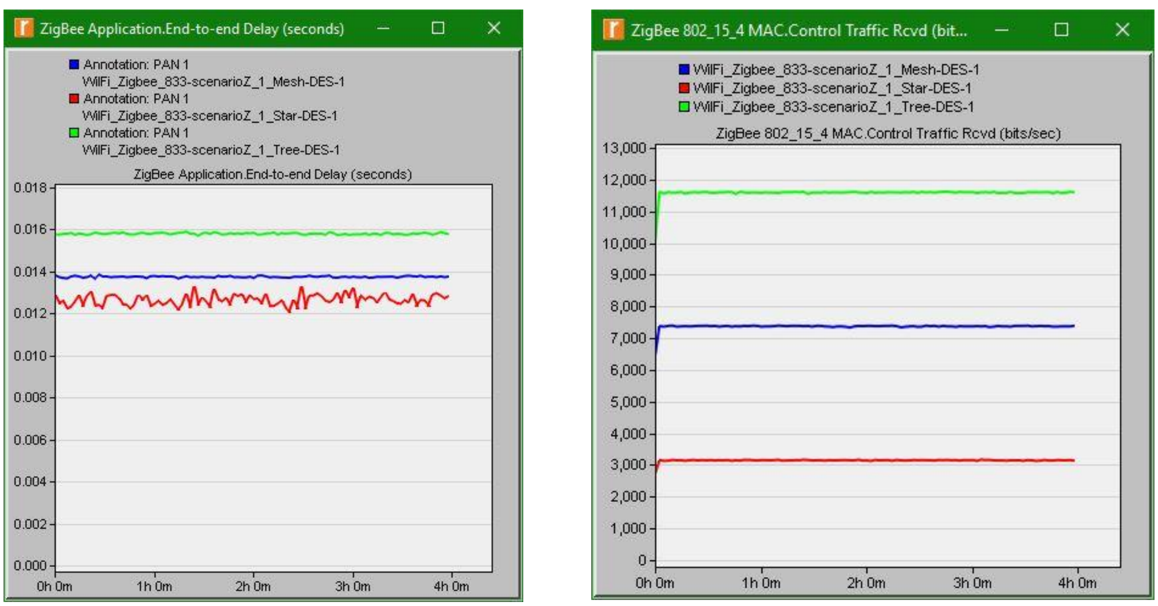


Figure 23: ETED Delay and Control Traffic Rcvd for Star, Mesh and Tree Topology

In this part, we are going to showcase the ability of a ZigBee protocol to recover the network performance during a router failure situation in multi nodes complex network. The router is responsible to connect with mobile end devices (Home appliances) and allow the coordinator to manage them from long range. Here, we are demonstrating that when router node fails; the ZigBee network will be rebuilding to maintain communication to the rest of the nodes. Therefore, a failure-recovery utility node is introduced to configure the router_4 to fail at 100s and recover at 600s.

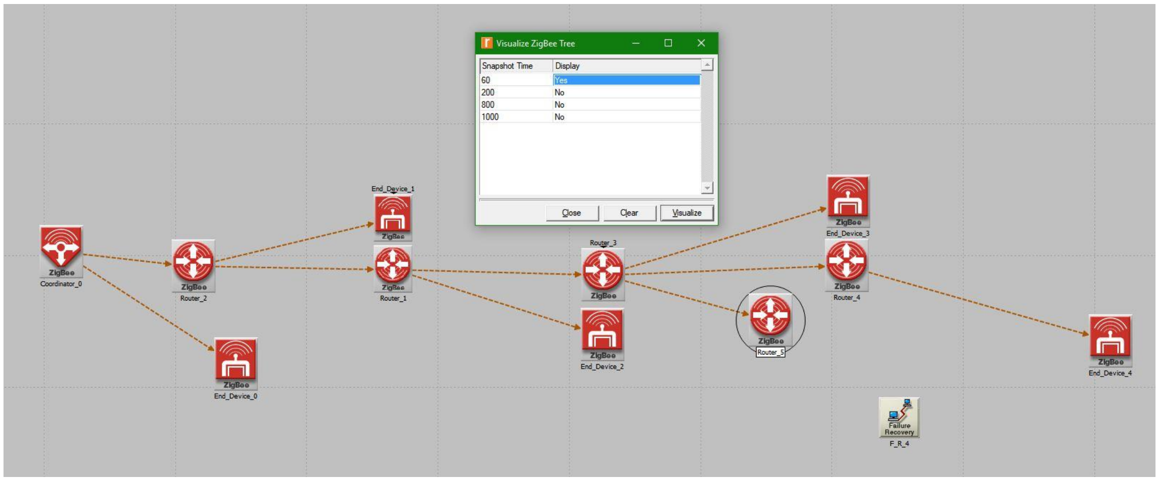


Figure 24: Tree visualization in 60s (Before Router_4 Failure)

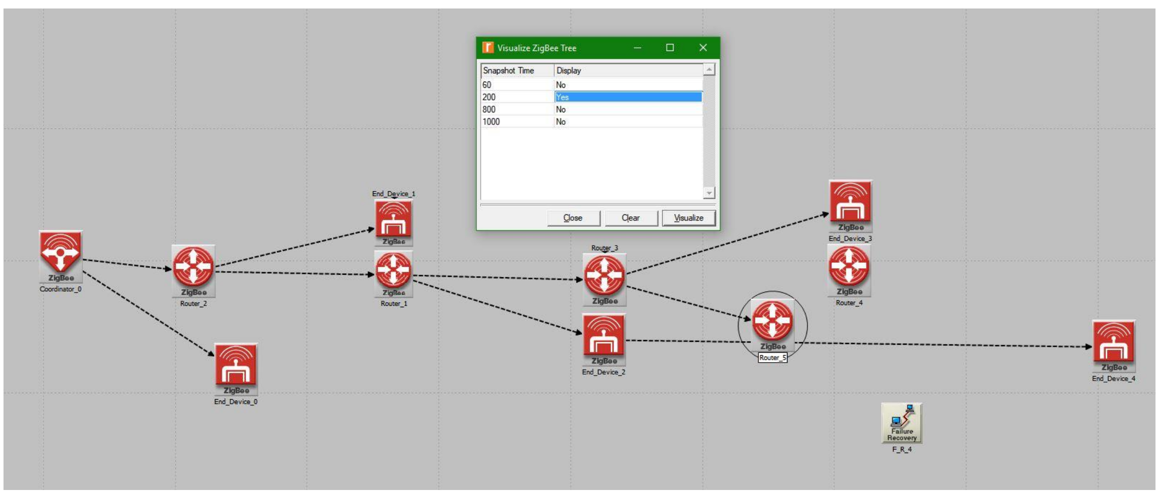


Figure 25: Tree visualization in 200s (After Router_4 Failure)

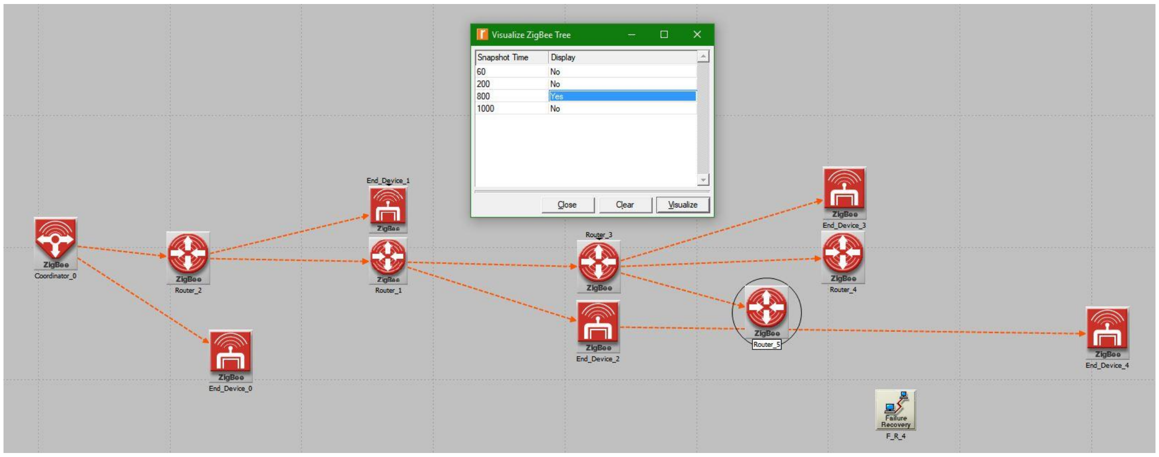


Figure 27: Tree visualization in 800s (After Router_4 Recovery)

Network Structure.PAN 1 at Simulation Time 60

File Edit View Help

	Coordinator	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5
1	Office Network.Coordinator_0 (0)					
2		Office Network.Router_2 (1)				
3			Office Network.Router_1 (2)			
4				Office Network.Router_3 (3)		
5					Office Network.Router_4 (12)	
6					Office Network.Router_5 (12)	
7						Office Network.End_Device_4 (18)
8					Office Network.End_Device_3 (44)	
9				Office Network.End_Device_2 (218)		
10			Office Network.End_Device_1 (1092)			
11		Office Network.End_Device_0 (5466)				

Network Structure.PAN 1 at Simulation Time 200

File Edit View Help

	Coordinator	Depth 1	Depth 2	Depth 3	Depth 4
1	Office Network.Coordinator_0 (0)				
2		Office Network.Router_2 (1)			
3			Office Network.Router_1 (2)		
4				Office Network.Router_3 (3)	
5					Office Network.Router_5 (12)
6					Office Network.End_Device_3 (44)
7				Office Network.End_Device_2 (218)	
8			Office Network.End_Device_1 (1092)		
9		Office Network.End_Device_0 (5466)			

Network Structure.PAN 1 at Simulation Time 800

File Edit View Help

	Coordinator	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5
1	Office Network.Coordinator_0 (0)					
2		Office Network.Router_2 (1)				
3			Office Network.Router_1 (2)			
4				Office Network.Router_3 (3)		
5					Office Network.Router_4 (20)	
6						Office Network.Router_5 (22)
7					Office Network.End_Device_3 (44)	
8				Office Network.End_Device_2 (218)		
9			Office Network.End_Device_1 (1092)			
10		Office Network.End_Device_0 (5466)				

Figure 26: ZigBee Network Structure at Simulation time 60s, 200s and 800s

Figure 24, 25, 26 and 27 are clearly showing us the flexibility of the ZigBee protocol. After the failure of the router_4 at 100s, the network structure changes to keep the connection with the end_device_4. Then the router_4 recovers at 800s and is added again to the new network structure.

As may see from figure 28, the failure and recovery of the router_4 do not produce any major impact on the data traffic of the end_device_4.

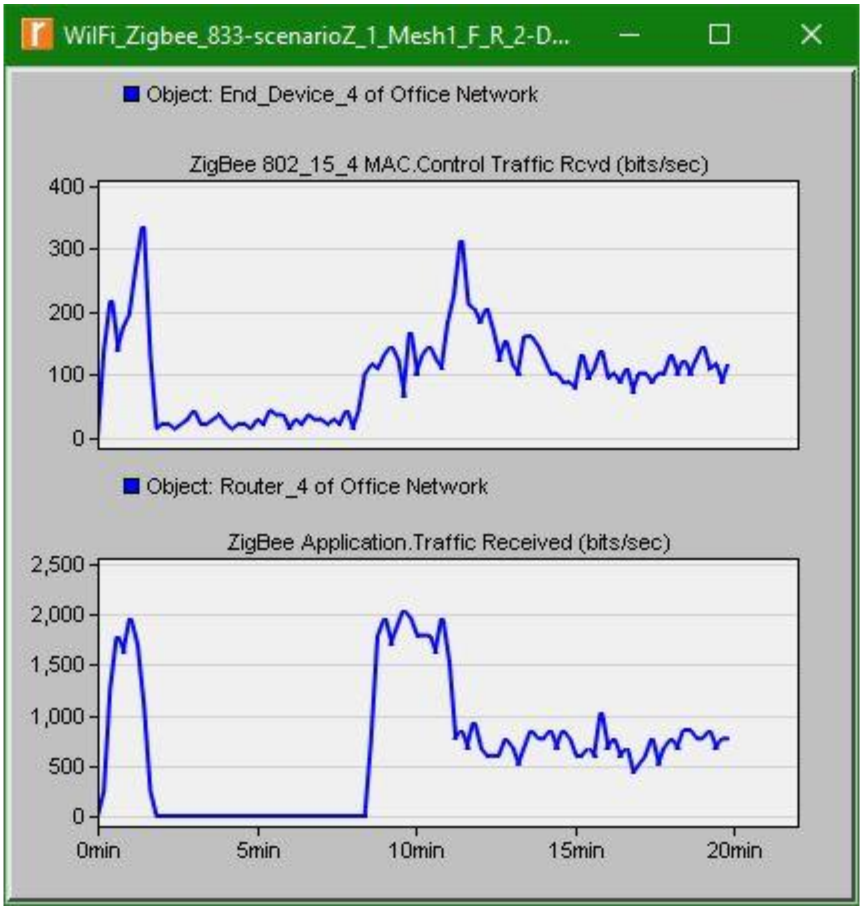


Figure 28: Performance of End_device_4 during Failure and Recovery of Router_4

Results: For smart home automation, ZigBee tree topology has the highest end to end delay and control traffic rcvd value due to its characteristics to always send the data traffic through the router towards end_devices (Home Appliances). Besides, the failure of any router in a ZigBee network does not compromise the performance of the network.

3.3. Performance based on the mobility of workstations and home appliances

<u>WiFi Sub-network</u>

For our next WiFi sub-network, we are considering a mobile workstation (Laptop or mobile phone). The mobile Work_Station_1 is coming from the outside of the WLAN server range and then goes through the range of the WLAN server. Like other WiFi sub-networks, the applications are Http, Email and Print.

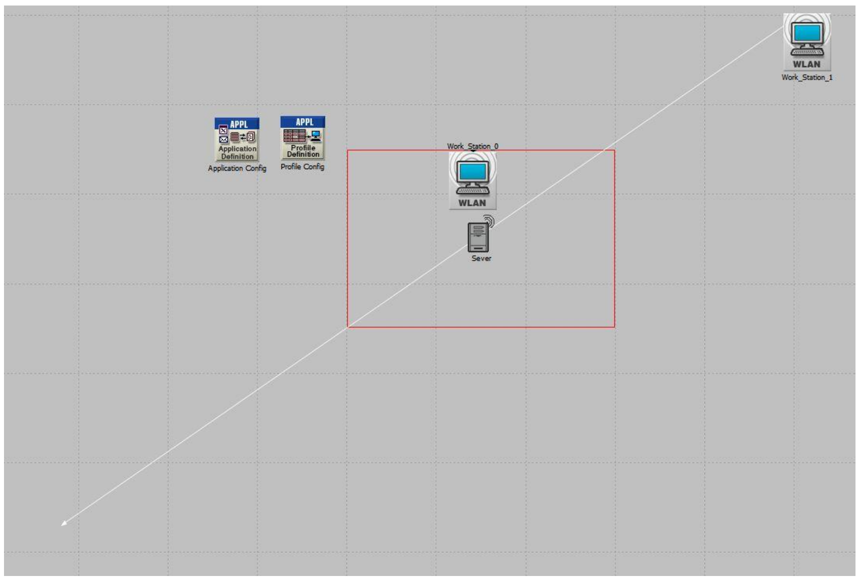


Figure 29: Route of Mobile_Work_Station_1

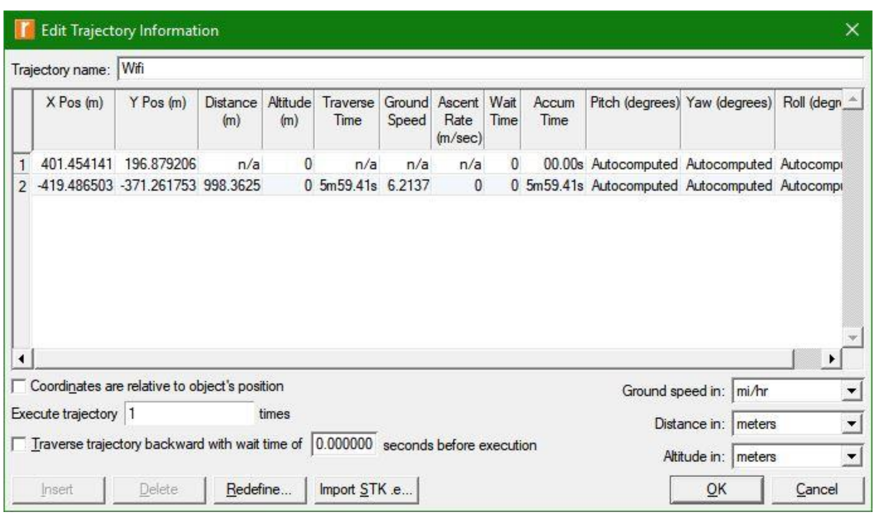


Figure 30: Trajectory Setting of Mobile_Work_Station_1

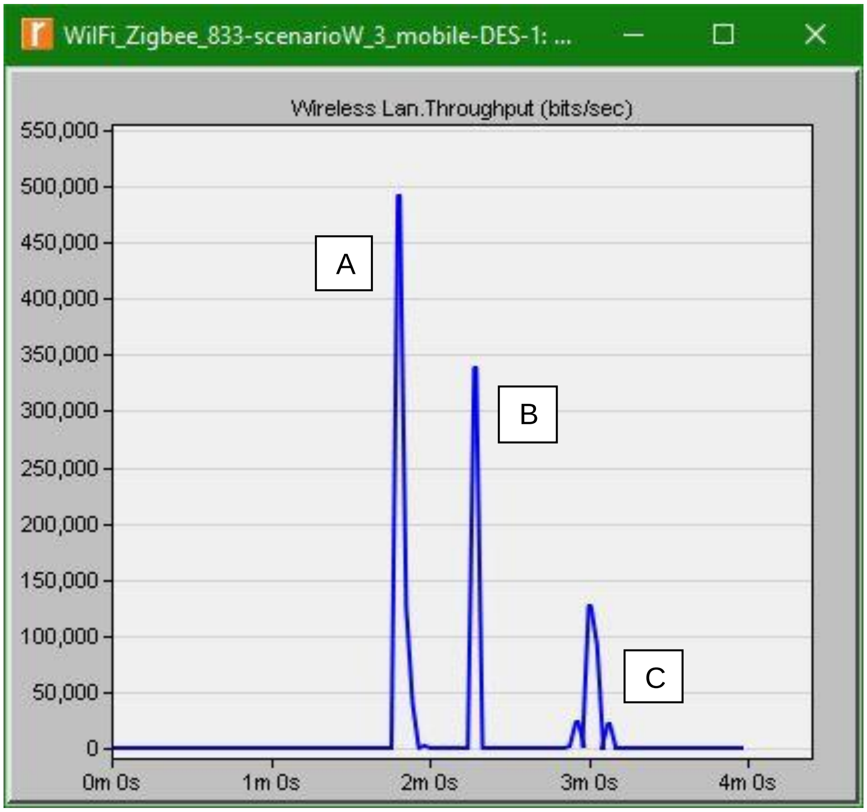


Figure 31: Throughput of Mobile_Work_Station_1

From figure 31, we have divided the graph into three sections A, B and C. Section A is the entering point of the mobile workstation towards the range of the WLAN server, section B represents the position of the mobile workstation inside the range of the server and section C is the leaving point of the range of the server.

Results: At section A, the mobile Work_Station_1 has lots of data need to send so that's why there is a high spike in figure 31. However, when mobile Work_Station_1 enters inside the range of the server at section B; the pressure of sending data has released. At the end before leaving the range of the WLAN server, the throughput fades away which is section C in figure 31.

ZigBee Sub-network

Here, a mobile end device (Home Appliance) is moving around the home under the ZigBee protocol. So, there is a high chance that the mobile end device can move across different PANs (Personal Area Network). When mobile end device moves from one PAN to another PAN, it requires handoff to maintain a connection with the coordinators. Figure 32 represents four coordinators such as coordinator_0, coordinator_1, coordinator_2 and coordinator_3 under the PAN ID of 1, 2, 3 and 4 accordingly. The PAN ID for the mobile end device is in an auto assigned mode so that it can easily recognize the PAN ID of the ZigBee coordinators available in the network.

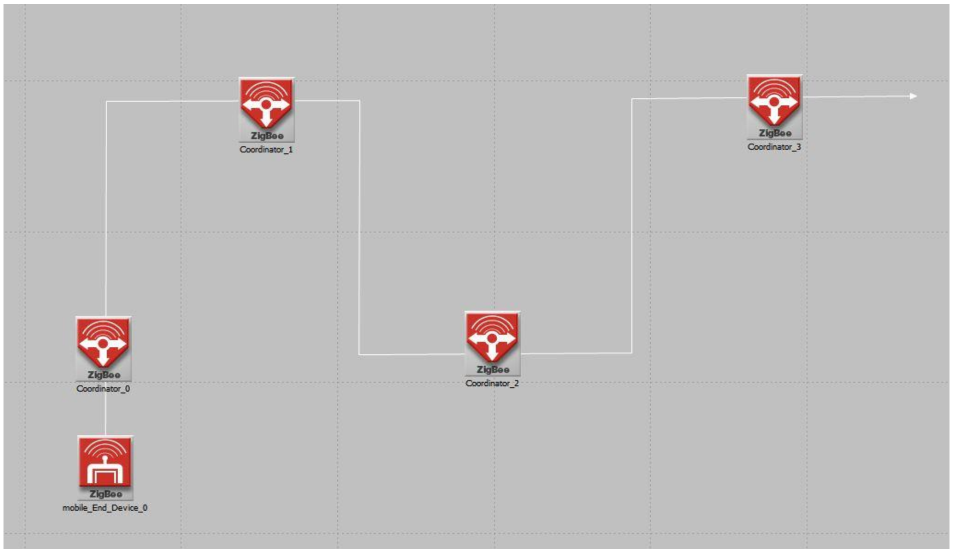
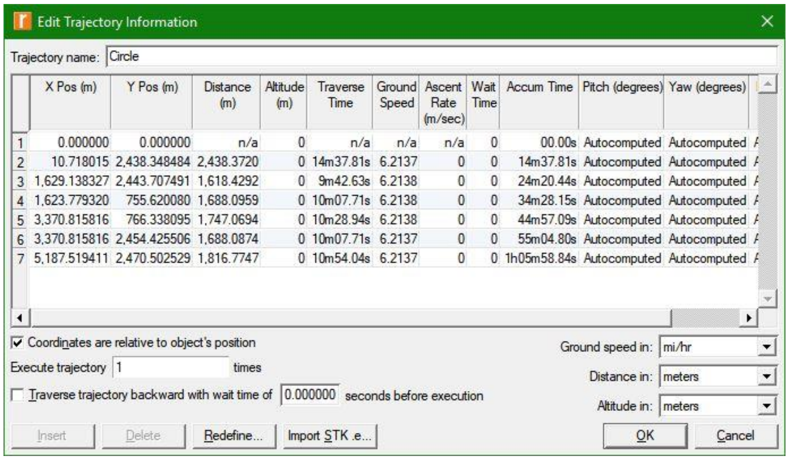


Figure 32: Mobile end device Traveling Route



	X Pos (m)	Y Pos (m)	Distance (m)	Altitude (m)	Traverse Time	Ground Speed	Ascent Rate (m/sec)	Wait Time	Accum Time	Pitch (degrees)	Yaw (degrees)
1	0.000000	0.000000	n/a	0	n/a	n/a	n/a	0	00.00s	Autocomputed	Autocomputed
2	10.718015	2,438.348484	2,438.3720	0	14m37.81s	6.2137	0	0	14m37.81s	Autocomputed	Autocomputed
3	1,629.138327	2,443.707491	1,618.4292	0	9m42.63s	6.2138	0	0	24m20.44s	Autocomputed	Autocomputed
4	1,623.779320	755.620080	1,688.0959	0	10m07.71s	6.2138	0	0	34m28.15s	Autocomputed	Autocomputed
5	3,370.815816	766.338095	1,747.0694	0	10m28.94s	6.2138	0	0	44m57.09s	Autocomputed	Autocomputed
6	3,370.815816	2,454.425506	1,688.0874	0	10m07.71s	6.2137	0	0	55m04.80s	Autocomputed	Autocomputed
7	5,187.519411	2,470.502529	1,816.7747	0	10m54.04s	6.2137	0	0	1h05m58.84s	Autocomputed	Autocomputed

Figure 33: Trajectory Setting

From the trajectory of the mobile_end_device_0 in figure 32, the mobile end device goes through four different PANs. The simulation results and network structure on different times also demonstrate clear evidence of successful handoffs and the impact of received traffic and throughput during those executions of network handoffs.

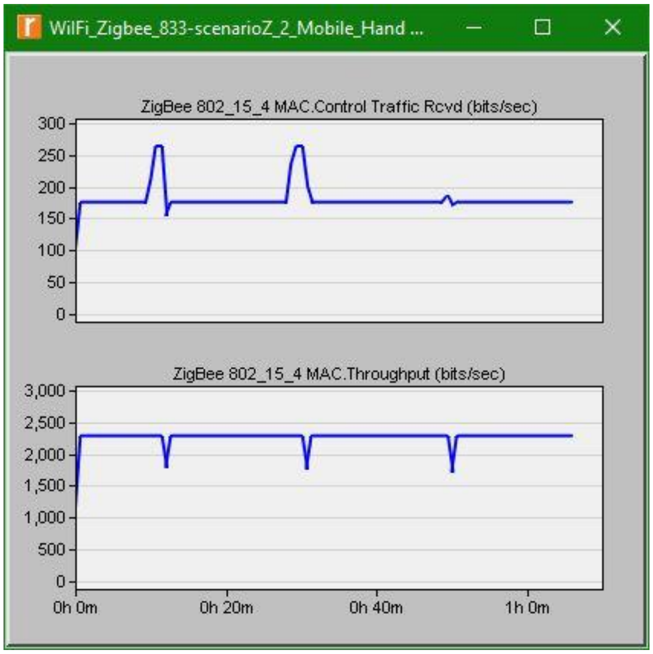


Figure 34: Control Traffic Rcvd and MAC Throughput

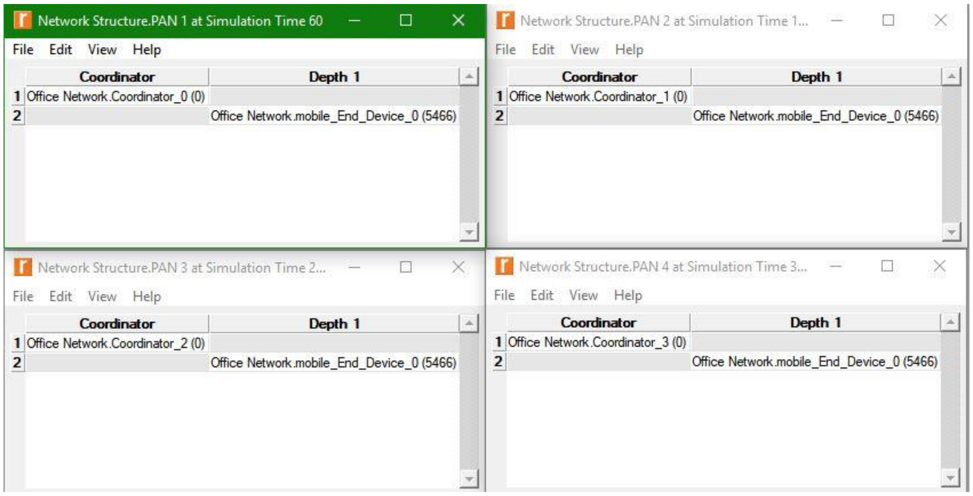


Figure 35: Network Structure on Different PANs

Results: Mobile home appliances can go farther distances from one PAN to another due to the capability of performing successful handoffs.

3.4. Performance during the coexistence between WiFi and ZigBee Sub-network

In this scenario shown in figure 36, a WiFi network is added with a ZigBee network to create a smart home automation setup using mobile workstations (Laptops, mobile phone, etc.) and mobile end devices (Home Appliances). The ZigBee network consists of 13 nodes (1 coordinator, 6 routers and 6 mobile end devices). A WLAN server and a mobile workstation represent the WiFi network. The server is responsible for Http browsing services. All other settings for WLAN server and mobile Workstation remain default. For the ZigBee network, the parameter settings for the coordinator, router and mobile end devices also remain unchanged. The simulation will run for 4 hours to analyze the network performance for these two different coexisted sub-networks.

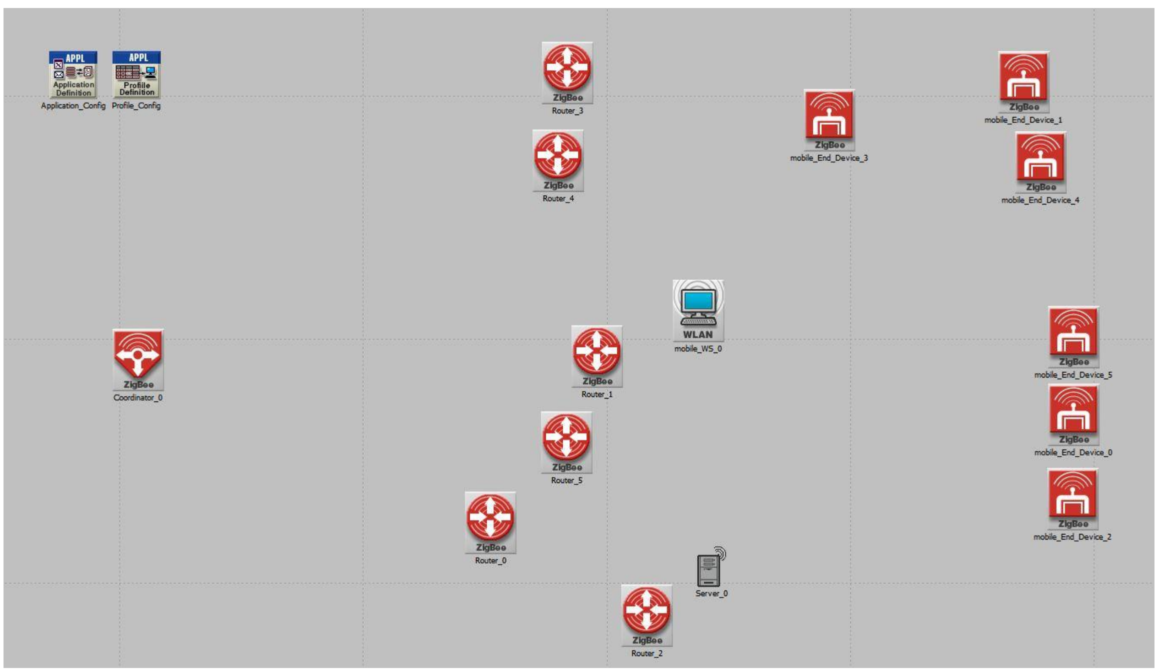


Figure 36: ZigBee with WiFi sub-network

Figure 37: ZigBee Throughput and Wireless LAN Throughput

Simulation results from figure 37, we can see that the ZigBee network with tree topology has the maximum throughput than the other two topologies (mesh and star). However, ZigBee star topology delivers the highest throughput in terms of Wireless LAN.

Results: When two different network technologies share the same space, the impact of interference is bound to happen. In this case, the coexistence of ZigBee and WiFi network is no exception. Out of three ZigBee topologies, the ZigBee star topology paired with WiFi shows the highest throughput because the coordinator is directly connected to the mobile end devices in a star topology. So, the coordinator can only be connected to a small no. of end devices and produce less interference than mesh and tree topology. Although, ZigBee tree topology shows the highest ZigBee MAC throughput in this scenario due to the fact that data traffic is forced to go through the routers towards end devices in a tree topology.

Chapter 4.

Conclusion

4.1. Accomplishment

In this project, the various characteristics and features of WiFi and ZigBee protocol have been demonstrated in order to build a wireless sensor network for home automation. For this purpose, typical scenarios of a wireless sensor network for home automation are introduced and simulated using riverbed modeler 17.5 academic edition. Through this project, the performance of both WiFi and ZigBee protocol is analyzed in terms of device distances, no. of home device connections and device mobility. Besides, the impact of interferences due to the coexistence of both WiFi and ZigBee technology in the same home network is also highlighted.

4.2. Future Work

In the future, we would like to build a more efficient home automation system under both WiFi and ZigBee protocol. We would like to improve the simulation modelling to analyze some more complicated scenarios. For instance, we will continue to analyze the performance of home appliances when assigning lighting control system, heating and cooling system to ZigBee whereas assigning PCs and smart TVs to WiFi. Furthermore, we would like to develop a mobile app which will act as the main control hub to control all connected devices under the wireless sensor network. The app can take full advantage of the wireless network by the coexistence of WiFi and ZigBee. Finally, we would like to add the GPS feature to get the location of each device.

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