PLANNING ZIGBEE NETWORK FOR MONITORING APPLICATION

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

THUREIN ZAW

ABSTRACT

ZigBee is the new wireless technology developed by ZigBee Alliance and guided by IEEE 802.15.4 Personal Area Network standard to overcome the limitations of Bluetooth and Wi-Fi. It's envisioned for wide range of applications. ZigBee nodes are self-organized and have the ability to communicate with each other and to collaborate to achieve the goals of the network. ZigBee can provide low-cost, low-power and wireless mesh network standard that means it is suitable for industrial monitoring or home control monitoring. The ZigBee standard also provides network security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard. It employs a suite of technologies to enable scalable, self-organizing, self-healing networks that can manage various data traffic patterns. In this project, we intend to study the different layers of ZigBee network, network layer performance metrics and use network simulator to plan it for some particular application. The first part is to understand the theory behind ZigBee technology, its advantages over existing technologies and explore how some of the networking protocol operates in a working environment. The second part is to concentrate on simulating the ZigBee Network using OPNET Simulator.

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LIST OF ABBREVIATOINS

ACK	Acknowledge
ACL	Access Control List
ATM	Asynchronous Transfer Mode
CBR	Constant Bit Rate
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSMA-CD	Carrier Sensing Multiple Access with Collision Detection
ETE	End-to-End
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical
IP	Internet Protocol
LAN	Local Area Network
LR-WPAN	Low Rate – Wireless Personal Area Network
MAC	Medium Access Control
OPNET	Optimized Network Engineering Tools
PAN	Personal Area Network
PER	Packet Error Rate
RIP	Routing Internet Protocol
TCP	Transmission control protocol
VBR	Variable Bit Rate
WAN	Wide Area Network
ZDO	ZigBee Device Object

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wireless networking has been growing rapidly in the past several years. Until now, wireless networking has been mainly focused on high-speed communications, and relatively long range applications such as the IEEE 802.11 Wireless Local Area Network (WLAN) standards. The first well known standard focusing on Low-Rate Wireless Personal Area Networks (LR-WPAN) was Bluetooth.[1] However it can only support for networking of few nodes with limited range. There are many wireless monitoring and control applications in industrial and home environments which require longer battery life, lower data rates and less complexity than those from existing standards. For such wireless applications, a new standard called IEEE 802.15.4 has been developed by IEEE. This new standard is called ZigBee.

ZigBee Standard has been researched by many communication engineers since it is a new emerging technology and still needed to be investigated. Since there is no standard covering the wireless sensor networking, it is an interest to investigate and evaluate this new standard. ZigBee protocol is guided by the IEEE 802.15.4 Personal Area Networks standard. It is primarily designed for the wide ranging automation applications and to replace the existing non-standard technologies. ZigBee is the architecture developed on top of the IEEE 80215.4 reference stack model and it currently operates in the 868MHz band at a data rate of 20Kbps in Europe, 914MHz band at 40Kbps in the USA, and the 2.4GHz ISM bands Worldwide at a maximum data-rate of 250Kbps. ZigBee is the standards-based technology that 1.addresses the unique needs of remote monitoring & control, and sensory network applications, 2.enables broad-based deployment of wireless networks with low cost, low power solutions, 3.provides the ability to run for years on inexpensive primary batteries for a typical monitoring application.

1.2 Problem Statement

There are many disadvantages in wireless sensor networks. Wireless personal area networks (WPANs) typically have a limited range, limited to relatively slow data rates when compared with WLAN technologies , compatibility and interoperability issues (WPAN technologies are not usually compatible with each other), not enough secure transmission and devices with inbuilt WPAN technologies can be considerably more expensive than devices without WPAN technologies. Therefore, a proper research and analysis on ZigBee technology is required to get more improvement for future networking. ZigBee can overwhelm these problems since it is a standard based technology.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objective of the project is to study the different layers of ZigBee network, study the network performances and plan it using network simulator for some particular monitoring application. The software, OPNET Simulator is used to simulate the network.

1.3.2 Scope of Study

The scope of the study includes:

- Study the Physical, Mac, Network and Application layers for ZigBee Network.
- Study the performance metrics of ZigBee networks.
- Simulations of ZigBee network in different setups.
- Analysis of results gained from the simulation.

1.3.3 The Relevancy of the Project

This project is relevant to the study of Communication System as well as the field of Computer networking. This project is also relevant to the recent technology of applying Wireless personal area networks in various fields such as Home Automation, Commercial Building Automation, and Tele-communication Applications and so on. Besides, the study of ZigBee network can be the next generation of enhancing technology.

1.3.4 Feasibility of the Project within the Scope and Time frame

The project starts by collecting materials such as books, journals and technical papers specifically on ZigBee technology, WPANs, Wi-Fi and top-down networking approach. Research will be done from time to time as part of getting a better understanding on this issue. This project will then focus on simulation the network protocol using a network simulation tool OPNET.

CHAPTER 2

LITERATURE REVIEW

2.1 IEEE 802.15.4 Standard

IEEE Standard 802.15.4 defines the physical layer (PHY) and medium access control (MAC) sub-layer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements typically operating in the personal operating space (POS) of 10 m.[2] This standard defines the protocol and interconnection of devices via radio communication in a personal area network (PAN). The standard uses carrier sense multiple access with collision avoidance (CSMA-CA) medium access mechanism and supports star as well as peer-to-peer topologies. The media access is contention based; however, using the optional super frame structure, time slots can be allocated by the PAN coordinator to devices with time critical data. [3] Connectivity to higher performance networks is provided through a PAN coordinator.

An LR-WPAN is a simple, low-cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements.[4] The main objectives of an LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol. Some of the characteristics of an LR-WPAN are as follows:

- Over-the-air data rates of 250 kb/s, 100kb/s, 40 kb/s, and 20 kb/s
- Star or peer-to-peer operation
- Allocated 16-bit short or 64-bit extended addresses
- Optional allocation of guaranteed time slots (GTSs)
- Carrier sense multiple access with collision avoidance (CSMA-CA) channel access
- Fully acknowledged protocol for transfer reliability

- Low power consumption
- Energy detection (ED)
- Link quality indication (LQI)
- 16 channels in the 2450 MHz band, 30 channels in the 915 MHz band, and 3 channels in the 868 MHz band

Two different device types can be seen in an IEEE 802.15.4 network; a full-function device (FFD) and a reduced-function device (RFD). The FFD can operate in three modes serving as a personal area network (PAN) coordinator, a router, or a device. An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD. An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor; they do not have the need to send large amounts of data and may only associate with a single FFD at a time. Consequently, the RFD can be implemented using minimal resources and memory capacity.

Full Function Device (FFD)

1. Provide all the features of ZigBee.
2. Normal power supply is needed.
3. No need to enter sleep mode.
4. It can either be coordinators or routers.

Reduced Function Device (RFD)

1. Provide part of ZigBee functions.
2. Mobile power supply is needed.
3. Save power by entering into sleep mode.

2.2 ZigBee Standard

ZigBee is the standard based on IEEE 802.15.4. ZigBee is an established set of specifications for wireless personal area networking (WPAN). ZigBee and IEEE 802.15.4 are standards-based protocols that provide the network infrastructure required for wireless sensor network applications. 802.15.4 defines the physical and MAC layers, and ZigBee defines the network and application layers. [5]

For sensor network applications, key design requirements revolve around long battery life, low cost, small footprint, and mesh networking to support communication between large numbers of devices in an interoperable and multi-application environment. A group of companies called ZigBee alliance are now providing a standardized base set of solutions for sensor and control system. The current working lists of ZigBee alliance are based on the following criteria:

- Home Automation
- ZigBee Smart Energy
- Telecommunication Applications
- Commercial Building Automation and
- Personal, Home, and Hospital Care

The ZigBee standard was developed to address the following needs:

- Low cost
- Secure
- Reliable and self healing
- Flexible and extendable
- Low power consumption
- Easy and inexpensive to deploy
- Global with use of unlicensed radio bands
- Integrated intelligence for network set-up and message routing

ZigBee is the only standards-based technology that addresses the unique needs of most remote monitoring and control sensory network applications. The term “ZigBee” originates from honeybees’ method of communicating newfound food sources. This silent-but-powerful communication system is known as the “ZigBee Principle.” By dancing in a zig-zag pattern, the bee is able to share critical information, such as the location, distance, and direction of a newly discovered food source to its fellow hive members.[6]

2.3 ZigBee Stack Architecture

Following the standard Open Systems Interconnection (OSI) reference model, ZigBee's protocol stack is structured in layers. The first two layers, physical (PHY) and media access (MAC), are defined by the IEEE 802.15.4 standard. The layers above them are defined by the ZigBee Alliance and together these layers make up the ZigBee technology stack architecture.

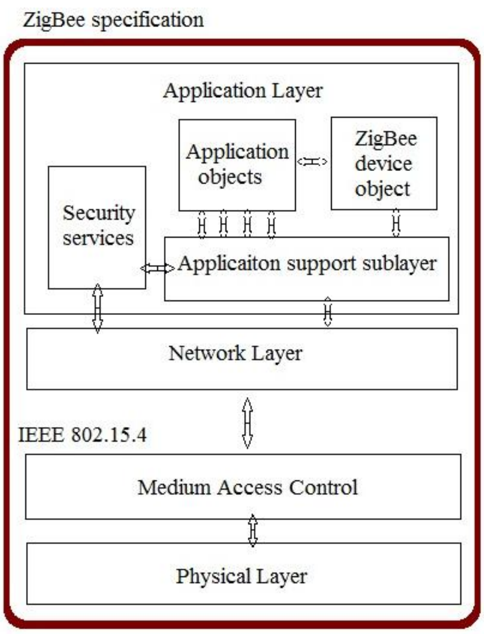


Figure 1: ZigBee Stack Architecture

ZigBee-compliant products operate in unlicensed bands worldwide, including 2.4GHz (global), 902 to 928MHz (Americas), and 868MHz (Europe). Raw data throughput rates of 250Kbps can be achieved at 2.4GHz (16 channels), 40Kbps at 915MHz (10 channels), and 20Kbps at 868MHz (1 channel). The transmission distance is expected to range from 10 to 75m, depending on power output and environmental characteristics. Like Wi-Fi, Zigbee uses direct-sequence spread spectrum in the 2.4GHz band, with Offset-Quadrature phase-shift keying modulation. Channel width is 2MHz with 5MHz channel spacing. The 868 and 900MHz bands also use direct-sequence spread spectrum but with binary-phase-shift keying modulation.

2.4 ZigBee Protocol

The ZigBee protocol has been created by ZigBee alliance companies. The ZigBee protocol was designed to provide an easy-to-use wireless data solution characterized by secure, reliable wireless network architectures.

ZigBee protocol features include:

- Support for multiple network topologies such as point-to-point, point-to-multipoint and mesh networks
- Low duty cycle – provides long battery life
- Low latency
- Direct Sequence Spread Spectrum (DSSS)
- Up to 65,000 nodes per network
- 128-bit AES encryption for secure data connections
- Collision avoidance, retries and acknowledgements

2.5 Device Types

ZigBee networks include the following device types:

- Coordinators,
- Routers, and
- End devices.

1. ZigBee Coordinator: This device starts and controls the network. The coordinator stores information about the network, which includes acting as the Trust Center and being the repository for security keys.
2. ZigBee Router: These devices extend network area coverage, dynamically route around obstacles, and provide backup routes in case of network congestion or device failure. They can connect to the coordinator and other routers, and also support child devices.
3. ZigBee End Devices: These devices can transmit or receive a message, but cannot perform any routing operations. They must be connected to either the coordinator or a router, and do not support child devices.

2.6 ZigBee Data Transmission

Three types of data transmission are possible such as

1. Transmission from a device to the coordinator
2. Transmission from the coordinator to the device
3. Transmission between any two devices

In star topology, transmission takes place only between coordinator and end devices. Therefore, transmission between any two devices is not possible.

1. Transmission from a Coordinator to a Device

- The coordinator has information to be transmitted to the device.
- Devices tracking the beacons, decode the pending address fields.
- If a device finds its address listed among the pending address fields, it realizes it has data to be received from the coordinator.
- It issues a Data-Request Command to the coordinator.
- The coordinator replies with an acknowledgement.
- If there is data to be sent to the device, it would transmit the data.
- If acknowledgements are not optional, the device would respond with an acknowledgement.[7]

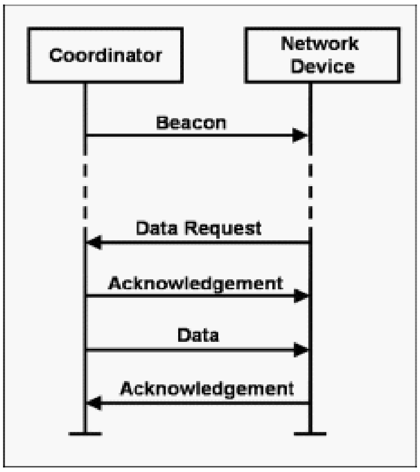


Figure 2: Coordinator to Device

2. Transmission from a device to a coordinator

- The device first listens to the beacon.
- On finding the beacon, it synchronizes first to the Superframe structure. This process makes it realizes the start and end time of the Contention access period.
- The device will now compete with its peers for a share of the channel.
- On its turn, it will transmit the data to the coordinator.
- The coordinator may reply back with an acknowledgement, if it is not optional.

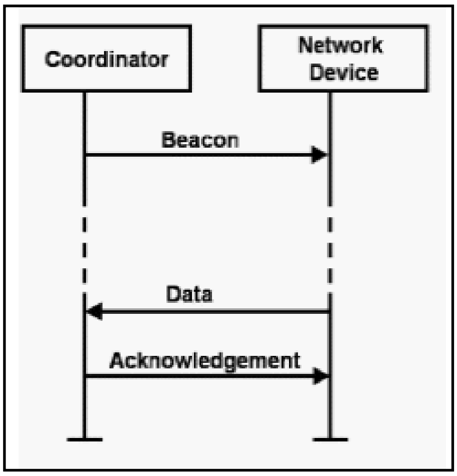


Figure 3: Device to Coordinator

3. Transmission between two devices

Transmission between two devices can either be by synchronization techniques or direct transmission method using unslotted CSMA-CA. However, synchronization technique is harder to implement and direct transmission might degrade the throughput performance of the PAN.

2.7 ZigBee Routing Layer

ZigBee Network uses two types of routing algorithm.

1. Distance Vector Routing and
2. Link state Routing.

In distance vector each node announces its routing table to its neighbors whereas in link state routing in it floods its routing table. Both update their routing tables periodically. In this project, most of the scenarios use mesh networking. Therefore, the routing protocol is Ad hoc on demand distance vector routing protocol.

2.7.1 AODV (Ad hoc On Demand Distance Vector) Routing Algorithm)

The Ad hoc On Demand Distance Vector (AODV) routing algorithm is a routing protocol designed for ad hoc mobile networks. AODV is capable of both unicast and multicast routing. It is an on demand algorithm, meaning that it builds routes between nodes only as desired by source nodes. It maintains these routes as long as they are needed by the sources. AODV uses sequence numbers to ensure the freshness of routes. It is loop-free, self-starting, and scales to large numbers of mobile nodes.[8]

2.7.2 Cluster-Tree Algorithm

The cluster-tree protocol is a protocol of the logical link and network layers that uses link-state packets to form either a single cluster network or a potentially larger cluster tree network. The network is basically self-organized and supports network redundancy to attain a degree of fault resistance and self-repair. Nodes select a cluster head and form a cluster according to the self-organized manner. Then self-developed clusters connect to each other using the Designated Device (DD).[9]

2.8 ZigBee: Advantages and Disadvantages

ZigBee network has its own advantages and disadvantages compared with other wireless personal area networks.

Advantages

1. ZigBee's main advantage is its ability to be configured in so-called mesh networks with wireless nodes that are capable of multi-year battery lives.
2. ZigBee supports large no of nodes in network.
3. ZigBee has Low latency period. It is around 30ms.
4. Power consumption in ZigBee is very low as compared to other wireless sensor network technologies hence long battery life.
5. Low cost
6. It can be used globally since ZigBee alliance is an open global standard source.
7. ZigBee network designs are simple.

Disadvantages

1. It works over short range.
2. Data rate is low.

2.9 How ZigBee Technology achieves Low Power with beacons

ZigBee low power-usage allows longer life with smaller batteries. Most of the monitoring applications require low power consumption. ZigBee networks are designed to conserve the power of the slave nodes. ZigBee sensor nodes may enter into deep-sleep mode and wakes up only for a fraction of time to confirm any network activity in the network. For example, the transition from sleep mode to data transition may take around 15ms and new nodes enumeration typically just takes 30ms.

ZigBee networks employ beacon or non-beacon environments. Beacon mode is used when the coordinator runs on batteries and enters into sleep mode for a certain period of time. Beacon enable mode is used to synchronize the network devices and describe the structure of the Superframe. The beacon intervals are set by the network coordinator and vary from 15ms to over 4 minutes. There are sixteen concurrent slots in the Superframe structure. Contention access period is the time duration for devices to compete each other to access the channel. Contention free period also called guaranteed time slots are reserved for some low-latency devices to access the channel immediately with any delay. Inactive portion is the time period the coordinator enters into sleep mode to save power. Beacon mode is a mechanism for controlling power consumption in extended networks such as cluster tree or mesh. It enables all the nodes to know when to communicate with each other. The primary value of beacon mode is that it reduces the system's power consumption.

Non-beacon mode is typically used for security systems, such as intrusion sensors, motion detectors, and glass-break detectors, and sleep 99% of the time. Remote units wake up on a regular randomly to announce their continued presence in the network. When an event occurs, the sensor wakes up instantly and transmits the alert. The network coordinator, powered from the main source, has its receiver power on all the time and can therefore wait to receive from each of the stations. Since the network coordinator has an "infinite" source of power it can allow other network nodes to sleep for unlimited periods of time, enabling them to save power.

2.10 ZigBee Network Topology

ZigBee and IEEE 802.15.4 standard is a simple but flexible data protocol, is designed to meet the simple quality of service requirements, for low-speed data transfer rate of the application to achieve optimized settings.

Main advantages include:

(1) energy-saving design to achieve a durable life.

(2) a flexible network architecture Road.

(3) low-complexity hardware and software design.[10]

The main purpose of the ZigBee Network Layer is to provide reliable and secure transmission. There are three kinds of networks topology, Star topology, Tree topology, Mesh topology.

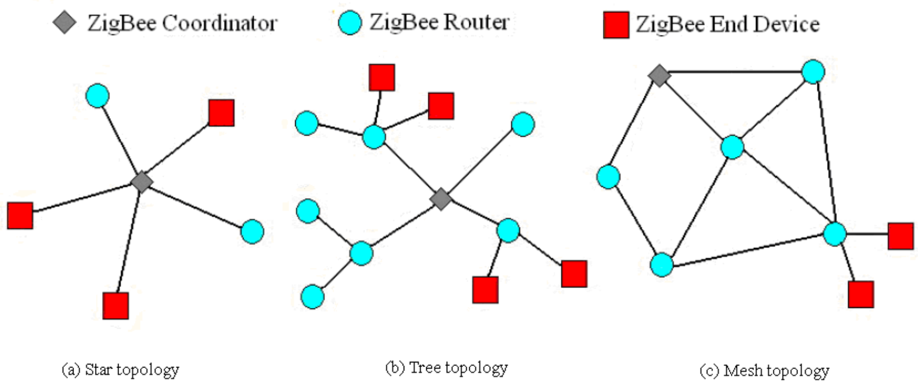


Figure 4: ZigBee Network Topologies

A ZigBee coordinator is responsible for the initial, maintenance and control of Networks. ZigBee Star topology is similar with the IEEE 802.15.4 topology where the device can only send and receive data with the coordinator. For the tree topology and mesh topology, there are many multi-hop devices in between to communicate and their backbones are constructed by one coordinator and many routers. The FFD coordinator and routers may join the network as a terminal device, and the other end of the device can be a FFD or RFD. In a tree network, the coordinator and the router can send beacons to periodically wake up the end devices. In the mesh network, end devices find the shortest path to the coordinator and can relay messagse easily with the routers but the coordinator is unable to send beacons.

Table 1: Network topology Comparison

	(Star topology)	(Tree topology)	(Mesh topology)
Main transfer protocol	Slotted CSMA/CA Protocol	Slotted CSMA/CA Protocol	UnSlotted CSMA/CA Protocol
Benefits	1. Easy to synchronize 2. Latency	1 Router search claim, lower power consumption 2 Can support sleep mode 3 Can support large purse seine network structure	1 Support multi-point connection node 2 Network for the high variability 3 Lower latency 4 Support large purse seine network structure
Shortcomings	1. Can only support small-scale network	1. More energy consuming 2. May have very high latency	1. Cannot support sleep mode 2. Router table establish a high energy consumption

2.11 Comparison between ZigBee, Bluetooth and Wi-Fi

ZigBee is distinguished from other wireless technologies as it is especially designed for monitoring application. The following table shows how it is different from other wireless technologies.

Table 2: Characteristics of ZigBee, Wi-Fi and Bluetooth

	ZigBee	Wi-Fi	Bluetooth
Range	10-100 meters	50-100 meters	10 – 100 meters
Networking Topology	Ad-hoc, peer to peer, star, or mesh	Point to hub	Ad-hoc, very small networks
Operating Frequency	868 MHz (Europe) 900-928 MHz (NA), 2.4 GHz (worldwide)	2.4 and 5 GHz	2.4 GHz
Complexity (Device and application impact)	Low	High	High
Power Consumption (Battery option and life)	Very low (low power is a design goal)	High	Medium
Security	128 AES plus application layer security		64 and 128 bit encryption
Typical Applications	Industrial control and monitoring, sensor networks, building automation, home control and automation, toys, games	Wireless LAN connectivity, broadband Internet access	Wireless connectivity between devices such as phones, PDA, laptops, headsets

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

In order to achieve the objectives of this project, all the required information are collected on the ZigBee Technology and wireless Personal Area Networks. Then, the simulation processes is started using OPNET modeler and the scenarios are simulated. After that, the performance of the network is analyzed using graphical interface.

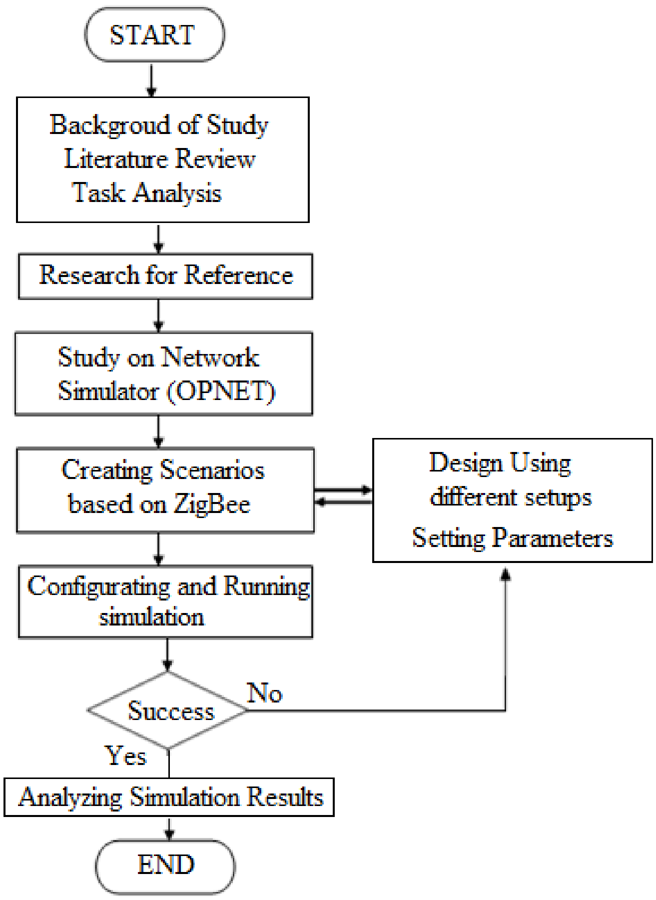


Figure 5: Project Activities Flow Graph

3.2 Tools and Equipments Used

The following software is utilized during the project:

- OPNET Modeler

3.2.1 OPNET Modeler

OPNET Modeller is a provider of management software for networks and applications. OPNET Modeller is an environment for network modelling and simulation, allowing design and study of communication networks, devices, protocols and applications with great flexibility and scalability.

Model development in OPNET Modeler is done through graphical model creation and C++ programming. The modeling environment is very flexible, and systems of any dimensions may be modeled. The models are divided into layers, Process model, Node Model and he complete project model. This facilitates the building of layered network models, and by creating a simple Process model and Node model, a large scale Project model may be built with few adjustments. Besides placing models in a graphical user interface the object oriented C++ is used to program the functionality of the models at the bottom level. The OPNET model in its very core also consists of C++ code. These codes are complied and executed just like a C++ program, and enables very detailed control of the model by the user (if the user is proficient in C++). When a model has been implemented, simulation parameters can be defined and monitored during simulation. OPNET Modeler also includes analysis tools for result evaluation and comparison.[10]

The OPNET ZigBee model uses four process models:

- ZigBee MAC model which implements a model of the IEEE 802.15.4 MAC protocol. The model implements channel scanning, joining and failure/recovery process of the protocol in the unslotted operation mode.
- ZigBee Application model which represents a low fidelity version of the ZigBee Application Layer as specified in the ZigBee Specification. The process model initiates network joins and formations, generates and receives traffic and generates different simulation reports.

- ZigBee Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) model which implements the media access protocol of the MAC layer.
- ZigBee Network model which implements the ZigBee Network Layer as specified in the ZigBee specification. This model is responsible for routing traffic, process network join, formation requests and generating beacons. [15]

3.2.2 ZigBee Model Feature

The model implements the following features:

- Application layer features
    - Generating and receiving application traffic
    - Initiating network discovery and network join
    - Failing and recovering ZigBee devices
- Network layer features
    - Establishing a network
    - Joining a network and permitting network joins
    - Assigning an address
    - Maintaining a neighbor table
    - Mesh Routing Process
    - Network Broadcast
    - Tree routing process
    - Transmitting and receiving data
    - Mobility
    - Beacon scheduling
- MAC layer features
    - Channel Scanning
    - CSMA/CA (Contention-based operation mode)

3.2.3 OPNET Simulation Flow Chart

The following figure shows the process of data transferring between coordinator and end devices during the simulation in OPNET modeler.

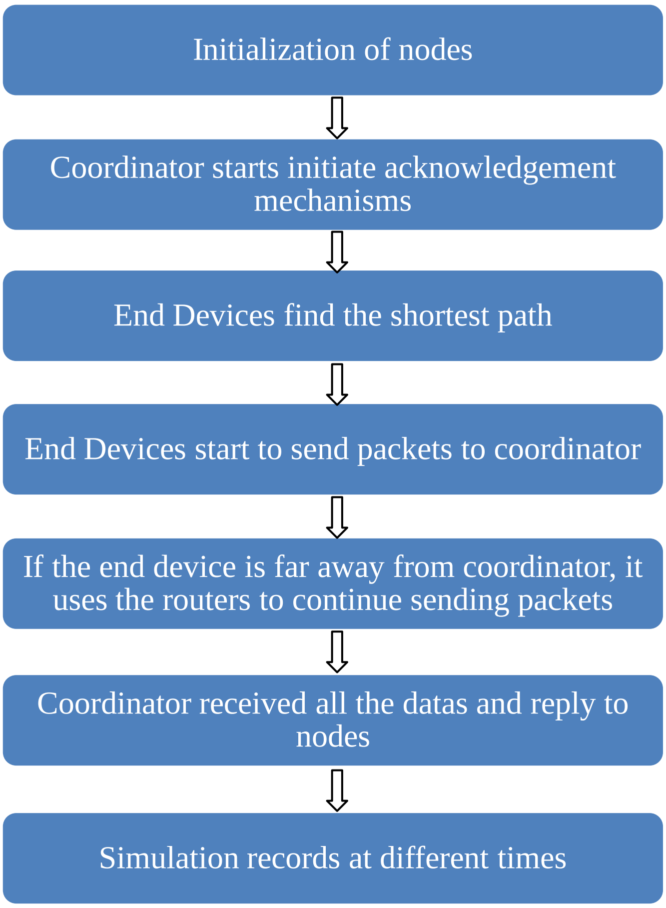


Figure 6: The process flow of ZigBee network simulation

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance Metrics

To evaluate the ZigBee network performance matrices, some of the network parameters are studied based on the theory. Different ZigBee networks are simulated in the project and the results are compared with each other. Most of the scenarios are simulated based on mesh routing algorithm because mesh routing is more preferred for ZigBee network routing. Among the two routing algorithm of ZigBee, the following experiments use Ad-hoc on-demand distance vector (AODV) routing protocol. The simulation below measures the important performance parameters metrics including:

1. End-to-End Delay: the delay experienced by a packet from the time it was sent by the source till the time it was received at the destination.
2. Communication Throughput: the average rate of successful message delivery over a communication channel shown in bits per second (bps).
3. Packet Loss Ratio: the ratio of loss packets received and transmitted during simulation.

The above parameters are evaluated using different packet sizes, different transmission power, and different numbers of nodes.

4.2 Network Simulation Parameters

The following table shows the configuration applied to ZigBee Networks in OPNET modular. These settings are commonly used in all simulations. However some networks are simulated with different values of packet sizes, topology types, depending on the experiments.

Table 3: Coordinator’s Network Layer Parameters

Coordinator’s Network Layer Parameters	
Maximum number of end devices and routers in one PAN	250
Maximum number of routers in a single PAN	6
Route discover timeout(sec)	10
CSMA-CA Parameters	Default
Transmission Bands	2450MHz Band

Table 4: The Media Access Control, Physical and Application Layer Simulation Parameters

MAC Layer Parameters	
Acknowledge wait duration (sec)	0.05
Maximum Number of retransmission	5
Minimum value of the back-off exponent in the CSMA/CA	3
Maximum numbers of back-offs the CSMA/CA algorithm	4
Channel sensing duration (sec)	0.1
Physical Layer Parameters	
Data rate(kbps)	250
Receiver sensitivity (dB)	-85
Transmission band (GHz)	2.4
Transmission power (W)	0.05
Application Layer Parameters	
Packet interval time/type (sec/constant)	1
Packet size/type (bits/constant)	1024

- Transmission Power – The power allocated to packets transmitted through the channel.

- Channel Sensing Duration – This is the duration for which each channel will be scanned for beacons after the beacon request is sent out. If 'Auto-Compute' is specified, the node automatically determines the channel sensing duration based on the data rate of the channel being scanned.

- Minimum value of the back-off exponent in the CSMA/CA – The value used in collision avoidance. If this value is set to 0, collision avoidance is disabled during the first iteration of the algorithm.

- Maximum numbers of back-offs the CSMA/CA algorithm – Number of back-offs which will attempt before declaring a channel access failure.

- Route Discovery time – The time duration for a packet to find the shortest link to the destination. In a Mesh topology, the network has built-in intelligence to ensure that messages reach their destinations. If the default route to the destination node is down, due to a failed intermediate node or link, the network can “discover” and use alternative routes for message delivery.

- Acknowledge wait duration – A system of message acknowledgements is available in ZigBee to confirm that messages reach their destinations. When a message arrives at its destination, the receiving device sends an acknowledgement to say the message has arrived. If the sending device does not receive an acknowledgement within a certain time interval, it resends the original message (it can resend the message several times until the message has been acknowledged).

- Data rate – The specific data rate that will be used by the MAC for the transmission of the data frames via physical layer.

- Packet interval time - Specifies the distribution name and arguments to be used for generating random outcomes for times between successive packet generations.

4.2.2 Path Loss Calculation

Path loss is simply the attenuation since it reduces the power density of the signal when it propagates through space. Path loss may be due to many effects, such as free-space loss,refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Free space attenuation can be calculated according to the following equation.

$$L_{FreeSpace}\,(dB) = -(20 \log d(m) + 20 \log f(MHz) - 27.5) \text{ [5]}$$

Where, LFreeSpace = FreeSpace attenuation in dB

d = distance in meters

f = frequency in MHz

In ZigBee, the frequency is 2.4GHz and the equation reduces to

$$L_{FreeSpace}\,(dB) = -\,(20 \log d(m) + 20\log(2405MHz) - 27.5)$$

$$= -\,(20 \log d(m) + 40.3)$$

For any distance between 10 meters to 500 meters, free space path loss can be specified.

Table 5: Calculation for Free Space Path Loss

Distance in meters between Nodes	Free Space Path Loss (dB)
10 meters	-60.3 dB
50 meters	-74.28 dB
100 meters	-80.3 dB
200meters	-86.32 dB
500meters	-94.28 dB

4.2.3 Transmit Power

The transmit power is the power consumed by the transceiver to transmit a data packet. The size of the data packet determines the transmit power. The longer the packet length is, the higher the power consumption. But, a different transmits power level for different packet sizes cannot be produced. The transmit power used in this project for the average packet size is 0.5 mW.

4.2.4 Received Power

Received power is the power consumed to receive a data packet. Effective transmit power is derived from adding the transmit antenna gain (Gt) to the total transmit power (Pt). Similarly, receiver antenna gain (Gr) and receiver power (Pr) can be derived from the following equation (free space model):

$$\Pr(d) = \frac{\text{Pt Gr Gt } \lambda}{(4\pi)^2 \, \text{d}^2 \, \text{L}}, \quad d > 0 \ [5]$$

Where, P_r = Receiver power in dBm

P_t = Transmitter power in dBm

G_r = Receiver antenna gain in dB

G_t = Transmitter antenna gain in dB

L =Attenuation at 2450 MHz in dB

4.2.5 Receiver Sensitivity

Receiver sensitivity is the minimum input signal into the receiver which can be successfully decoded. The IEEE 802.15.4-2003 standard sets the requirement of –85 dBm one percent Packet Error Ratio (PER) minimum sensitivity. In the experiment, the frequency used is 2.4 GHz and minimum receiver sensitivity used is -85 dBm. Receiver sensitivity can be expressed in Watt.

$$Pr = \frac{10^{(\frac{dBm}{10})}}{1000}$$

$$Pr = \frac{10^{(\frac{-85}{10})}}{1000}$$

$$\text{Pr} = 3.16\, x\, 10^{-12}\, W$$

4.2.6 End-to-End Delay Performance Study

The end –to-end delay (ETE) is defined as the end-to-end delay of all the packets received by the 802.15.4 MACs of all WPAN nodes in the network and forwarded to the higher layer. The delay includes many factors like the transmission delay, propagation delay, processing delay, and queuing delay experienced at every node in the route. The end-to-end delay is normally the time taken for a data packet to reach its destination node. And the average delay is calculated by taking the average of delays for every data packet transmitted. The parameter comes into account only when the data transmission has been successful. The delay parameter can be defined as follow:

Packet Delay = Receive Time at Destination – Transmit Time at Source

$$\text{Average Delay} = \frac{\text{Sum of all Packet Delays}}{\text{Total Num of Received Packets}}$$

[7]

The average delay can also be defined as a successful transmission between two consecutive packets which correctly received by the coordinator. From a theoretical viewpoint, the transmission delay *D*trans can be written as

$$\text{Dtrans} = \frac{\text{L}}{\text{Rb}} + \text{Tprop} + \text{Tproc}$$

Where, T_{prop} is the propagation delay,

T_{proc} is the processing time at the node,

L is the packet length, and

R_b is the transmission data rate.

The time Tproc includes both the processing delay introduced by the node and the delay introduced by the backoff algorithm.

The simulation is performed in a point to point network with four different setups such as

- Different Packet Sizes,
- Different Numbers of Hops Count,
- Different Number of Packets received,
- Different Transmission Power.

4.2.6.1 Impact of Packet Sizes

Varying the transmission packet size has a direct influence on the ETE delay of ad hoc wireless nodes. Based on the formula, End-to-end delay will increase if the packet length (L) becomes large. This is because the larger the packet size, the longer the packet transmission, propagation and processing time. The minimum packet size used in the experiment is 32 bytes and the maximum packet is 2048 bytes. As seen from the below diagram, the impact of packet size is very obvious for end-to-end delay. The diagram shows the simulation of using different packet sizes from 32 bytes to 2048bytes. The variation is very high as the delay reaches the highest peak of 0.0115 for the largest packet size.

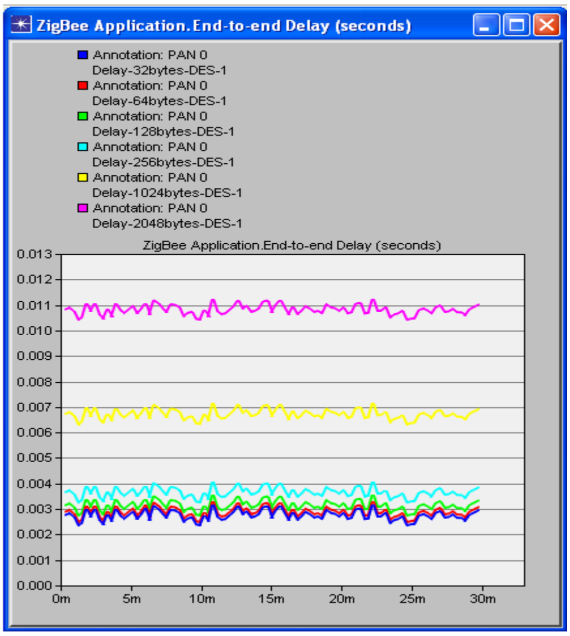


Figure 7: End to End Delay Diagram for Different Packet sizes

4.2.6.2 Impact on the Numbers of Hops

Number of hops greatly affects on the End-to-end delay performance. The longer the packet transmission, propagation and processing time is, the higher the end to end delays are. From the figure below, the end to end delay reaches until 0.044s. The simulation diagrams are mentioned in Appendix B.

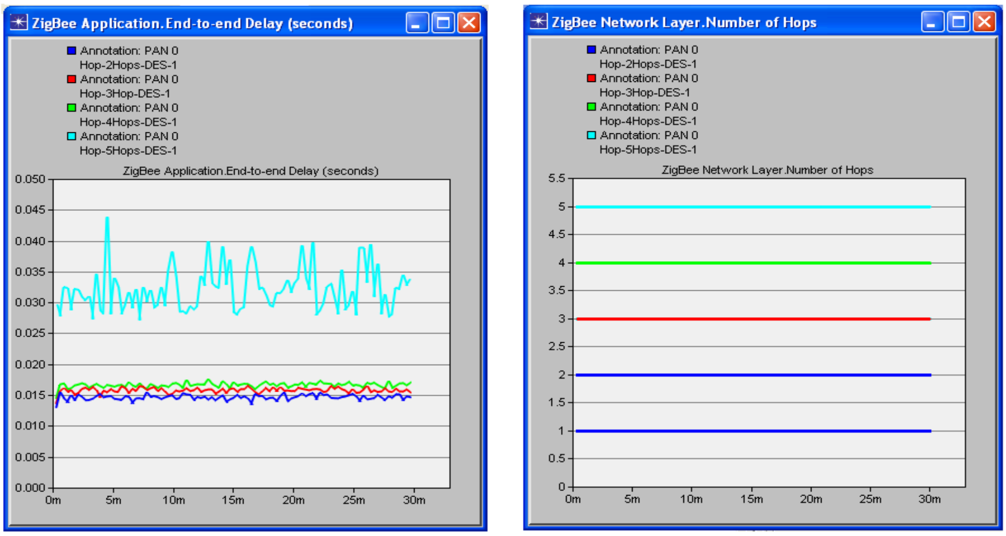
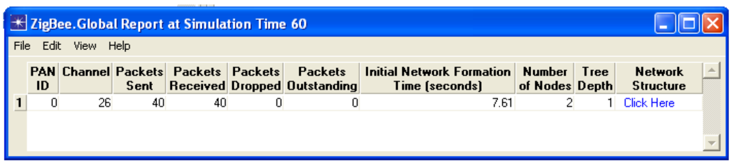


Figure 5: End to End delay Comparison for Different Numbers of hops

4.2.6.3 Impact of Different number of Packet received

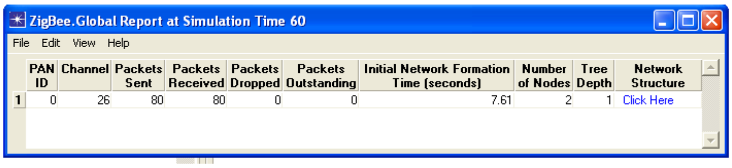
Average delay is the ratio of sum of all packet delays by total number of received packets. According to the statement, end to end delay will increase if more packets are transmitted and received. The simulation is done by varying the packet sent. The blue line shows that it’s transmitted with 80 packets and delay is a bit higher than the other one. The red line indicates that only 40 packets are sent and less delay than the previous one.



ZigBee.Global Report at Simulation Time 60

	PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	0	26	40	40	0	0	7.61	2	1	Click Here

(a)



ZigBee.Global Report at Simulation Time 60

	PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	0	26	80	80	0	0	7.61	2	1	Click Here

(b)

Figure 8: Network structure for Different Number of receiving Packets

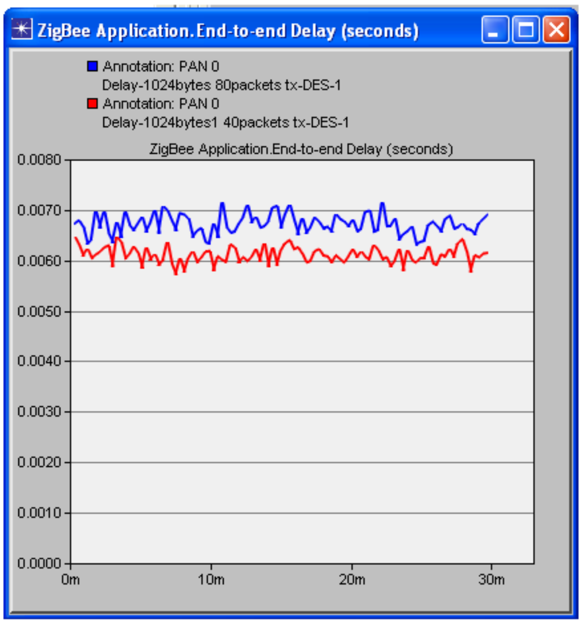


Figure 9: End to End delay for Different Number of receiving Packets

4.2.6.4 Impact of transmission Power

As varies from the minimum values of 0.05 Watt to 5 Watt, the end-to-end delay measurement is the same for low power or high power transmission. Not much change is observed.

4.2.7 Communication Throughput Performance Study

In communication networks, such as Ethernet or packet radio, throughput or network throughput is the average 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. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot. The throughput of a node is measured by first counting the total number of data packets successfully received at the node, and computing the number of bits received, which is finally divided by the total simulation time. The throughput of the network is finally defined as the average of the throughput of all nodes involved in data transmission. The equation for throughput can be defined as:

$$\text{Throughput of a Node} = \frac{\text{Total Data Bits Received}}{\text{Simulation Runtime}}$$

The throughput for the network can be defined as:

$$\text{Network Throughput} = \frac{\text{Sum of Throughput of Nodes Involved in Data Trans}}{\text{Number of Nodes}}$$

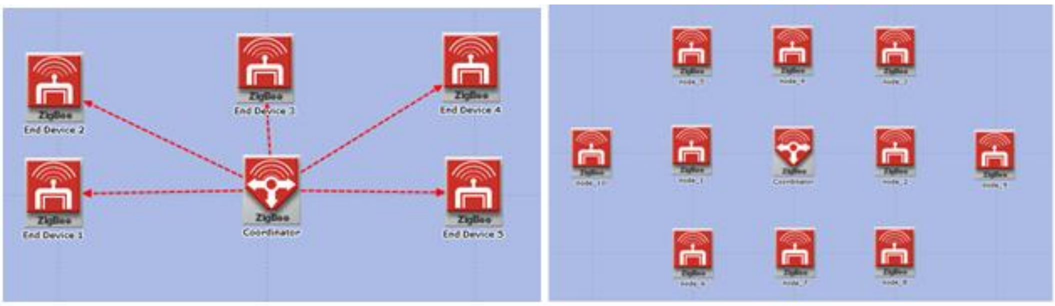
[7]

The simulation for throughput is performed by three steps:

1. Different number of nodes
2. Different packet sizes
3. Different Transmission power

To observe the behavior of network throughput, the following scenarios are created.

There are four networks simulated with node numbers of 5, 10, 50 and 100 shown in figure 1, 2 and 3. All networks use AODV networking protocol and mesh routing algorithm. Some simulation parameters are based on default setting available in OPNET. Beacon order and Superframe order are fixed and cannot be changed. The simulation time is 30minutes. The simulation area ranges 100x100 meters to cover connectivity between the nodes. The coordinator is in the position of (50, 50) axis.



(a) (b)

Figure 10: (a) 5 Nodes and (b) 10 Nodes Network

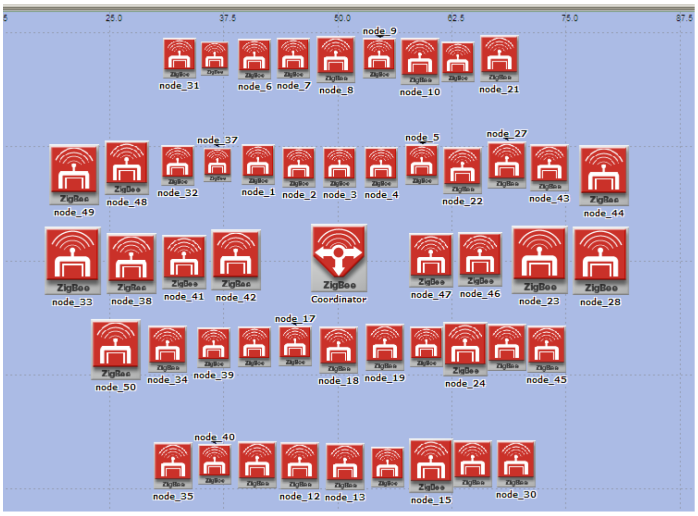


Figure 11: 50 Nodes Network

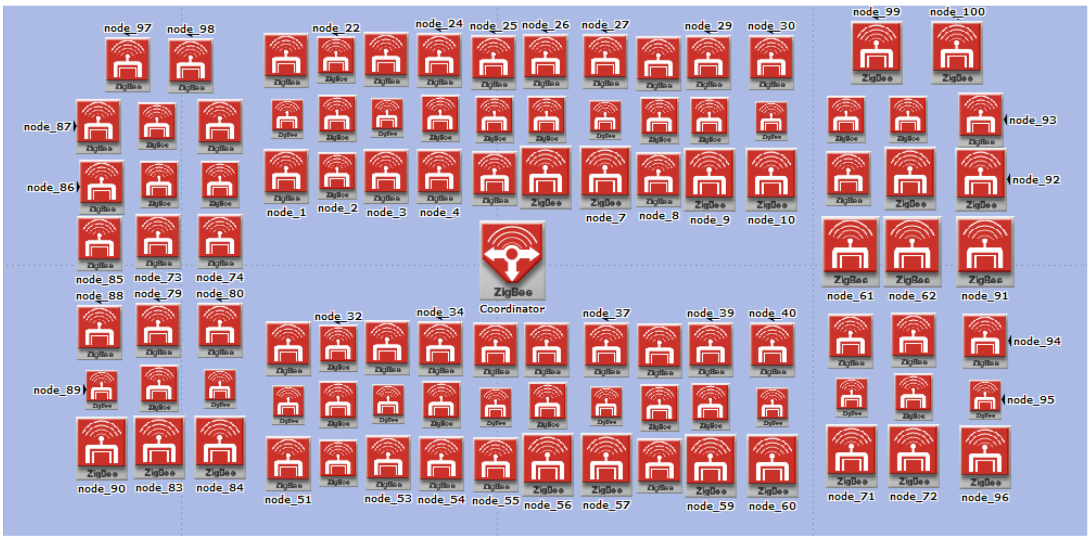


Figure 12: 100 Nodes Network

4.2.7.1 Impact of different number of nodes

Based on the theory, the throughput will decrease when the numbers of nodes are increased because the data being received by the MAC layer increases. When the number of nodes increases above 50, more collision will take place as the MAC layer and it cannot handle the increased number of nodes. Then, the throughput will decrease. However, based on the experiments, there are some variations in smaller number of nodes. These results can be seen in the following diagrams. The first diagram is simulated with maximum number of 5 nodes and the second diagram is simulated with maximum of 100 nodes.

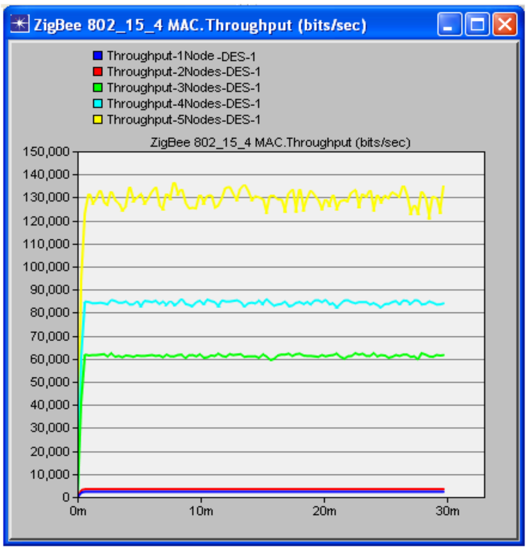


Figure 13: Throughput measurement for small number of nodes

The above diagram shows that in a smaller network, network throughput becomes higher when the number of nodes increases because there is no collision and the coordinator can handle all the data packets sent. However, the below diagram shows that when number of nodes exceed more than 50 or 60 nodes, MAC layer cannot handle the traffic since more collisions are taking place, and the throughput decreases.

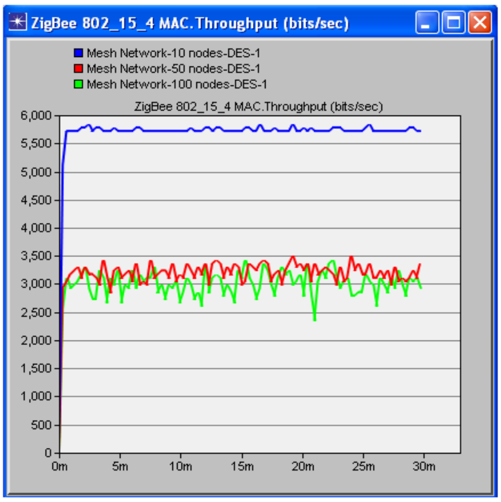


Figure 14: Throughput measurement for large number of nodes

4.2.7.2 *Impact of Packet Size*

Packet Size also influences on the communication throughput rates. For packet size of 32 bytes, the minimum throughput is 370 bps (bits per seconds) and for 2048 bytes, the maximum throughput value reach 4.4 kbps. It means that if the packet size is further increased, the MAC throughput will gradually increase as well.

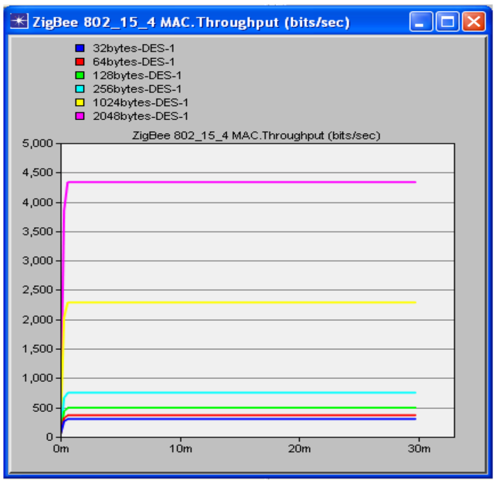


Figure 15: MAC throughput for different packet sizes

4.2.7.3 *Impact of transmission Power*

As varies from the minimum values of 0.05 Watt to 5 Watt, the throughput measurement is the same for low power or high power transmission. Not much change is observed.

4.2.8 Packet Loss Ratio Performance Study

Packet loss occurs when one or more packets of data travelling across a network fail to reach their destination. There are numerous factors for packet loss such as insufficient bandwidth, channel congestion problems, routing problems, router configuration, etc. In a wireless environment, multipath fading or interferences might affect the successful transmission and reception of information. Since an end-to-end ad hoc wireless route may consists of multiple wireless links, packet loss is therefore important to evaluate. In the experiment, the packet loss occurs with congestion when the coordinator cannot handle the traffic being sent by the end nodes. The packet loss ratio can be calculated as follows with the formula.

$$\text{Packet Loss Ratio} = \frac{\text{Num of lost packet}}{\text{Num of lost packet} + \text{Num of successful packet received}}$$

[7]

The experiment is done based on the three scenarios of 10 nodes, 50 nodes and 100 nodes. As seen from the graph, higher the number of nodes is, the more chances of congestion can happen. Packet loss ratio for 100 nodes ranges between 0.010851 and 0.032929 means (1: 3).

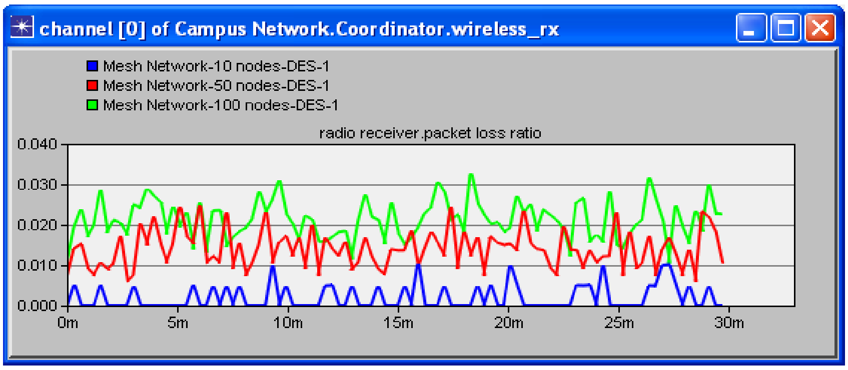


Figure 16: Packet loss ratio

Table 6: Objects Report for radio receiver packet loss ratio

Scenario	Object Name	Minimum	Average	Maximum	Std Dev
10 nodes	Channel[0]	0	0.0018515	0.010363	0.0029804
50nodes	Channel [0]	0.0060976	0.013905	0.024730	0.0046672
100nodes	Channel [0]	0.010851	0.021198	0.032929	0.0047750

4.3 Analysis of Star, Tree and Mesh Network Analysis

Using the OPNET modeler, the three topologies, star, tree and mesh, are simulated in order to study their performance. In star topology, nodes are connected to a single hub node. The hub "coordinator" requires greater message handling, routing and decision-making capabilities than routers or end devices. If one of the communication links is failed, it will only affect the respected node. If the coordinator fails to respond, the entire network will be broken down. The initial star topology scenario described below has 6 End Devices (reduced function device) and 1 coordinator (full function device) shown in figure 2.

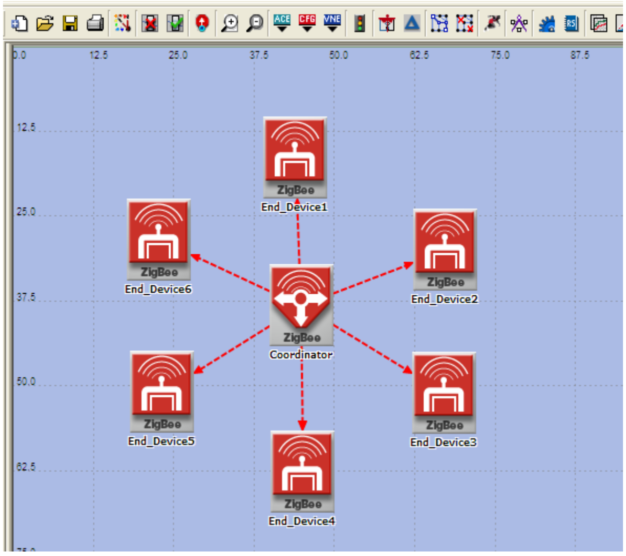


Figure 17: Star Network

In a tree network, a coordinator initializes the network, and is the top (root) of the tree. The coordinator can now have either routers or end devices connected to it. The following diagram consists of 6 End Devices, 4 routers and 1 coordinator.

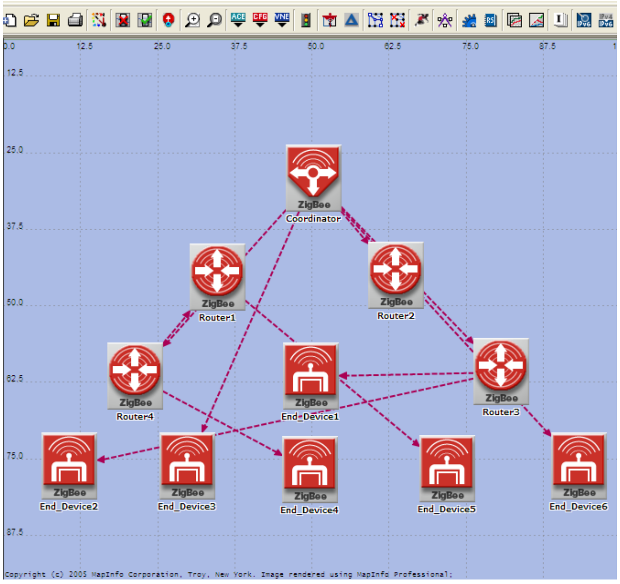


Figure 18: Tree Network

A mesh topology is the most flexible topology of the three. Flexibility is present because a message can take multiple paths from source to destination. If a particular router fails, then ZigBee's self healing mechanism (route discovery) will allow the network to search for an alternate path for the message to take. The below scenario consists of 8 End Devices, 4 routers and 1 coordinator.

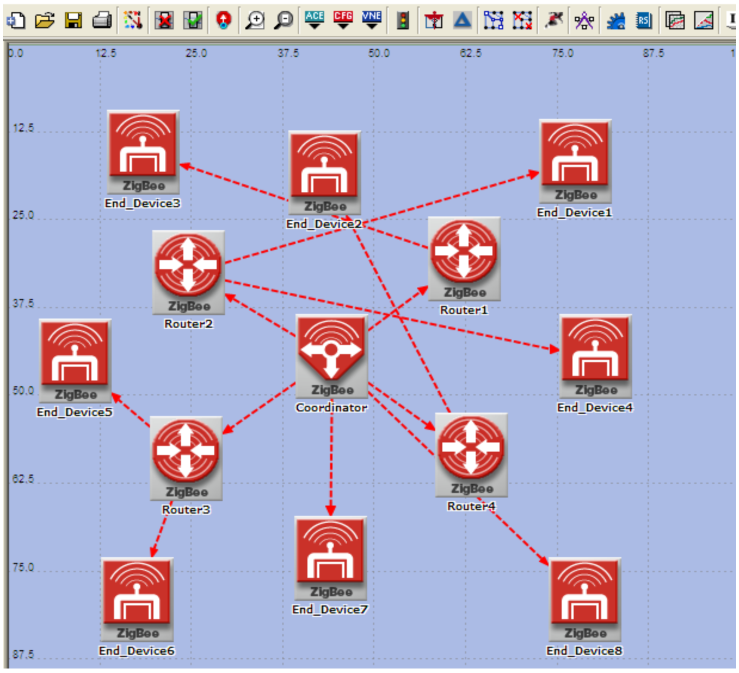


Figure 19: Mesh Network

4.3.1 *End-to-end delay result*

The End–to–End delay (ETE) measures the delay of all the packets received. It's an OPNET global statistics. Global statistics provide information that relates to the overall system. Different object may contribute to the global statistics. As observed from the following figure, the ETE delay in the tree topology is higher than the other two topologies because the tree topology has multi-hop nodes and the time taken for the source and destination between nodes is longer. The Star and the Mesh topologies have similar end-to-end delay in this simulation. The Tree topology has a higher end-to-end delay of 50% and increasing.

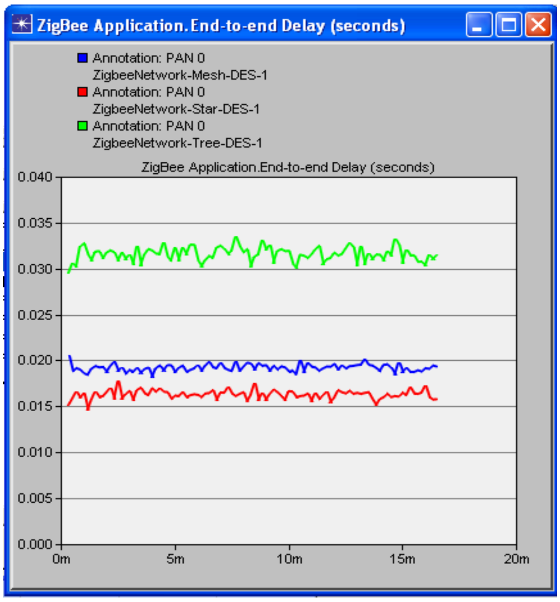


Figure 20: End-to-end Delay comparison of three topologies

4.3.2 *Coordinator Throughput*

The throughput is the number bits per second a node can deliver. In this statistic, the ZigBee coordinator throughput is the focus. The result shows that the ZC throughput of the Star topology is the highest, since the entire traffic passes through the coordinator. The coordinator in the Tree topology has the second highest throughput because if the parent node does not recognize the address of the destination to be one of its children, it sends it to its parent node. The Mesh topology is not as reliant to the coordinator traffic as the other two topologies since some nodes can communicate with each other through routing table.

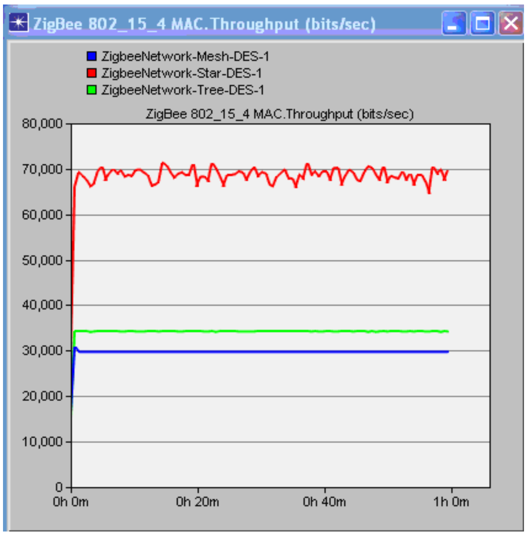


Figure 21: Coordinator Throughput comparison of three topologies

4.3.3 Global Statistics MAC throughput

The global throughput is a global statistics and any object could contribute to its value. It gives a general idea of the overall throughput of the system. In this simulation, the Tree topology has the highest global throughput (bits/second). The Mesh topology has the second highest global throughput. Finally, the Star topology has the lowest global throughput.

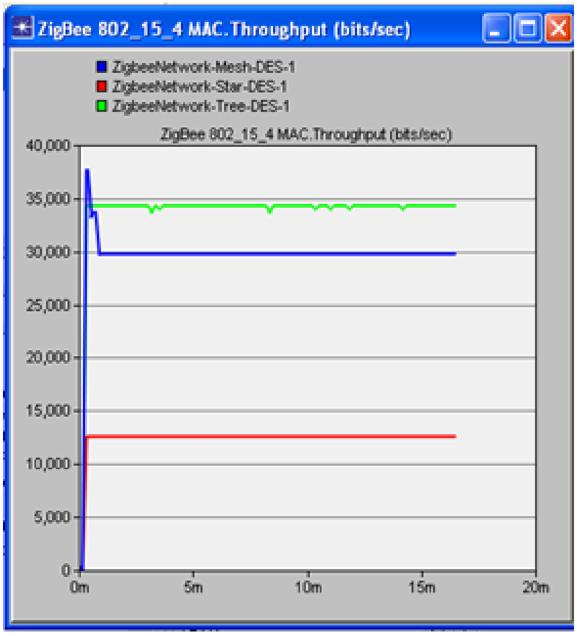


Figure 22: Global Throughput comparison of three topologies

4.3.4 *Network Structure and Global Statistics Report at simulation time 60*

As observed from Global report, there is no packet drop and all the packets sent by the source have been received by the destination with the network depth of 2.

Network Structure.PAN 0 at Simulation Ti...

File Edit View Help

	Coordinator	Depth 1
1	Office Network.Coordinator (0)	
2		Office Network.node_0 (1)
3		Office Network.node_4 (2)
4		Office Network.node_1 (3)
5		Office Network.node_5 (4)
6		Office Network.node_2 (5)
7		Office Network.node_3 (6)

(a)

Network Structure.PAN 0 at Simulation Time 60

File Edit View Help

	Coordinator	Depth 1	Depth 2
1	Office Network.Coordinator (0)		
2		Office Network.node_2 (1)	
3			Office Network.node_10 (1092)
4			Office Network.node_11 (1093)
5		Office Network.node_3 (1094)	
6			Office Network.node_9 (2185)
7			Office Network.node_6 (2186)
8		Office Network.node_0 (2187)	
9			Office Network.node_8 (3278)
10		Office Network.node_1 (3280)	
11			Office Network.node_7 (4371)
12		Office Network.node_13 (5466)	
13		Office Network.node_12 (5467)	

(b)

Network Structure.PAN 0 at Simulation Time 60

File Edit View Help

	Coordinator	Depth 1	Depth 2	Depth 3
1	Office Network.Coordinator (0)			
2		Office Network.Router4 (1)		
3			Office Network.Router1 (2)	
4				Office Network.End_Device5 (218)
5			Office Network.End_Device4 (1092)	
6		Office Network.Router3 (1094)		
7			Office Network.End_Device1 (2185)	
8			Office Network.End_Device2 (2186)	
9		Office Network.Router2 (2187)		
10		Office Network.End_Device3 (5466)		
11		Office Network.End_Device6 (5467)		

(c)

Figure 23: Network structure (a) Star Network (b) Mesh Network (c) Tree Network

ZigBee.Global Report at Simulation Time 60

File Edit View Help

	PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	0	26	520	519	0	1	11.45	13	2	Click Here

Figure 24: Global statistics report for Mesh Network at simulation time 60

4.3.5 Discusstion

A ZigBee mesh network operates in a peer-to-peer topology, using non-beacon enabled, unslotted CSMA-CA access mode. In the simulation, the network operates in a full peer-to-peer mode, and virtually any device can function as a router. Due to the absence of beacon frames, there are no active and inactive periods. Since incoming data may occur at any time, the devices cannot go to sleep or prolonged periods of time. As a result, energy efficiency cannot be observed.

4.3.5.1 Calculating Beacon Intervel with fixed vaule of OPNET moduler

The structure of the superframe structure is determined by two parameters. The Superframe Order (SO) and the Beacon Order (BO). The superframe order is the variable which is used to determin the length of the superframe duration. The beacon internval is determined by the variable BO. If the beacon interval is the same as the superframe duration (BO=SO), there is no inactive portion.

For this research, ZigBee simulations are conducted with fixed beacon order and superframe order because they cannot be changed. Beacon Order (BO) is 6 and Superframe Order(SO) is 0. The beacon interval and the active and inactive part of the superframe can be calculated as follows:

For Beacon Interval (BO =6),

BI = aBaseSuperFrameDuration * 2^(BO) [5]

aBaseSuperFrameDuration = aBaseSlotDuration * aNumSuperframeSlots [5]

aBaseSlotDuration = 60symbols

aNumSuperFrameSlots = 16

aBaseSuperFrameDuration = 60* 16symbols = 960symbols

To calculate the beacon interval with BO = 6 and SO= 0,

BI =960 * 2^(BO) symbols

BI = 960* 64 = 61440 symbols

$$\boldsymbol{BI\ at\ 250kbps} = \frac{61440}{250000} = 0.24576\ secs$$

The Superframe duration can be calculated using the superframe order (SO =0) as follows:

SD = aBaseSuperframeDuration * 2^(SO)

SD = 960*2^(SO) symbols

SD = 960* 1 = 960 symbols

$$\boldsymbol{SD\ at\ 250kbps} = \frac{960}{250000} = 0.00384\ secs$$

$$aBaseSuperframeDuration = \frac{SD}{16} = \frac{0.00384}{16} = 0.00024 \text{ secs}$$

And Inactive Portion of the superframe can also be calculated as,

Inactive Portion = BeaconInterval – SuperframeDuration

= 0.24576 secs – 0.00024 secs

= 0.24552 secs

It means inactive portion is very large compared with Superframe Duration and it’s not possible to use that Beacon Interval. The Result shows that OPNET moduler does not support ZigBee as an beacon enabled network.

4.4 Analsysis of Cluster Tree Networks

The cluster tree protocol is a protocol of the logical link and network layers that uses link-state packets to form either a single cluster network or a potentially larger cluster tree network. The network is basically self-organized and supports network redundancy to attain a degree of fault resistant and self-repair. Nodes select a cluster head and form a cluster according to the self-organized manner. In the experiment, three cluster and four cluster networks are simulated and the coordinator performanced is oberved.

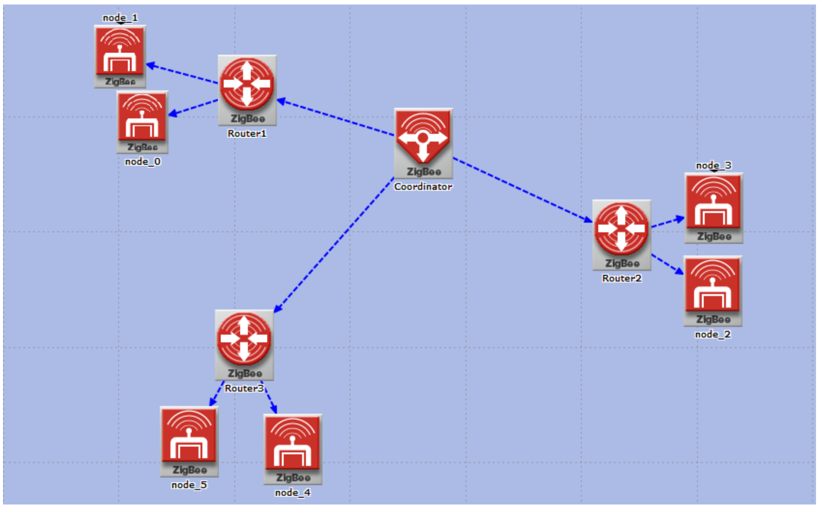


Figure 25: Three Cluster Network

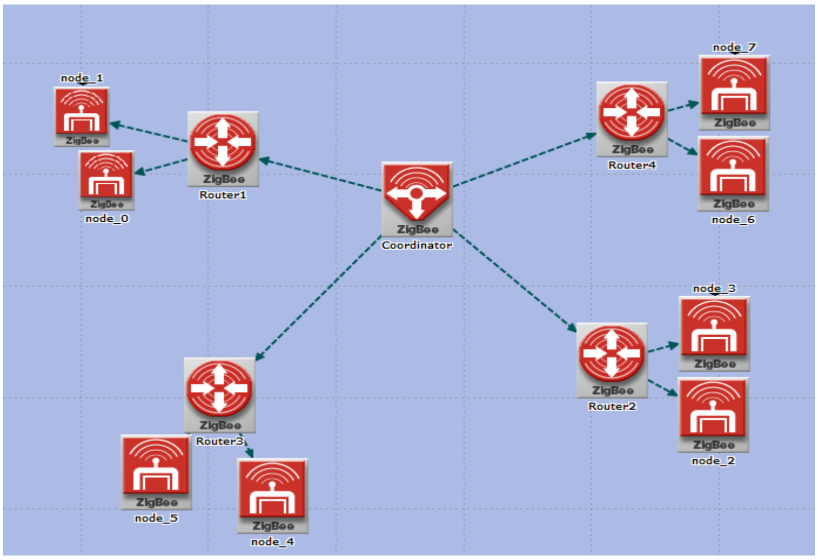


Figure 26: Four Cluster Network

From the first diagram, we can see that the coordinator can only support efficiently for maximum of three clusters. When another cluster is added to the network, the traffic doesnot reach to the end node 5 and the packet loss occurs. This might be due to the fact of some congestion problem of Coordinator.

4.4.1 End-to-End Delay Result

By increasing the quantity and the transmission of packets, the situation of delay and loss will occur. The diagram shows that the delay for four cluster network is higher because of high packets amount and processing time is longer. The time taken for each end device is increased and four cluster network delay can be seen as 1600 seconds.

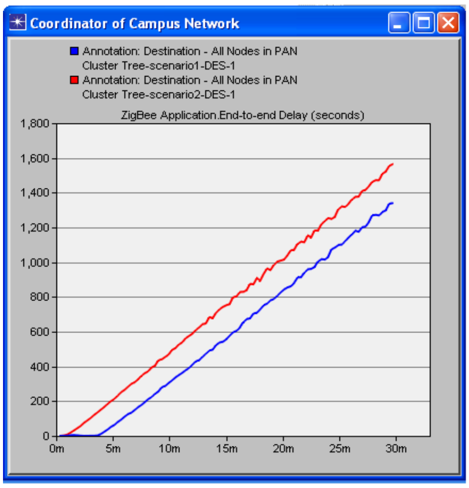


Figure 27: End to end delay for Cluster Tree Network

4.4.2 Throughput Result

The throughput detemined the network efficiency depending on the nodes and after comparing the two graph, Coordinator of four cluster network (scenario2) is handling more traffic and high throughput.

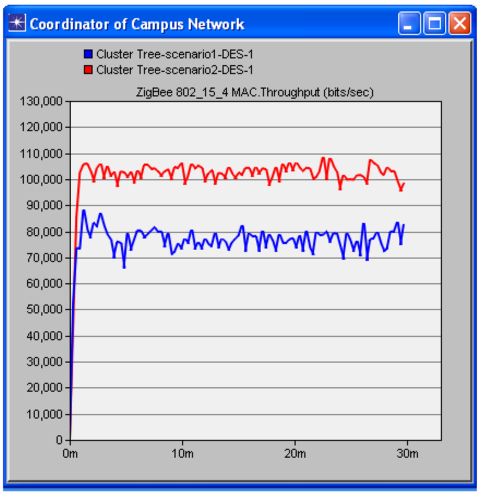


Figure 28: Throughput for Cluster Tree Network

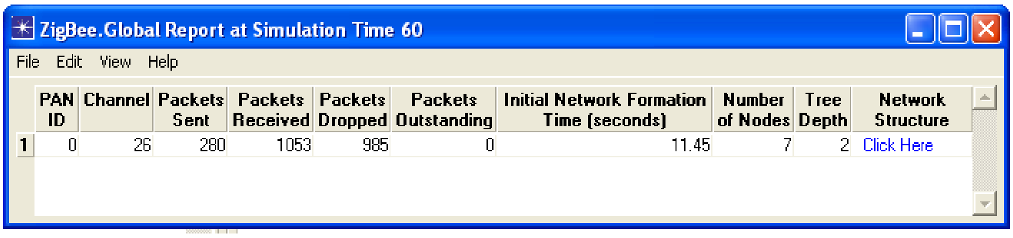
4.4.3 Packet Delivery Ratio Result

This is a percentage of data packets which are successfully received versus the number of data packets transmitted and is an important metric in determining how reliable the network link is.The delivery ratio is only considered for data packets. Firstly the total number of transmitted packets is counted, followed by the total number of received packets and the total number of dropped packets. The delivery ratio is calculated as the percent of packets received to the packets transmitted. The number of transmitted packets is equal to the sum of the number of received packets and number of dropped packets. Packet delivery ratio can be determined by the following equation.

$$\text{Delivery Ratio} = \frac{\text{Number of Received Packets}}{\text{Number of Transmitted Packets}} \text{ x } 100\%$$

[12]

The following two diagrams represent the network structure of three cluster and four cluster networks.

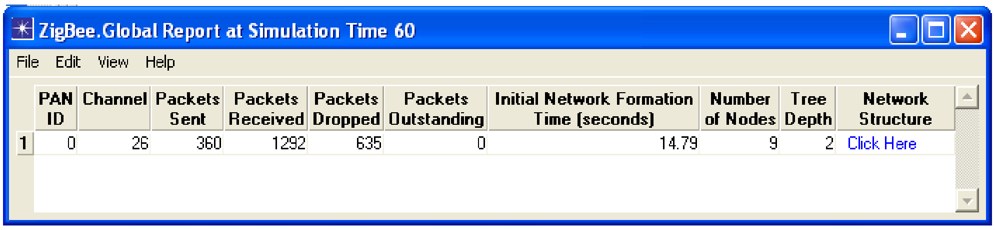


ZigBee.Global Report at Simulation Time 60

File Edit View Help

	PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	0	26	280	1053	985	0	11.45	7	2	Click Here

Figure 29: Network report of three clusters Network



ZigBee.Global Report at Simulation Time 60

File Edit View Help

	PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	0	26	360	1292	635	0	14.79	9	2	Click Here

Figure 30: Network report for four clusters Network

Packet delivery ratios can be calculated as follows:

$$\text{Packet Delivery ratio for three cluster network} = \frac{1053}{280} = \frac{11}{3} = 3.76$$

$$\text{Packet Delivery ratio for four cluster network} = \frac{1292}{360} = \frac{16}{5} = 3.59$$

4.5 Discussion

The range between two wireless nodes can be estimated as follows:

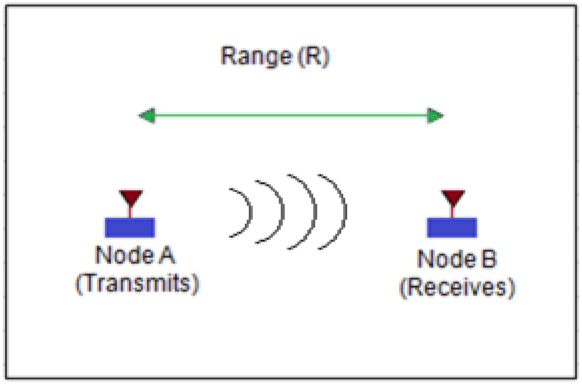


Figure 31: Range Estimation

The range between two wireless nodes can be estimated at some distance. The formula is stated as below:[5]

$$R\ (\ estimated\ range) = 10\text{^}[\frac{\text{Pt}-\text{Pr} - Fade\ \ Margin\ -10ɤ\ log\ (f) + 30ɤ\ -32.44}{10ɤ}]$$

The calculation is for the situation where node A transmits a 2450MHz signal with 0.5mW (-3dBm) output power and receiver sensitivity of -85dBm in a environement with a path-loss exponent 2 (Shown in Appendix E) and a fade margin of 10dB .

Node A transmit power (include the antenna gain) [P_t (dBm)]	=	-3 dBm
Node B receiver sensitivity [P_r (dBm)]	=	-85 dBm
Path-loss Exponent [ɤ]	=	2
Fade Margin [Fm (dB)]	=	10 dB
Signal Frequency [f (MHz)]	=	2405

$$Estimated\ range\ (R) = \frac{0.5mW - 3.2pW - 10 - 10*2*\log{(2405)} + 30*2 - 32.44}{10*2}$$

$$= \quad 39.53\ meters$$

Therefore, the average transmission range between two nodes is 39.53 meters (129.65 feet).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Throughout this project, ZigBee protocols, performances metrics and parameters are thoroughly studied and evaluated with OPNET modeler. This project focused on designing and implementing ZigBee networks and their performance. Various parameters are especially needed to be focused for each network simulation. Star, Tree and Mesh network topologies and Cluster tree topologies are discussed and analyzed. The simulation results generally discuss end-to-end delay, throughput, packet loss ratios, packet delivery rations and range capabilities. Evaluating and simulating energy resources is an essential factor for estimating the life-time of a sensor node because the full operation of the wireless node depends on internal battery power. Eventually, OPNET model for ZigBee network does not support energy models. It also does not support contention-free operation and slotted operation mode. Therefore, life-time of a wireless node and their duty cycles cannot be evaluated. In general, the project gives a truly understanding of ZigBee networks in real applications where as they can be deployed as monitoring applications in Home security systems or industrial automation systems.

Based on simulation results, ZigBee wireless personal area networks are highly reliable and observable. ZigBee networks can operate in a secure environment with minimum disruption. It meets the requirements of flexibility, low power and high performance. IEEE 802.15.4 supports a strong foundation for ZigBee wireless networking. Therefore, it can be concluded that ZigBee technology is the most suitable solution in wireless sensor network areas. It has lots of advantages over monitoring applications and can be deployed anywhere. ZigBee has revolutionized the way of monitoring the wireless personal area networks.

5.2 Recommendation

ZigBee is an interesting technology that needs to be studied and explored more and more. It is a low bandwidth, cost effective, and secure protocol that can be used in many areas. This protocol is well suited to Monitoring and control field. Reliability of the network is such a key factor. Some future works still need to be done on ZigBee network and application layers. These two layers were intentionally provided without any source code and only object code is provided. These source codes need to be studied and implement for further research. Some future works are described as follows:

1. Access to OPNET source code of the network and the application layers,
2. Study the Coexistence with other technologies such as Wi-Fi, Bluetooth, and
3. Implement and test ZigBee applications in real network environments.

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APPENDIXES

APPENDIX A

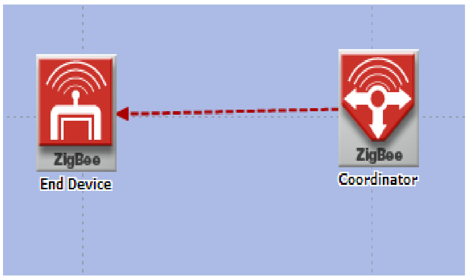
Gantt Chart

MILESTONE FOR THE SECOND SEMESTER OF FINAL YEAR PROJECT

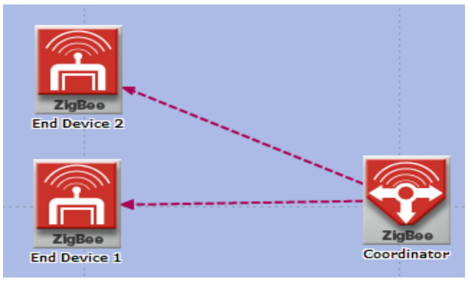
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W20	W21
Project Continue																	
Briefing Session																	
OPNET Installation																	
Submission of Project Report 1				20/8													
Project Work Continue																	
• Configuring and Implementation of ZigBee Network																	
• Testing and Troubleshooting																	
Submission of Progress Report 2								24/9									
Mid-Semester Break																	
Project Work Continue																	
• Simulation for some particular application																	
Pre-EDX																	
Submission of Draft Report													20/10				
Submission of Final Report														4/11			
Submission of Technical Report														4/11			
Oral Presentation																	
Complete Final Report																23/12	

APPENDIX B

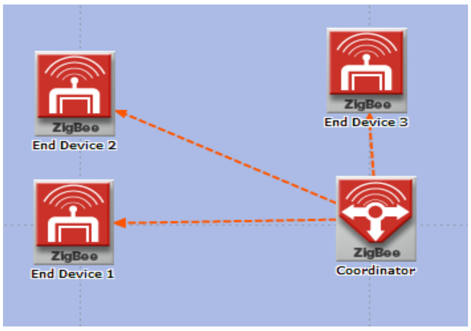
Network Nodes Diagrams



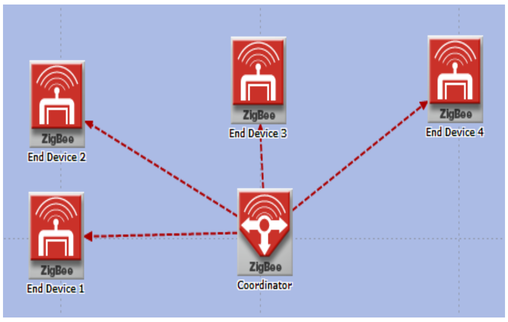
One Node Connected



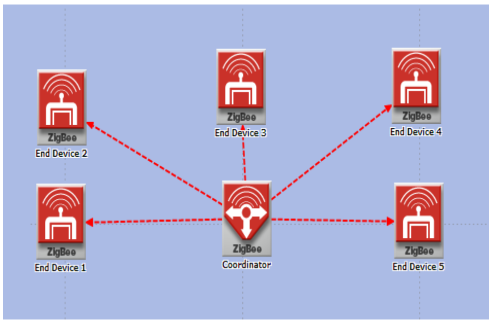
Two Nodes Connected



Three Nodes Connected



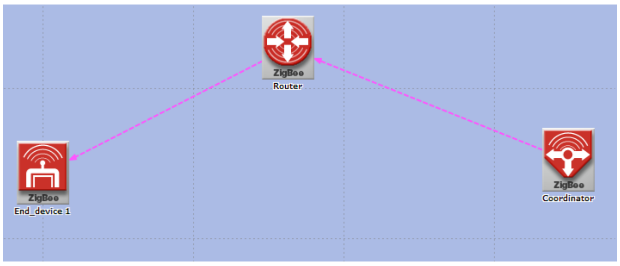
Four Nodes Connected



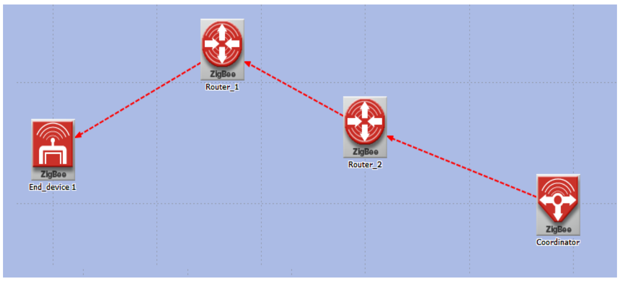
Five Nodes Connected

APPENDIX C

Hop Delay Diagrams



Two Hops range Network



Three Hops range Network

Four Hops range Network

Five Hops range Network

APPENDIX D

ZigBee standards and releases

ZIGBEE VERSION	COMMENTS AND DETAILS
ZigBee 2004	This was the original release of ZigBee - defined as ZigBee 1.0 which was publicly released in June 2005.
ZigBee 2006	This release of the ZigBee standard introduced the concept of a cluster library and was released in September 2006.
ZigBee 2007	The next version of the ZigBee standard was released publicly in October 2008 and contained two different profile classes
ZigBee PRO	ZigBee PRO was a profile class that was released in the ZigBee 2007 release. ZigBee PRO provides additional features required for robust deployments including enhanced security.
RF4CE	RF4CE - Radio Frequency for (4) Consumer Electronics was a standard that was aimed at audio visual applications. It was taken on board by the ZigBee Alliance and the Version 1.0 of the standard was released in 2009.

APPENDIX E

Path Loss Exponent Table

Table 7: Path-loss Exponent (n) for Different Environments

N	Environment
2.0	Free space
1.6 to 1.8	Inside a building, line of sight [2]
1.8	Grocery store [2]
1.8	Paper/cereal factory building[2]
2.09	A typical 15m x 7.6m conference room with table and chair [3]
2.2	Retail store [2]
2 to 3	Inside a factory, no line of sight [2]
2.8	Indoor residential [4]
2.7 to 4.3	Inside a typical office building, no line of sight [1]

APPENDIX F

ZigBee Model Description

The ZigBee1 model suite includes a discrete event simulation model that lets you analyze network performance in ZigBee wireless personal area networks (PANs). The ZigBee model suite includes a model of the IEEE 802.15.4 MAC protocol. This document describes the ZigBee model suite. The following topics are covered:

Model Features: ZigBee

The model implements the following features:

- Application layer features
  - Generating and receiving application traffic
  - Initiating network discovery and network join
  - Failing and recovering ZigBee devices
- Network layer features
  - Establishing a network
  - Joining a network and permitting network joins
  - Assigning an address
  - Maintaining a neighbor table
  - Mesh Routing Process
  - Network Broadcast

— Tree routing process

— Transmitting and receiving data

— Mobility

— Beacon scheduling

• MAC layer features

— Channel Scanning

— CSMA/CA (Contention-based operation mode)

Many of these features are highlighted in ZigBee example project that is included with the model library.

Model Limitations: ZigBee

The following features have not been implemented:

• Multicast traffic

• Indirect transmission

• Security

• Slotted mode

• Contention-free operation mode

• Support for other OPNET application models (such as HTTP, e-mail, and other standard network applications, custom applications, ACE and ACE Whiteboard applications)

Node Models: ZigBee

ZigBee-enabled nodes are included in the zigbee object palette.

Figure 32: ZigBee Object Palette

Model Attributes: ZigBee

The ZigBee model suite includes the following types of attributes:

· Local Attributes

· Global Attributes

Local Attributes

The following attributes are available for configuring ZigBee device models:

· Application Traffic attributes

- Destination
- Packet Interarrival Time
- Packet Size
- Start Time
- Stop Time

· ZigBee Parameters

- MAC Parameters
- Network Parameters
- PAN ID
- Physical Layer Parameters

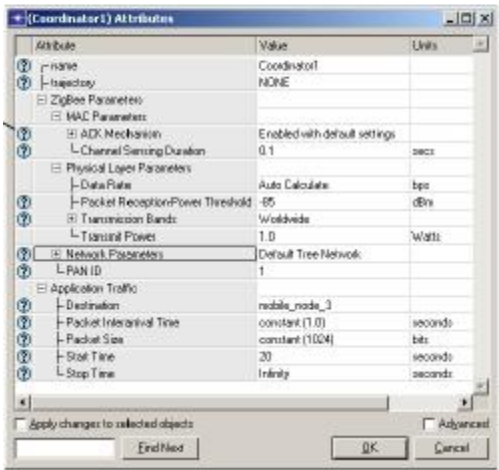


Figure 33: ZigBee Device Model Attributes

Global Attributes

The ZigBee model suite includes the following global attributes (accessible from the Configure/Run Simulation dialog box):

- Network Formation Threshold
- Report Snapshot Time

For a description of these attributes, click on the help icon next to each attributenin the software.

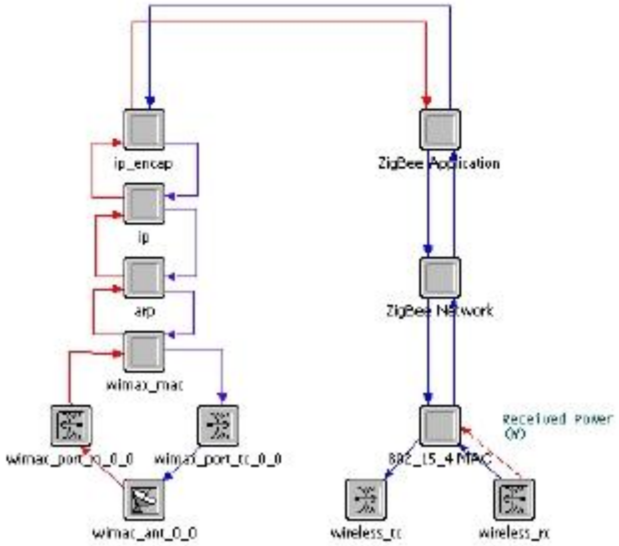


Figure 34: ZigBee Architecture on Coordinator–WiMAX Gateway Models

Process Models

The ZigBee model uses the following process models.

Table 8: ZigBee Process Models

Process	Description
zigbee 802 15 4 mac	This process implements a model of the IEE 802.15.4-2003 MAC protocol. The model implements the channel scanning, joining, and failure / recovery procedures of the protocol, in the unslotted operation mode.
zigbee application	This process model represents a low-fidelity version of the ZigBee Application Layer as specified in the 2006 ZigBee Specification. The process model initiates network joins and formations, generates and receives traffic, and generates the ZigBee "General Report at Simulation Time <x>".
zigbee csma ca	This process model implements the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) function of the ZigBee MAC Layer.
zigbee network	This process model implements the ZigBee Network Layer as specified in the 2006 ZigBee specification. It is responsible for routing traffic, processing network join and formation requests, and generating beacons.
End of Table 41-2	

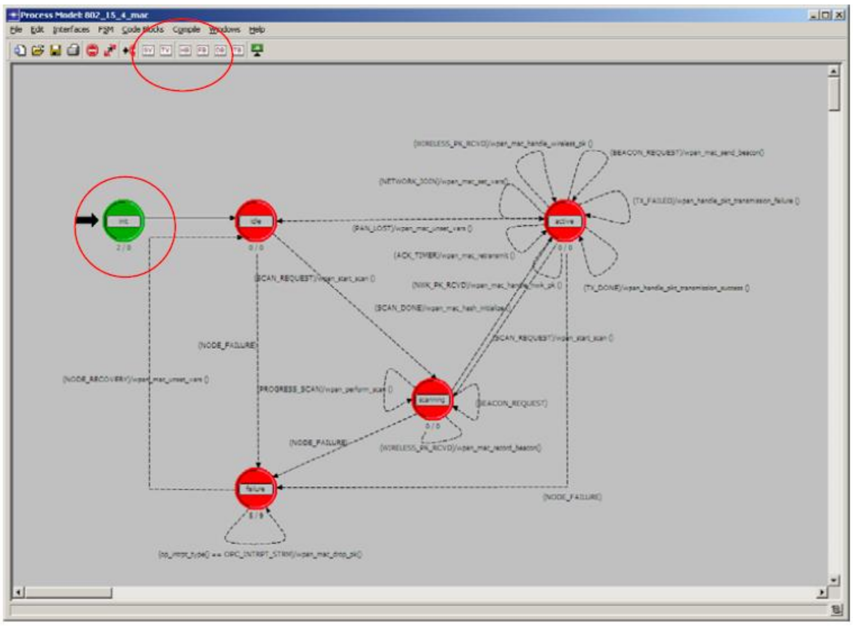


Figure 35: ZigBee Process Model

<u>Reference Documents</u>

Information on the ZigBee protocol is available on the ZigBee Alliance website (http://www.zigbee.org). ZigBee models are implemented based on information available from the following sources.

Table 9: Reference Document: ZigBee

Reference	**Document**
IEEE	IEEE 802.15.4-2003 Specification
ZigBee Alliance	ZigBee Specification, Document 053474r13
End of Table 41-3	