A Design of Variable Transmission Power Control for Wireless Ad-hoc Network

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This thesis is submitted in partial fulfilment of the academic requirements
for the degree of
Master of Science in Electrical Engineering
in the Faculty of Engineering and the Built Environment
University of Cape Town
2015

As the candidate's supervisor, I have approved this dissertation for submission.

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Declaration

I declare that this thesis is my own work. Where collaboration with other people has taken place, or material generated by other researchers is included, the parties and/or materials are indicated in the acknowledgements or are explicitly stated with references as appropriate.

This work is being submitted for the Master of Science in Electrical Engineering at the University of Cape Town. It has not been submitted to any other university for any other degree or examination.

Ojuetimi Ifedayo Akinsolu 18/05/2015

Name Date

Dedication

To God Almighty, for His faithfulness and unfailing love upon my life. I am also dedicating this work to my sweet husband, family members, friends and colleagues for their consistent support from the beginning of this master’s programme.

Abstract

Wireless Ad-hoc Network has emanated to be a promising network paradigm that can handle last mile technology due to unprecedented growth of internet users. This network is promising because it extends network to remote areas such as congested environments, rural environments etc. It is known that nodes involved in Wireless Ad-hoc Network rely on battery energy as their source of power. Energy consumption has become one of the major challenges experienced in Wireless Ad-hoc Network, which must be properly tackled. This could be traced to the effect of transmission power on the nodes in the network. Transmission power largely determines the amount of energy consumed by each node in the network. Therefore, a power control technique must be adopted in order to manage and select the optimal transmission power with respect to distance. This transmission power must be sufficient to transfer information from one node to another.

Literature have proposed different algorithms for power control technique in Wireless Ad-hoc Network. Some researchers looked at the power control technique in terms of minimising energy consumed from different perspectives, which include power aware routing and power control topology management. However, most of these algorithms were applied at different layers in OSI model such as physical layer, data link layer, network layer and application layer.

To achieve a reduced energy consumption at each node in the network, a novel algorithm for transmission power control was designed to select optimal transmission power. The proposed algorithm was designed in such a way that it selects transmission power based on the distance between the nodes without affecting the network throughput. Graph theory is used in this research to model the network topology, and transmission power with respect to the distance.

This algorithm was used to investigate the effect of transmission power control in Wireless Ad-hoc Network. The performance of the proposed algorithm was evaluated using OMNeT++ network simulation, which is C++, based.

The results obtained from this algorithm show that varying the transmission power with respect to distance reduces the energy consumed at each node. This will increase the node lifetime and the network lifetime.

Acknowledgements

I would like to express my sincere gratitude to Almighty God for His infinite mercy, grace and favor upon my life since the beginning of this program, without him I wouldn't have gone this far in my life. He has been my source of strength, joy and breakthrough. All praise, glory and adoration to the Lord Almighty.

My profound gratitude goes to my supervisor, Prof. Mqhele Dlodlo for his supervision, support, guidance, advice, fatherly love throughout this research. I would like to thank Mr. Lateef Akinyemi for his support, mentoring, contributions towards this research. Thank you so much for not getting tired of me, your immense contributions made me go this far in this research. I would like to appreciate the following group of people and individuals for their mentorship, assistance, constructive critiques and contribution towards my research:

- MED Communication Research group for their wonderful comments, support.
- Mr. Daniel Adeyemo for his encouragement and daily advice. You are such a wonderful colleague.
- Mr. Samson Orimolade for his advice, moral support, encouragement.
- Mr. Joshua Adeleke and Mr. Henry, Mr. Joseph Orimolade and Mrs. Didaceinne for their encouragement, support and assistance.

I would like to express my sincere appreciation to my elder brother Dr. Adewunmi Gideon Fareo for believing in me. Thank you so much for your wonderful words of encouragement, guidance, financial support and brotherly love. I would like to say a big thank you to my mother, Mrs. Olanrewaju Akinsolu for your prayers that have helped me thus far. My appreciation goes to Iyabo Olasode and Pumeza Fareo for their support and encouragement. I want to appreciate my wonderful, caring, loving, precious and understanding husband, Ajibola Akinsete, for your support, advice, patience financial support and prayers.

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Glossary

Beacon Message: It is a control signal message used to establish communication link before a data is sent. The nodes in the network use beacon message to learn about its environment.

Delay: This is the duration it takes for a signal to travel from the source to the destination nodes.

Friis Free Space Propagation Model: It is a radio propagation model that uses unobstructed line of sight between the transmitter and the receiver. It allows direct propagation between the transmitter and the receiver.

Graph Theory: It is a mathematical model that can be used for network optimisation, network topology construction etc. whereby nodes and wireless links are represented with vertices and edges respectively.

IEEE: The Institute of Electrical and Electronic Engineers is the world's largest professional association for the advancement of technological innovation and excellence, as well as being a major publisher of scientific journals and organiser of conferences, workshops and symposia.

Network Lifetime: A metric that measures the total amount of time a particular network remains active.

Node Lifetime: A metric that measures the total amount of time a node is required to remain active in a network.

OMNeT++: It is a general purpose, public-source, discrete event simulator (DES) tool that is written in C++.

QoS: Quality of Service is a network performance metric that evaluates the overall performance of network in terms of throughput, transmission delay, error rates etc. in order to produce a network service of high of quality.

RSSI: Received Signal Strength Indicator is the measurement of power present in the received signal strength of a node. It is a unit less one-byte value that ranges from 0 to 255. 0 signifies the minimum signal strength level while 255 signifies the maximum signal strength level.

Throughput: It is the average rate of successful delivery of packets through a communication node.

TPC: Transmission power control is a technique used to select power level output in devices in order to reduce unwanted interference and energy consumption.

Two-ray Propagation Model: It is a radio propagation model that takes Line of Sight and the ground reflected ray between the transmitter and receiver into consideration.

WAN: Wireless Ad-hoc Network is a communications network made up of autonomous mobile and stationary nodes that are set up in an Ad-hoc physical topology without any centralised systems.

Chapter 1

1 Introduction

1.1 Background

In the midst of recent development in wireless networks, Wireless Ad-hoc Network has emanated as a promising network paradigm for next generation wireless network (NGWN).

Wireless Ad-hoc Network has fascinated great attention and interest by those who research on wireless communication networks from the industrial sector, commercial sector, standard communities as well as the educational sector. This interest stems from the capability of wireless Ad-hoc network to integrate different technologies, service providers and network services, thereby providing ubiquitous and seamless broadband services to end users.

Architecturally, Wireless Ad-hoc Network is the collection of autonomous nodes that establish wireless communication through a set of radio links between a pair of nodes without any infrastructure such as access point or base station [1][2]. Wireless Ad-hoc network has self-organising, self-creating and self-administering capabilities with little or no administrative process [1][2][3]. Based on the unique features of Wireless Ad-hoc network, it can provide network services and connectivity where last mile technology is difficult and expensive to manage such as disaster environment, earthquake environment, battlefields etc. Remote areas where deployments of network infrastructure are scarce or limited can adopt Wireless Ad-hoc Network to bring mobile telecommunications and internet access to door steps of end users[3][4][5]. Each node involved in Wireless Ad-hoc Network acts as host and router forwarding data to the next node known as relay node or to the destination that may be within the transmission range[6][7][8].

Many factors such as Power control, Quality of Service (QoS), node failures, topology maintenance, transmission reliability, congestion control, etc., affect the smooth performance of Wireless Ad-hoc Network [6]. These factors degrade the network capacity, throughput and network performance of the network topology.

This research focuses on Power control, which is a major challenge in Wireless Ad-hoc Network. Power control is the intelligent selection of transmitter power output in a communication system to achieve optimal performance within the system [9]. It is used to control the effect of interference in order to elongate the network capacity, thereby minimising energy consumption in order to increase the battery life span. As well as improving also to Quality of Service (QoS) [6][9][10][11]. Hence, power control is classified into two groups: power controlled topology management algorithm and power aware routing. The power controlled topology management algorithm approaches are considered to find the optimal transmission power level needed for transmission [6][11][12]. In general, Power control relies on the physical layer, data link layer, network layer, transport layer and the application layer by deducing the interference rate, transmission range and received signal strength quality [6]. It equally has proven to be effective in Cellular networks because it is being controlled by a centralised infrastructure (known as base station)[6][10]. Each transmitting device receives at an appropriate power level which minimises interference and maintain a reliable Quality of Service (QoS) using a power control technique [6][13]. Lack of power control technique in cellular networks could lead to near-far effect, which affects all mobile users transmitting at the transmission power level that is not satisfactory to the receiving side in the network and the network capacity [6]. While power control has shown effectiveness in Cellular networks, its technique is still a major challenge in Wireless Ad-hoc network. This stems from the features of Wireless Ad-hoc Network such as absence of centralised administration process and network topology [6][11]. With the execution of functional power control techniques, Wireless Ad-hoc Network can enhance parameters such as routing, throughput, clustering, interference, energy consumption etc. [6]. Nodes in Wireless Ad-hoc Network are independent in nature and they rely on battery as a source of energy for performing all the activities required of them. The nodes operate on different operation modes, which are, transmit mode, receive mode, idle mode and sleep mode. Therefore, different energy consumption is required of them. In order to minimise energy consumed in the transmit mode, Transmission Power Control technique is used. This Transmission Power Control must be managed in a distributed manner unlike Cellular networks that used centralised power control management [6][13]. Different literature have proposed wide range of algorithms for Transmission Power Control, which cut across the Physical layer to the Application Layer. However, few related works have only been done on the physical layer in terms of power control. Kawadia *et al* [14] proposed Common power

(COMPOW) algorithm for transmission power control in Ad-hoc networks in which the power control algorithm assigns common power to nodes in the network. However, large energy resources were used in the attempt to reduce energy consumption. There was a significant increase in overheads. Mohammed *et al* [15] investigated the impact of dynamic Transmission Power Control technique on Ad-hoc On-demand Distance Vector (AODV) routing protocol. However, delay was experienced in the network due to the performance of AODV routing protocol. In addition, frequent broadcast messages were sent, which consumed significant amount of transmission energy. More of the related works will be discussed in Chapter 2 of this dissertation. This research focuses on the design of a Variable Transmission Power Control (VTPC) for Wireless Ad-hoc Network and the investigation of the impact of transmission power control in wireless Ad-hoc network using Distance based power control technique and Graph theory approach. The Graph theory is used to model the network topology that will minimise the cost function, which is transmission power. The Distance based power technique is used to estimate the distance between the sender and receiver. It will be implemented at the physical layer of the Open Systems Interconnection model (OSI). The impact will also be investigated with Best Approach To Mobile Ad-hoc Network (B.A.T.M.A.N.) as suggested in [15].

1.2 Definition of Transmission power control

Transmission power control is a technique used to select power level output in order to obtain good network performance, increase network capacity, reduce interference, and reduce energy consumption, which will increase the battery life span. It is known that the transmission power largely determines the amount of energy consumed in the battery. If the transmission power is too high, it affects the power consumption in the transmitter thus reducing the battery life span and increasing the interference between nodes operating at the same frequency. However, if the transmission power is too low, the signal-to-noise ratio at the receiver will be affected. The Transmission Power Control technique will manage the power output of each node in Ad-hoc Network putting into consideration the network constraints.

1.3 Problem Statement

Owing to the independent nature of nodes in Wireless Ad-hoc Network, energy consumption has become a major concern. This is due to nodes in Wireless Ad-hoc Network that are solely dependent on battery for their power. The sole dependence of nodes on battery will limit the node's lifetime and network lifetime. One of the major factors that cause rapid energy dissipation in Wireless Ad-hoc Network nodes is transmission power. Therefore, in this research an investigation into how transmission power affects consumption of energy in Wireless Ad hoc Network will be made. In addition, a Variable Transmission Power Control algorithm will be developed in order to minimize the rate of consumption of energy by the nodes in Ad hoc Network.

1.4 Research Questions

Following the problem identified in section 1.3, there are research questions of interest which arise and which will be dealt with in this research project. They are:

- What will be the effect of variable transmission power in Wireless Ad-hoc Network, considering the distance between node pair?
- What will be the implication of the Transmission Power Control technique with respect to transmission energy consumption rate?
- What is the relationship between received signal strength, distance between nodes and transmission power?
- Will the throughput of network be affected in the process of varying transmission power with respect to distance?

1.5 Objectives of the Research

The main objective of this research is to design an algorithm that will efficiently assign the appropriate transmission power with respect to the distance between nodes in the network. The Variable Transmission Power Control (VTPC) is addressed at the physical layer. This will be further used to:

- Investigate the impact of transmission power control and routing protocols over Wireless Ad-hoc Network.
- Compare and contrast the effect of variable transmission power control and constant transmission power in the network.
- Analyse the node lifetime and the energy consumption rate of each node involved in the establishment of the network.
- Analyse the end-to-end delay and throughput of the network.

1.6 Scope and Limitation

This dissertation aims to design and test an algorithm for Variable Transmission Power Control (VTPC), which minimises the rate of energy consumption. The minimum transmission power selected with respect to distance between nodes in Ad-hoc Network must be able to establish a reliable link and connectivity between the source and the sink. This must not be to the detriment of the network throughput in the process of selection. In order to assess the effectiveness of the proposed algorithm, the performance of the variable transmission power is compared with constant transmission power. Although constant transmission power has always been used to analyse the performance of nodes in Wireless Ad-hoc Network. This study focuses on designing a variable transmission power control technique for Wireless Ad-hoc Network and investigating the impact of using variable transmission power on nodes in Wireless Ad-hoc Network.

The routing protocol considered in this piece of work to route data packets in the network is Best Approach to Mobile Ad-hoc Networking (B.A.T.M.A.N.) routing protocol. B.A.T.M.A.N. routing protocol discovers the best and reliable next hop to the destination with minimised overhead. The performance of this routing protocol will be compared with other Wireless Ad-hoc Network routing protocols. However, the parameters that will be used in this research to measure the performance evaluation of the network are energy consumption, nodes lifetime of each node, throughput and end-to-end delay. This is due to their importance in analysing the effect of power control in Wireless Ad-hoc Network. In this study, the analysis of the performance metrics will be evaluated in OMNeT++ environment, which is a C++ based application.

1.7 Knowledge Contribution of the Research

Wireless Ad-hoc Network has poised to be one of the network paradigms in Next Generation Wireless Networks (NGWNs) that will bring ubiquitous access to internet services, provide last mile technology to areas that have limited access to network infrastructures due to its features. Nevertheless, Power control has been a major threat to the nodes in the network. This research work is contributing to body of knowledge in the aspect of power control by designing an efficient Transmission Power Control algorithm, the VTPC that addresses this challenge, and which minimises the rate of consumption of energy at each node involved in Wireless Ad-hoc Network.

1.8 Application of Research

Some of the areas that nodes in Ad-hoc Networks that are equipped with Transmission Power Control technique will be applicable are:

- Disaster management
- Urban, Sub-urban areas (such as cities etc.)
- Remote areas
- Military (Battlefield)
- Rural environment
- Universities, colleges

1.9 Publication

- **Akinsolu. O. Ifedayo**, Smart. C. Lubobya and Mqhele. E. Dlodlo. “Investigating the impact of Transmission Power Control in Wireless Ad-Hoc Networks”. Southern Africa Telecommunications Networks and Applications Conference (SATNAC), 2014. This Work-in-Progress (WIP) paper focused on investigating the factors affecting the performance of the nodes in the network and the impact of transmission power control technique in Wireless Ad-hoc Network.

1.10 Dissertation Outline

An outline of the research work contained in this thesis is thus summarised.

In this chapter, the fundamental study regarding Wireless Ad-hoc Networks was discussed extensively. A concise introduction to the concept of Wireless Ad-hoc Network with emphasis on Power transmission was also given. The problem associated with this and way to address the problem were stated.

In chapter 2, the background on the various techniques that have been adopted in recent times to proffer solution to the problem identified of power transmission control will be discussed. The proposition of the variable power control was put forward and the reason for this was equally stated.

Chapter 3 discusses the methodology and the mathematical modelling approach used for the proposed study .The proposed energy efficient algorithm called Transmission Power Control (TPC) for minimizing the energy consumption in each node is discussed. Transmission Power Control (TPC) concept will be explained in details. The relationship between received signal strength and distance between nodes is discussed as well in this chapter. Also, the flowchart and algorithm for the successful implementation of the method were equally stated as well.

Chapter 4 presents clearly the Experimental approach adopted for the proposed scheme using OMNeT++ for its implementation and the comparison of this with other simulators is equally done. The Discrete Event Network Simulator used in analysing the proposed research is discussed. The network scenario, the performance evaluation parameters and the simulation parameters are discussed as well.

In chapter 5, the experimental results and the analysis of the results obtained were discussed.

Chapter 6 gives the concluding remarks like the conclusion, research contribution and recommendations. Concise discussions relating to the performance of the proposed scheme with other techniques were presented and future works that could be done in this area were clearly spelt out as well.

CHAPTER 2

2 Literature Review and Background of Wireless Ad-Hoc Network

2.1 Introduction

This chapter presents the essential overview of Wireless Ad-hoc Network, power control algorithm. Technologies deployed with Wireless Ad-hoc Network in a wireless environment will be discussed in this chapter. The significance of Open Systems Interconnection (OSI) model in Ad-hoc networking and the challenges of the wireless nodes involved in Ad-hoc Networking will be briefly discussed.

2.2 Overview of Wireless Ad-Hoc Network

Wireless Ad-hoc Network is the collection of autonomous nodes (i.e. a router with multiple hosts and wireless communication devices) that do not depend on centralized infrastructure networks (i.e. infrastructureless-based networks)[1][2]. The Wireless Ad-hoc Network, otherwise known as Wireless Mesh Network uses Multihop wireless technology in which each node (except the source and the destination nodes) behaves as a relay to forward data packets to its next hop. The nodes are incorporated with routing functionality whereby they act as both host and router conveying information from the source to the destination that is not within the communication range[1][3][4]. The nodes could be placed on or in airplanes, airports, buses, cars, shopping malls, perhaps even on streets, houses, rural environments, disaster environments as a stationary node(s) to provide broadband internet access and wireless communication[2]. The network topology could operate in a confined area due to limited spaces or could use gateway nodes to integrate with infrastructure-based networks such as mobile communication and broadband access services. Wireless Ad-hoc Network has been envisaged to form a stub network connecting to the backbone networks. Stub networks carry network traffic within a local network. It only allows nonlocal network traffic to use a single interface when transporting data packets out of its network[2].

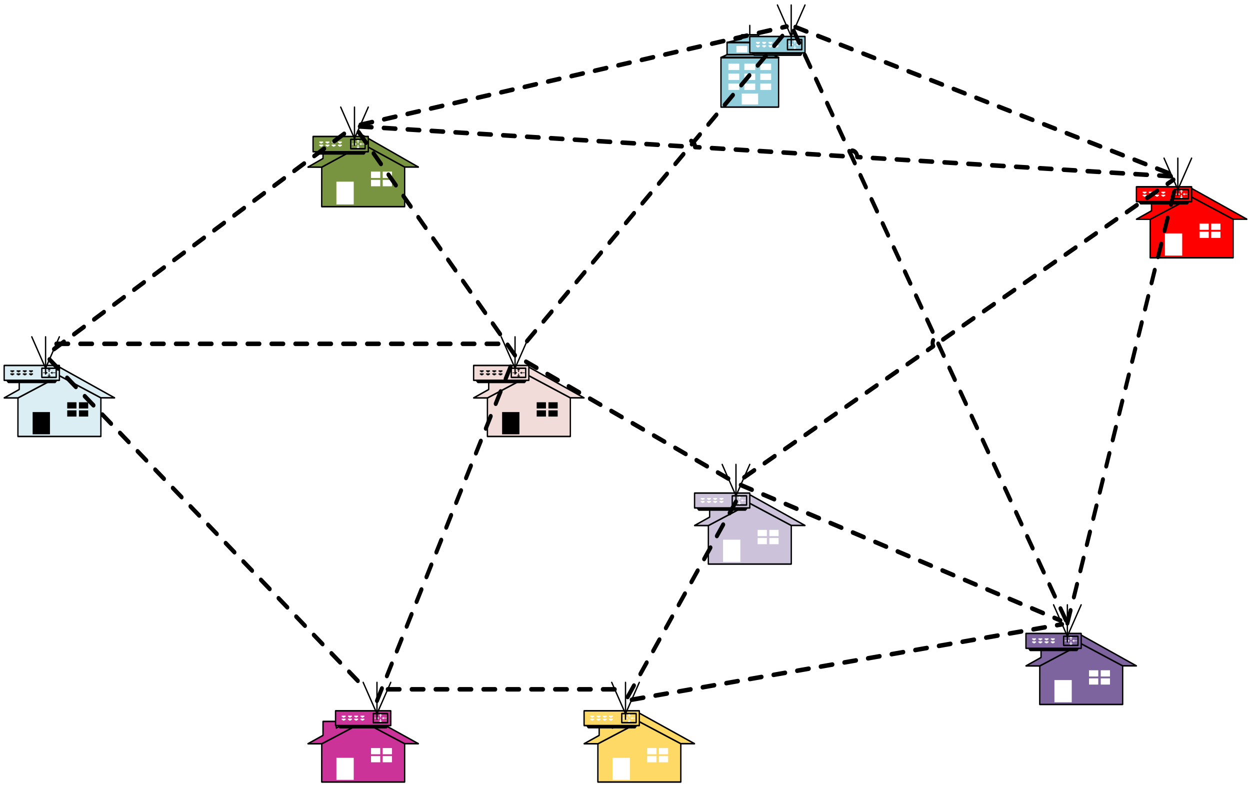


Figure 2.1. Wireless Ad-Hoc Network adapted from [5]

The nodes in the network include wireless routers (acting as relay nodes/bridges), gateway nodes, wireless transmitters and receivers with either omnidirectional or directional smart antennas[1][2] as shown in Figure 2.1. The network topology, which depends on the node position, transmission power levels, interference, weather condition, terrain (where the mobile nodes are located which could be either indoor or outdoor), coverage pattern and node mobility, changes with respect to time and distance as the wireless communication links break and reconnect[1][2]. Wireless Ad-hoc Network has some unique features such as flexibility, rapid deployment, less administrative management, cost-effectiveness, dynamic topology and mobility[6][7].

2.3 Application of Wireless Ad-hoc Network

The application of Wireless Ad-hoc Network has gone beyond tactical networks; it can be extended to environments that are congested (such as urban environments) where the deployment of fixed network is difficult and cost-effective to implement. It can be integrated with mobile telecommunication to provide broadband internet access, and other network services to remote areas (such as rural environment) where deployment of fixed infrastructure will not be easily achievable[8].The highlights of applications of Wireless Ad-hoc Network are as follows:

Tactical networks:

- Military communication and operations
- Automated battlefield

Emergency services:

- Search and rescue operations
- Disaster recovery
- Replacement of fixed infrastructure in case of environmental disasters
- Policing and fire fighting
- Supporting doctors and nurses in hospitals

Commercial and civilian environments:

- E-commerce: electronic payments anytime and anywhere
- Business: dynamic database access, mobile offices
- Vehicular services: road accident guidance, transmission of road and weather conditions, taxi cab network, inter-vehicle networks
- Sports stadiums, trade fairs, shopping malls
- Networks at construction sites

Home and enterprise networking:

- Home/office wireless networking
- Conferences, meeting rooms
- Personal area networks (PAN), Personal networks
- Networks at construction sites

Education:

- Universities and campus settings such as Ad-hoc communications during meetings or lectures
- Virtual classrooms

Entertainment:

- Multi user games
- Wireless P2P networking
- Outdoor internet access
- Robotics pets
- Theme parks

Coverage extension:

- Extending cellular network access
- Linking up with the internet, intranets, etc.

Context aware services:

- Follow-on services: call forwarding
- Information services: location specific services, time-dependent services

2.4 Challenges in Wireless Ad-hoc Network

The architecture of Wireless Ad-hoc Network is associated with some crucial problems that have opposed a general solution of Ad-hoc Network and these problems affect all facet of networking. These problems mitigate the rapid deployment of Wireless Ad-hoc Network[9], and are discussed below:

Security and Scalability: Nodes involved in Ad-hoc network are within the transmission range, therefore, a defected node could easily connect to the network and has access to the vital information sent. Owing to the fact that Ad-hoc networking does not rely on centralized administration, the network traffic management might be difficult to achieve, making Wireless Ad-hoc Network to be vulnerable to security threat[9][10].

Quality of Service (QoS): The frequent break and reconnection of links in Wireless Ad-hoc Network affects the QoS. This could be traced to the mobility of nodes in Ad-hoc networking.

If the nodes involved in Ad-hoc networking have limited battery lifetime, they will easily disassociate from the network after the depletion of battery, which will affect the network capacity and network performance. Other nodes that are still alive will be affected in return due to more work load on them[9][10].

Power Control: Wireless Ad-hoc Network experiences power related issues due to limitation of battery power. It might be hectic to recharge or replace batteries in the deployed devices, and multiple multihop routing could cause the nodes' power to deplete at a faster rate. Also, any unnecessary increase in transmission power would affect the energy consumed by the nodes[9][10].

Routing: The challenges related to routing are due to dynamic and frequent network topology of the system. The movement of the nodes affects the communication links, which in turn affects the bandwidth available. The limited battery lifetime, mobility and transmitting power of the each node in the network are major challenges affecting the routing performance of the network[9][10].

2.5 The Technologies Adopted In Wireless Ad-Hoc Network

Wireless Ad-hoc Network is accomplished by adopting only a few predominant technologies employed in wireless networking application. The Institute of Electrical and Electronics Engineer (IEEE) 802.11 standard is the most prominent physical layer standard used in Ad-hoc networking[11]. These standards are explained below:

2.5.1 Bluetooth Technology

Bluetooth is a technology designed to connect different short-range wireless communication devices such as smart phones, laptop computers, tablet PCs, cameras, printers, scanner and other devices. The Bluetooth technology was formalized by Bluetooth Special Interest Group (SIG) and other prominent companies which include Sony Ericsson, Toshiba, Nokia, IBM, Motorola, Microsoft and Intel[6][12]. The industry at large has shown a tremendous interest in Bluetooth due to its operability in providing Ad-hoc connectivity in Wireless Personal Area Network (WPAN). Bluetooth technology has been standardized by IEEE 802.15 working group as IEEE 802.15.1 standard for Bluetooth specification[6]. Any device can use the Bluetooth application once it is integrated into a low cost chip in electronic devices like wireless mouse, wireless keyboard, wireless digital camera and so on.

Bluetooth device is a short-range wireless communication radio transmitter and receiver that uses Frequency Hopping Spread Spectrum (FHSS) approach. This approach avoids interference in an unlicensed Industrial Scientific Medical (ISM) frequency spectrum at 2.4GHz, which has up to 79 channels of 1 MHz each with a frequency hopping of 1600hop/sec[12][13][14][15]. The effective transmission range of Bluetooth is between 0-10m[15].

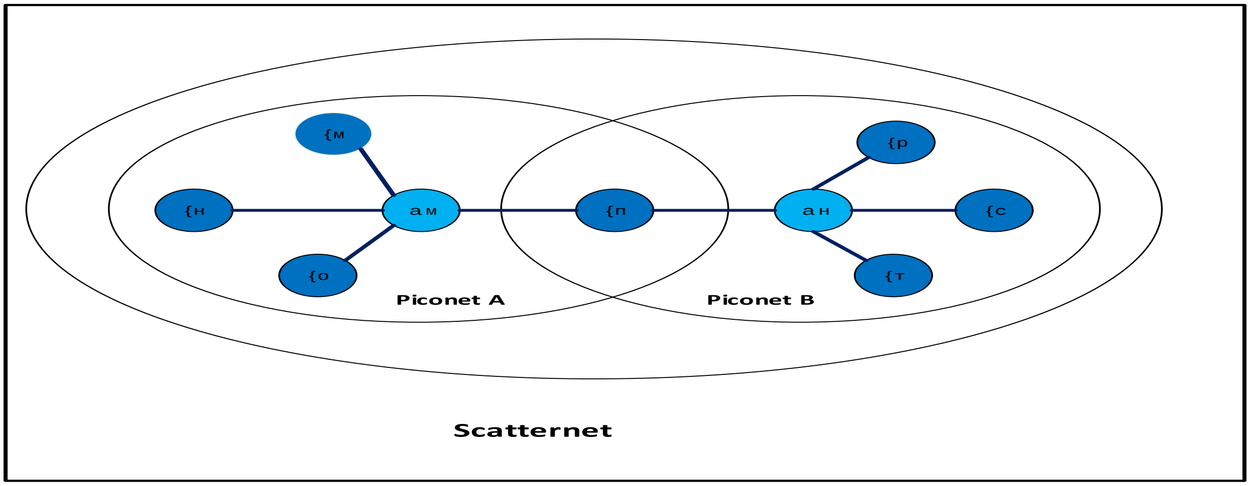


Figure 2.2. Bluetooth Piconet and Scatternet Diagram adapted from [14]

The Bluetooth technology is designed for Wireless Personal Area Network (WPAN). It provides two types of small networks: Piconet and Scatternet. The Piconet consists of eight nodes or less, whereby one of the nodes is a master while the rest are slaves. Scatternet is made-up of two or more Piconets. A master node in one Piconet can be a slave node in another Piconet. The node can receive messages from both Piconets and act like master/slave at the same time. They communicate with a technique called multi-hopping[12]. Multi-hopping is a wireless technology used by each node(s) within the network to store and forward data packet using the intermediate nodes (also known as the relay nodes) between the transmitter and receiver[16]. Figure 2.2 shows a basic Bluetooth network setup in which Piconet A contains M1, which is the master node, connected to S1, S2, S3, S4 and Piconet B contains M2 that is the master node to S3, S5, S6, and

S7. Piconet A and Piconet B form a Scatternet where S3 is the common slave node between Piconet A and Piconet B. Also, M1 is a slave to Piconet B[13][12][14].

2.5.2 IEEE 802.11 Technology

The IEEE 802.11 is a standard specified for Wireless Local Area networks (WLAN) technology. It was designed based on Open System interconnection (OSI) model. The IEEE 802.11 technology often called Wi-Fi (Wireless Fidelity) deals with set of Media Access Control (MAC) Layer and Physical Layer (PHY) specifications for implementing Wireless Local Area Networks (WLAN) interface communication between computers, routers, base stations and other wireless devices. Table 2.1 shows the OSI model of IEEE PHY and MAC Standard for Wi-Fi. There are two operational modes for WLANs, which are infrastructure-based and Ad-hoc based. The wireless interface of a device can be specified to work on any of the two modes. The frequency that each IEEE 802.11 interface operates on ranges from 2.4 - 60GHz depending on the extension introduced by Wireless Alliance of the IEEE 802.11[12][13].

The IEEE 802.11 has become a de-facto standard for use with wireless nodes with different extensions like IEEE 802.11a/b/g/n/s, etc. The PHY layer performs different functions such as encoding scheme, decoding, modulation, error correction, power management and so on, which is explained in details in a later section of this chapter. The MAC layer handles two different types of services which are the Distributed Coordination Function (DCF) and Point Coordination Function (PCF)[17][18]. The DCF is based on the Carrier Sense Multiple Access Collision Avoidance (CSMA/CA) technique. The CSMA/CA technique is a contention based approach whereby the channel is first sensed before any node transmits in order to avoid collision and retransmission of frames among nodes.

Table 2.1 IEEE PHY and MAC Standard for Wi-Fi [12]

TCP/IP	IEEE
Application Layer	Application Layer
Transport Layer	Transport Layer

Network Layer	Network Layer
Data Link Layer	Logical link Control (LLC)
	Media Access Control (MAC)
Physical Layer	Physical Layer

If a node operating in DCF mode wants to send a packet, the medium is sensed first. If the sensitivity energy is above the specified threshold, the node waits until when the medium is clear and idle before transmitting. Otherwise, the node sends a Request-To-Send (RTS) frames to the receiver. If the receiving node replies with a Clear-To-Send (CTS) frame, the transmitting node forwards the main packets to the receiver that must respond with an Acknowledgement (ACK) frame if the packet was received successfully. With PCF, contention-free approach is used in which nodes such as an access points control the network traffic using a point coordinator at any given period. The PCF may poll any access point to transmit packets at a given period of time, then polls another access point to transmit for another time frame and it continues down the polling list of access points[12][13][17][18]

2.5.3 ZigBee Technology

The ZigBee alliance and IEEE worked together to foster a specification of the protocol stack for IEEE 802.15.4 named ZigBee. It was designed to cater for low data rate and low power consumption devices that use applications with low throughput in an Ad-hoc network connectivity. The IEEE's interest was on the physical and MAC layer but ZigBee focused on the network, transport and application layer to enhance applications which require wireless networking, scalability and security[12][19].

ZigBee has same wireless technology as Bluetooth but it can be utilized in Ad-hoc network. The ZigBee devices operate in an unlicensed ISM frequency band 2.4GHz at 250kbps data rate. The ZigBee wireless transmission range is between 10 – 75m. The supported modulation techniques of ZigBee are Offset Quadrature Phase Shift Keying (OQPSK) modulation and Binary

Phase Shift Keying (BPSK) modulation. A number of 27 channels are allocated to ZigBee, which includes 1 channel between 868 and 868.6 MHz, 10 channels between 902.0- 928.0 MHz and 16 channels between 2.4 and 2.4835 GHz. The PHY and MAC layers of ZigBee use energy constrained devices to minimize energy consumption with limited transmission range capacity. The ZigBee accommodates different network topologies such as star, mesh and cluster tree[12][19].

2.6 OSI Model

Due to the features of Wireless Ad-hoc Network such as self-configuring, self-organizing, self-creating and independent capabilities, the OSI layers have significant interactions. The physical layer should be able to administer the dynamic network topology of the node and assign the appropriate transmission power and propagation model required for the nodes wireless communication connectivity. The MAC layer must manage the collision, retransmission in the network channel. The network layer must be able to establish an energy efficient shortest path required to route packets from the source to the destination for pervasive wireless communication. The transport layer must be able to handle the packet loss and delay in transmission. The application layer has to manage the persistent disconnection and reconnection with the delay and packet loss properties[4] [11]. The following sections explained the OSI layers in details.

2.6.1 Physical Layer

The Physical layer manages the modulation and demodulation, encryption (coding) and decryption (decoding) of data packets, management of both transmission and receiving power, channel fading, interference coordination, path loss etc. The network resources are maximised by the nodes involved in Ad-hoc networking because the nodes have the capability to manage the network administration. Therefore, power management is a major focal point of this study. The propagation models (e.g. Friis free space, two-ray, Nakagami, Rayleigh etc.) cannot be left out because they vary according to the terrain in which the wireless Ad-hoc network is being deployed[4] [11].

2.6.2 Data Link Layer

The Data link is sub-divided into two layers, which are Logical Link Control (LLC) and Media Access Control (MAC). The LLC layer takes care of source and channel coding, data rate and power awareness. The MAC layer evaluates the data packets sent between the nodes to be free from error so that the integrity of the information is maintained. The MAC layer controls the network traffic, channel sensing by using CSMA/CA scheme to detect when the channel is busy or idle. An acknowledgement receipt is sent if a data packet was successfully received. This layer also helps to disconnect and re-establish wireless links between nodes[11] [10].

2.6.3 Network Layer

The Network layer provides an efficient way to select the best path to route data from the source to the destination. Several Ad-hoc routing protocols have been established to ensure the coordination of how nodes decide which direction to route data between nodes. Routing protocols are categorized into three groups which are Reactive routing protocol, Proactive routing protocol and Hybrid routing protocol [11][20] . An illustration of these protocols is made in Figure 2.3

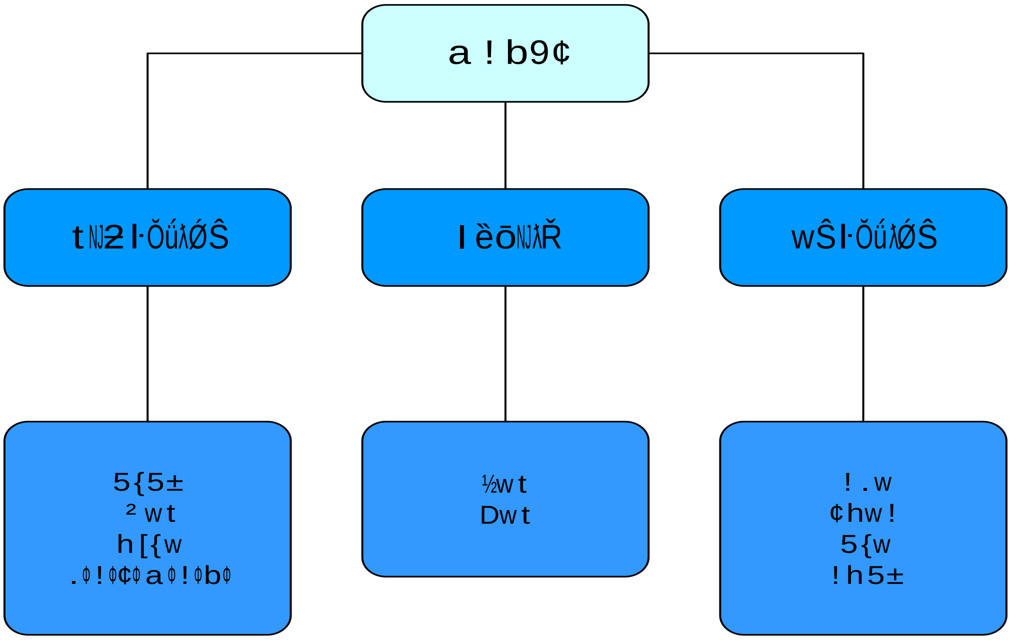


Figure 2.3. Wireless Ad-hoc Network routing protocol structure

The Ad-hoc On-demand Distance Vector (AODV) Routing is a source On-demand routing protocol that reduces the number of broadcast messages by establishing route based on demand. It uses two mechanisms which are route discovery and route maintenance to learn the best path from source to the destination[21][22][23]. The Optimized Link State Routing (OLSR) is one of the table - driven routing protocols, which provide a route for network communication at all times. The OLSR uses selected nodes called Multipoint Relays (MPRs) to send frequent route broadcast messages instead of using all the nodes in the network. Each node in the Ad-hoc network keeps record of the available path in the routing table and updates it periodically[1][20][24][25]. The Best Approach To Mobile Ad-hoc Networking (B.A.T.M.A.N.) is one of the recent proactive (table-driven) routing protocols. It discovers the best and reliable next hop to the destination with minimised overhead. The B.A.T.M.A.N. does not need to learn the entire route to the destination since each node only maintains the route information about its next hop which makes a rapid and dynamic implementation[26][27][28].

2.6.4 Transport Layer

The schemes for wired, fixed infrastructure and Ad-hoc networking are different from each other. The simultaneous disconnection of wireless links and dynamic network topology of Ad-hoc networking should be handled carefully so that there will be no misconception between congestion and disconnection of links. The Transport layer in Ad-hoc networking ensures that delay and packet loss are minimised in the transmission process in order to avoid unnecessary retransmission of data packets. The Transport layer handles congestion control, end-to-end data delivery, flow control and end-to-end connection between source, destination and the intermediates nodes[11][10].

2.6.5 Application Layer

Application layer must ensure that all applications such as emails, file sharing and transfer, voice over IP (VoIP), etc. are not affected by persistent disconnection and reconnection of wireless links in order to reduce the rate of packet loss and delay in the process[11].

2.7 Overview of power control algorithms

The main aim of power control algorithm in Wireless Ad-hoc network is to increase the network performance, network capacity, node lifetime, network lifetime and the battery life span of each node. According to Nuraj *et al* [29], different approaches are used to design the power control management in Wireless Ad-hoc network. These approaches are group into five, which are:

- Node-Degree Constrained Approach
- Location Information Based Approach
- Graph Theory Approach
- Game Theory Approach
- Multi-Parameter Optimization Approach

The various power control algorithm approaches are now discussed in detail below:

2.7.1 Node-degree constrained approach

Node-degree is regarded as the number of edges connected to vertex in the network. It is denoted by $deg(n)$, where $deg(n)$ is the degree of node n in the network comprising of N nodes[29][30]. In Ad-hoc network, degree of node can be said to be the total number of the neighbouring nodes, i.e.

$$deg(n) = |N(n)|. \tag{2.1}$$

Therefore, the mean of degree of the node is

$$deg(n)_{mean} = \frac{1}{N}\sum_{n=1}^{N} deg(n). \tag{2.2}$$

If n has no neighbouring nodes, it is said to be isolated and $deg(n) = 0$.

The nodes in the Ad-hoc network can be of diverse degree. The minimum degree of node of an Ad-hoc network is

$$deg(n)_{min} = min\{deg(n)|n \in N\}, \tag{2.3}$$

while the maximum degree of node of an Ad-hoc network is given by

$$deg(n)_{max} = max\{deg(n)|n \in N\}. \tag{2.4}$$

Node-degree constrained approach can be used for designing power control algorithm to choose transmitting power that will provide connectivity between nodes and its neighbouring nodes[29].

2.7.2 Location Information based approach

The information on location of nodes in the network can play a vital role in power control algorithm. Nodes in Wireless Ad-hoc network using omnidirectional antenna can use Received Signal Strength location technique to measure distance between transmitter and receiver and estimate location of the nodes. Nodes that use directional antenna can use Time of Flight (ToF) location technique, which includes Time of Arrival (ToA), Angle of Arrival (AoA), and Time Difference of Arrival (TDOA) to determine the location of nodes in Ad-hoc Networks as well as the distance between a node pair[29].

2.7.3 Graph Theory approach

Graph theory is another power control approach used for optimization of transmission power in Wireless Ad-hoc Network. It has wide application in Ad-hoc Network because of its simplicity characteristic. It is used to construct a network topology, which minimises some cost function such as transmission power, etc.[29].

Consider now an Ad-hoc Network G that consists of a set of vertices V, represented as nodes in the network or points on a graph and a set of edges E, represented as wireless links in a network or a line joining two points on a graph. This can be written as $G = (V, E)$. It can be deduced that a network with no parallel links and loop is said to be simple. Therefore, a simple network is a network that is connected if and only if the vertices are connected to each other through edges i.e. x is connected to y and y is connected to x where $x, y \in V$. The edges in the network are assigned weights, which could be the transmission power, distance etc. It can be said that the weight of a path is the addition of weights of the edges[30]. This can be shown graphically in the Figure 2.4 below. The letters A, B, C, D, E, F, and G represent the edges of the graph.

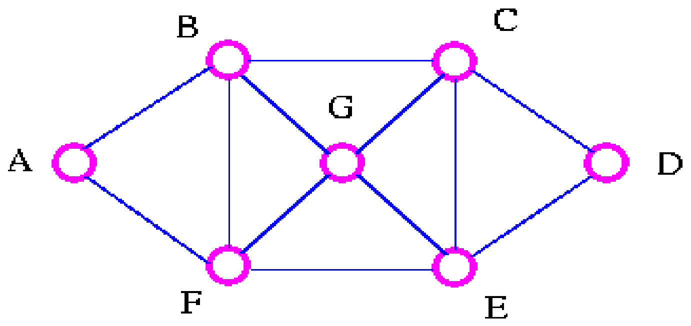


Figure 2.4: The Graph Theory [29,55]

Let vertex and edge of the graph be represented as V and E respectively. The graph is a triple route consisting of vertex set called V(M) and edge set E(M) and a relation that connects with each edge,two vertices are called end points[55].

2.7.4 Game Theory Approach

Game theory approach is another power control approach used to design power control algorithm for Wireless Ad-hoc Network. Game theory involves a set of players, a set of strategies and a set of possible payoffs. The players take part throughout the game process, using different strategy options available for the players. A player’s reward for choosing a particular strategy is the payoffs. The game theory is used to optimise the payoffs of each player by selecting the best strategy that will optimise the possible payoffs of the players. The players are the node involved in the network. The strategies are the transmission power levels and the payoffs involve parameters that are been optimised such as energy consumption, network performance, network capacity, etc.[29].

2.7.5 Multi-Parameter Optimization Approach

Multi-parameter approach is a dynamic approach for maximizing parameters such as interference, network connection and consumption of energy in the network. It uses localisation algorithm with node density to select the optimal power for node taken the node mobility into consideration[29].

2.8 Related Works

Several contributions have been in place concerning energy consumption minimization in wireless Ad-hoc technology to improve the network life and general network performance. Some researchers considered transmission power control at the physical layer, MAC layer, Network Layer and the application layer. Some of the reviewed papers are as follows.

Gomez *et al*[31] did analytical study to investigate the impact of variable-range transmission power control on physical and network layer of the nodes involved in Multihop Wireless Networks. Their study showed that variable-range transmission power outperformed a common range transmission power by 50% in terms of energy consumption and network capacity. Gomez *et al* found in their work that the average traffic capacity will not be affected as the size of the network grows and that variable-range transmission requires a lower transmission power compared to common-range transmission. The research done by Gomez *et al* buttresses the fact that Transmission Power Control (TPC) is achievable and that it increases network performances generally. However, if the size of the network increases, i.e., more nodes are added to the network, then the rate at which nodes interfere with each other increases, which in turn affects network traffic capacity.

Macedo *et al* [32] modified the Medium Access Control (MAC) existing routing protocols to incorporate Transmission Power Control (TPC) and Rate Adaptation (RA). Rate adaptation affects the time required for a packet to be transmitted. Macedo *et al* modified DSDV routing protocol to be aware of TPC and energy consumption. They broadcast the control message at a minimum transmission power level to learn about its environment and store the transmission power level in a payload. In their research work, it was found through analytical analysis that fewer hops reduce the energy consumption and end-to-end delay in Multihop Wireless Networks. However, the findings of Macedo *et al* is not suitable for low traffic.

Niranjan Krishnamurthi *et al* [33] proposed an energy module which was implemented and analysed in OPNET to determine the energy consumption when nodes are in transmitting, idle and sleeping modes. Topology control was considered in their research whereby each node would determine the transmission power needed for its transmission of packet from one node to another and at the same time maintaining the network connectivity.

Niranjan Krishnamurthi *et al* and Macedo *et al* used same technique for TPC. They achieved this by making the nodes to send help packet at the initial stage and hold-up for an acknowledgement from the relay node or next hop. If the response is not obtained within the limited time, the help packet will be retransmitted using an increased power level. The transmitting node will continue in this process until it reaches the maximum transmission power level or an acknowledgement has been received. The transmitting node will increase the transmission power to match the value on the help packet. The technique adopted by Niranjan and Macedo consumes a lot of energy in the process of trying to establish network connection between two nodes. As the node sends the help packet to its neighbour, each transmission power results in energy consumption per transmission, such that, the higher the transmission power required transmitting the help packet, the more is the energy consumed. Having this at the back of our mind, it might require five stages of retransmission before network connectivity could be established. This will result in wastage of battery power. The same process applies to all the nodes involved in the network connection, which might affect the overall performance of the network.

Mohammed *et al* [34] used a simulation based approach to investigate the impact of dynamic transmission power control technique on Ad-hoc On-demand Distance Vector (AODV) routing protocol with random way-point mobility model. They proposed that Transmission Power Control should be investigated with other routing protocol (such as Optimised Link State Routing (OLSR) protocol) in order to analyse their impact on wireless Ad-hoc Networks. However, AODV used in this research for the analysis initiates delay in network traffic and sends frequent broadcast messages that consume transmission energy. This will definitely have an impact on the network performance.

Krunz *et al* [35] did a survey on several Transmission Power Control approaches. They stated that Transmission power control protocol has the potentials to improve the throughput performance of the Wireless Ad-hoc Networks and simultaneously decreases energy consumption. Some of the approaches e.g. SIMPLE/PARP were successful in achieving reduction in energy consumption but at the expense of the reduction in network throughput performance. The authors proposed routing protocol at the MAC layer, called the interference – aware routing protocol that could mesh with the Network layer. The shortcoming of their proposed scheme is not backward compatible with IEEE 802.11 standard, which makes it difficult to deploy such scheme in real network.

Eun-Sung *et al* [36] fostered a Power Control MAC (PCM) protocol at the MAC Layer that will grant each node involved in network establishment to vary transmit power level on a per packet basis. The proposed protocol will allow each node to utilize different power level to send Request-To-Send (RTS), Clear-To-Send (CTS) and Data Acknowledgement (DATA-ACK). They proposed in their work that in order to minimize energy consumption, RTS-CTS is sent with maximum power while DATA-ACK is sent with minimum transmit power. However, DATA-ACK periodically uses maximum transmission power to transmit in order to maintain non-degradation of the network throughput and performance simultaneously. The proposed power control MAC protocol experience some drawbacks such as the complexity in the implementation which was crucial because of the persistent increase and decrease in the transmit power. The performance of PCM could be affected by fading and it does not support spatial reuse as compared to IEEE 802.11.

Kawadia *et al* [37] addressed the impact of power control with some parameters (such as end-to-end delay, throughput and energy consumption). They designed Transmission power aware routing protocol such as COMPOW protocol, CLUSTERPOW protocol and MINPOW routing protocol. These routing protocols require large energy resources due to the routing algorithms that have numerous instances.

Gujral *et al* [38] investigated the impact of transmission range and mobility on routing protocols over Ad-hoc networks. They used some of the general and most accepted routing protocols (i.e. AODV, DSDV, DSR) by varying the transmission range, the speed of mobility and the number of nodes to analyse the Packet Delivery Ratio (PDR), end-to-end delay, overall energy consumption and network performance of Ad-hoc Networks. The three routing protocols were compared, and the results showed that AODV performed better with maximum PDR and throughput that is directly proportional to transmission range. DSR and DSDV have maximum routing overhead as compared to AODV. They confirmed that with 550m transmission range, DSR protocol performed better than AODV and DSDV routing protocols. The AODV protocol was realised to experience maximum end-to-end delay. The analysis carried out could be adopted to actuate the appropriate radio transmission range in different environment in Ad-hoc environment without affecting the overall network performance.

Yin *et al* [39] improved on one of the existing routing protocols called Optimized Link State Routing (OLSR) protocol in order to create power awareness. Power Aware-Optimized Link State Routing (PA-OLSR) is expected to find the lowest cost path from the source to the destination by considering the nodes with lengthy lifetime to be used as the Multi-Path-Relay (MPR) node. They chose node lifetime and transmission power as the network performance measures. Their results showed that PA-OLSR routing protocol degrades the effect of interference on the nodes involved in transmitting and receiving of data packet in the network. This increases the life span of each node, the network and improves the successive packets transmitted.

The related works discussed so far looked at various approaches to solving the problem with energy consumption in wireless Ad-hoc network. Therefore, it is proposed in this work a novel way of solving the problem of energy consumption at the physical layer of the OSI model. The proposed methodology will be discussed in details at the next chapter of this dissertation.

2.9 Chapter Summary

This chapter discussed the overview of power control, Wireless Ad-hoc Network, challenges faced in Wireless Ad-hoc Network such as Power control, Quality of Service, etc. Power control is the major concern in this study. A review of related works was equally done on transmission power control at different OSI layers.

Chapter 3

3 Proposed Methodology

3.1 Introduction

As discussed in previous chapters, energy consumption is one of the major factors that has to be taken into consideration in Wireless Ad-hoc Network. This is because the nodes that form Ad-hoc network topology rely on battery power for smooth operations. Transmission power is known to be a major contribution to the dissipation of energy in the autonomous nodes. This can be because transmission power determines the amount of energy consumed by each node. The transmission power must be high enough to guarantee the transmission and should be low enough to save energy in the nodes. Therefore, there is a need for Transmission Power Control (TPC) technique to be incorporated with efficient routing protocol. This will increase the network lifetime as well as the node lifetime. It will minimise the consumption of energy at each node.

In this chapter, we proposed a Variable Transmission Power Control algorithm with respect to the distance between a pair of nodes, which will be implemented at the physical layer of the node. In the rest of this chapter, the Transmission Power Control concept will be discussed in details. The Received Signal Strength Indicator (RSSI), the channel propagation model, the proposed algorithm, methodology and the energy model of the radio will equally be discussed extensively.

3.2 Transmission Power Control

Power is one of the scarce and important resources in wireless communication. If one or more nodes in wireless Ad-hoc network have little or no energy, then data transmission will be interrupted briefly or permanently which might create a serious havoc in the Ad-hoc network especially when a vital information is in transit and it requires an urgent response. This will in turn affect the performance of the entire network. Moreover, nodes involved in Wireless Ad-hoc network act as host, relay node forwarding data of the neighbouring nodes and receiving node.

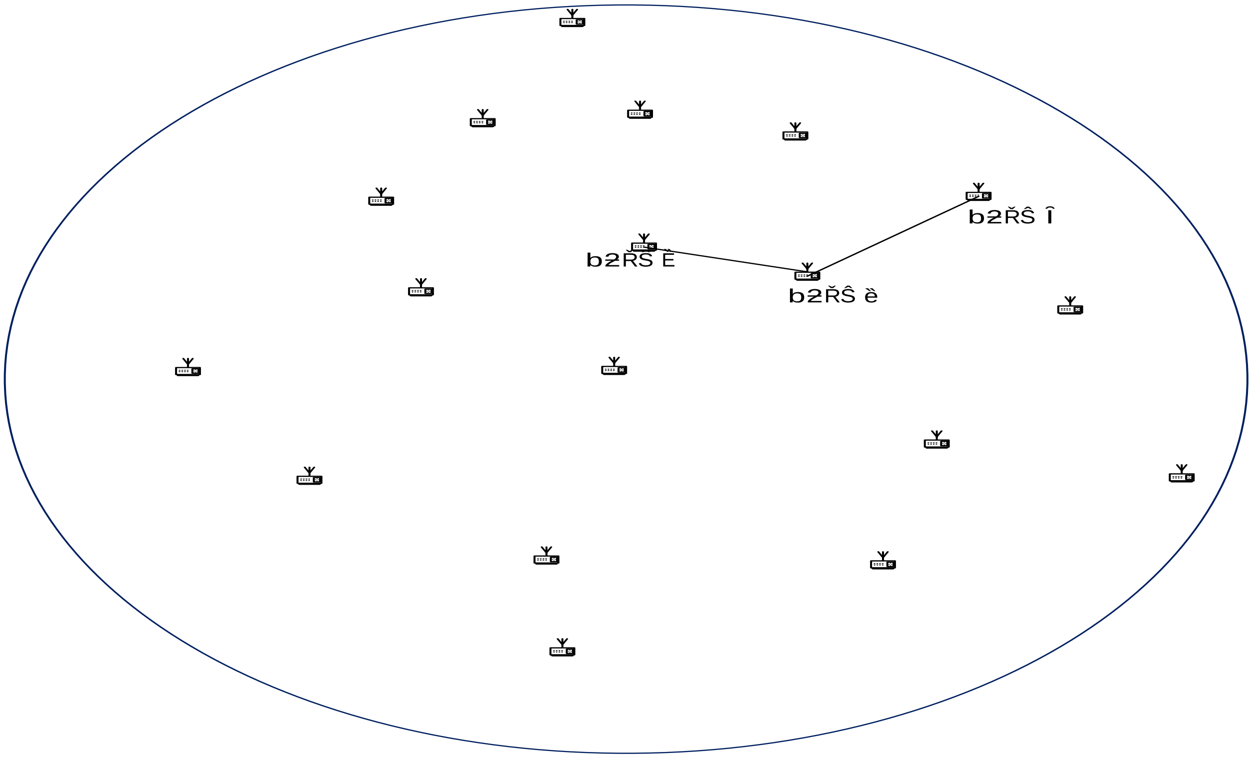


Figure 3.1. Wireless nodes in Ad-hoc network

Let us consider nodes x, y and z as shown in Figure. 3.1, which describes a Wireless Ad-hoc network topology. If node x wants to send a data packet to node z, node x can only achieve that if and only if node x has enough battery energy for transmitting the data packets and the two nodes are within each other's transmission range. Otherwise, node x can as well transmit the data packets through the intermediate node which lies within its transmission range if the sink node z is out of the transmission range but node y is within the range of node x and node z. If node x transmits data packets to node z through the intermediate node y at fixed transmission power, the total transmission power will be:

$$P_{fp}(x,z) = P_{fp}(x,y) + P_{fp}(y,z). \qquad (3.1)$$

If node x varies the transmission power with respect to the distance between the nodes, the transmission power will be:

$$P_{vp}(x,z) = P_{vp}(x,y) + P_{vp}(y,z). \qquad (3.2)$$

Typically, the total power consumption using fixed transmission power will be greater than total power consumption using variable transmission power provided the fixed transmission power is not the minimal transmission power. This is usually the case for fixed transmission power as transmit power will always be above minimal transmission power.

Therefore, the sum of the variable transmission power required to transmit data packets between node x and node z through node y is less than the sum of fixed transmission power required to send data packets from node x to node z through the intermediate node y, i.e.

$$P_{vp}(x,y) + P_{vp}(y,z) < P_{fp}(x,y) + P_{fp}(y,z) \tag{3.3}$$

This is equivalent to:

$$P_{vp}(x,z) < P_{fp}(x,z) \tag{3.4}$$

where P_{fp} and P_{vp} are respectively the fixed transmission power and variable transmission power needed to transmit from one node to another. Therefore, energy consumption rate will be reduced at each node with respect to the transmission power. In wireless Ad-hoc Network, the nodes are randomly placed in an optimal position. This is due to the terrain of the environment, landscape, buildings, etc. Some nodes are closer to each other while some are at a longer distance to each other thereby creating both short and long links between each pair of nodes in the network. The signal strength of nodes closer to each other will be stronger while nodes that are far from each other will experience the opposite, which can be linked to the function of distance between the two nodes. The signal strength quality received at the sink is said to indicate the transmission power from the source. This means that if the signal quality of the receiver is poor, a high transmission power will be required to send the packets from the source to the destination without any error or packet loss. When two nodes are close to each other, low transmission power is sufficient to establish wireless communication between the two nodes while a high transmission power is required to transmit between nodes that are far from each other. Therefore, an optimal transmission power must be selected with respect to the distance between nodes in other to minimise energy consumed at each node. Therefore, a Transmission Power Control algorithm is designed which selects the optimal transmission power level required to convey information between a pair of nodes with respect to the distance between the nodes. The optimal transmission power must be able to provide a reliable link that must not be detrimental to the network throughput and it is given as

$$OTP_a = \sum_{x,z=1}^{a} P_{vp}(x, z) \tag{3.5}$$

where OTP_a is the Optimal Transmission Power with respect to ‘a’ where ‘a’ is the number of nodes involved in the transmission and reception of packets in the network. In order to achieve this, the distance and link characteristics must be taken into consideration. However, the received signal strength deals with these factors.

3.3 Received Signal Strength Indicator (RSSI)

Received Signal Strength Indicator is the measurements of power present in a received radio signal and it is also referred to as the signal strength[40][41]. Figure 3.2 illustrates the relationship between signal strength and distance d'. As the distance between the transmitter and the receiver increases from d' to $3d'$, the received signal strength decreases. Similarly, the received signal strength increases as the distance between the transmitting node and receiving node decreases[42]. The distance d' between the transmitter and the receiver (or relay node) can be known, if there is an analytical relationship between the signal strength and the distance d'. This can be represented using the inverse square law as given in [41][44]. The received signal strength P_r' is inversely proportional to the distance d' as shown in equation (3.6):

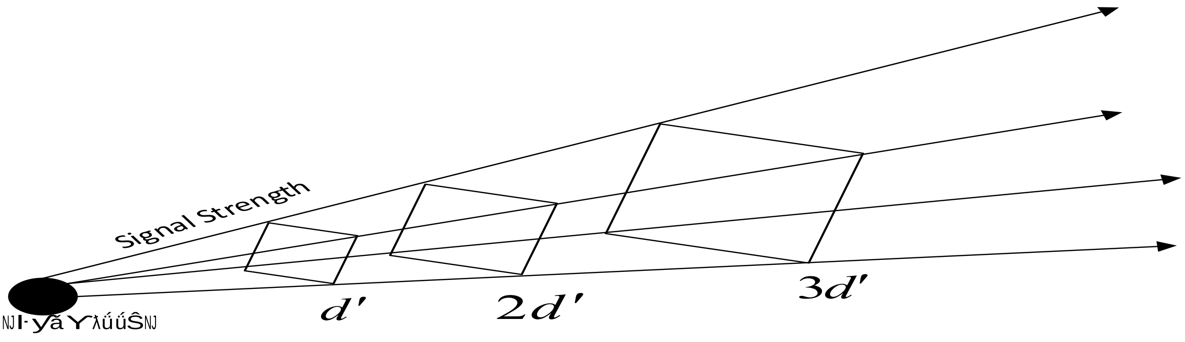


Figure 3.2. Signal strength propagation relationship with signal adapted from [43]

$$P_r' \propto \frac{1}{d'^{(n)}} \tag{3.6}$$

where d' is distance between nodes, n is the propagation constant, P_r' is the received signal power measured in mW(milli-watts).

$$P_r'(mW) = \frac{P_t'(mW)}{d'^{(n)}} \quad (3.7)$$

where P_t' is the transmission power measured in mW. P_t' and P_r' in equation (3.7) can be expressed in dBm (It is a measure of power), i.e.

$$10 \log P_r'(mW) = 10 \log P_t'(mW) - 10n \log d' \quad (3.8)$$

Therefore, equation is now written as:

$$P_r'(dBm) = (B - 10n \log d') \quad (3.9)$$

where B is the transmission power in dBm, n is the propagation constant. Both B and n determine the relationship between the received signal strength and the distance between the two nodes.

In this research, the RSSI will be based on IEEE 802.11 standard. In IEEE 802.11 standard, RSSI is a unit less one-byte value that ranges from 0 to 255. 0 is the minimum signal level while 255 is the maximum signal level [45]. There is no general conception among vendors on how the RSSI is measured with respect to the signal strength and power levels. Different vendors such as Atheros, Cisco, symbol etc. defined their signal strength level based on their perspective which is from 0 - RSSI_Max [45]. Cisco scale of RSSI range was chosen in this research that ranges from 0 to100, where 100 is the RSSI_Max. The RSSI value is being utilised internally by the microcode on the Cisco wireless Network Interface card (NIC) adapter to set the signal strength energy level. The RSSI values were mapped with dBm using Cisco conversion. This is because there has been inconsistency in the RSSI conversion to dBm or mW[45]. For the purpose of this research, we considered Cisco parameters given in Table 3.1[45].

Table 3.1 RSSI Lookup Table [45]

RSSI can be implemented on existing wireless communication system with little or no hardware notification. It has lower communication overhead, lower cost and is also used to estimate distance based on radio

RSSI	dBm	RSSI	dBm	RSSI	dBm
0	-113	39	-72	78	-29
1	-112	40	-70	79	-28
2	-111	41	-69	80	-27
3	-110	42	-68	81	-25
4	-109	43	-67	82	-24
5	-108	44	-65	83	-23
6	-107	45	-64	84	-22
7	-106	46	-63	85	-20
8	-105	47	-62	86	-19
9	-104	48	-60	87	-18
10	-103	49	-59	88	-17
11	-102	50	-58	89	-16
12	-101	51	-56	90	-15
13	-99	52	-55	91	-14
14	-98	53	-53	92	-13
15	-97	54	-52	93	-12
16	-96	55	-50	94	-10
17	-95	56	-50	95	-10
18	-94	57	-49	96	-10
19	-93	58	-48	97	-10
20	-92	59	-48	98	-10
21	-91	60	-47	99	-10
22	-90	61	-46	100	-10
23	-89	62	-45		
24	-88	63	-44		
25	-87	64	-44		
26	-86	65	-43		
27	-85	66	-42		
28	-84	67	-42	-	
29	-83	68	-41		
30	-82	69	-40		
31	-81	70	-39		
32	-80	71	-38		
33	-79	72	-37		
34	-78	73	-35		
35	-77	74	-34		
36	-75	75	-33		
37	-74	76	-32		
38	-73	77	-30		

The minimum level for each node to detect a signal is -90dBm equivalent to RSSI value of 22, which is known as the Receiver Sensitivity. The Receiver Sensitivity is the minimum level that separates a noise signal from the actual signal. If the value of RSSI is less than 22, the signal level will be regarded as noise.

propagation model [41][42].

3.4 Propagation Model

In wireless communication, the transmission medium is the radio channel between transmitter and receiver. The radio channel contributes to the performance of the wireless system. In radio channel, the signal strength inversely varies with the distance between two nodes. The signal from the transmitter can get to the receiver over multiple paths through direct path propagation, reflection, diffraction and scattering. This phenomenon is called multipath propagation[46]. In this research, the radio channel is taken into account by using radio propagation models such as the friis free-space propagation model (direct-path propagation) and two-ray ground model propagation (reflection) which depend on the reference distance between the two nodes (source and sink).

The reference distance between the transmitter and the receiver is given by [47]

$$d'_{ref} = \frac{4\pi h_t h_r \sqrt{L}}{\lambda} \qquad (3.10)$$

where h_t and h_r are, respectively, the height of the transmitter and receiver from ground, λ is the wavelength of the carrier signal, $L \geq 1$ is the system loss factor which depends on the antenna loss, filter loss and line attenuation. We considered using Omnidirectional antenna in this research with h_t and h_r equals to 1m, $L = 1$ (assuming there is no system loss) and $\lambda = \frac{3*10^8}{2.45*10^9}$ $= 0.122m$. Therefore, from equation (3.10), we obtain $d'_{ref} = 103m$.

If the distance between the transmitter and receiver is less than cross over distance i.e. $d' < d'_{ref}$, then friis free-space equation will be used. The received signal power will be calculated from equation (3.11) in [41][42][47]

$$P'_{rx} = \frac{P'_{tx} G_t G_r \lambda^2}{(4\pi)^2 d'^{(2)} L} \qquad d' < d'_{ref} \qquad (3.11)$$

where $P'_{tx}, P'_{rx}, G_t \; and \; G_r$ are respectively transmitter, receiver signal strength, antenna gain for transmitter and receiver.

If the distance between the transmitter and receiver is greater than or equal to the cross over distance i.e. $d' \geq d'_{ref}$, the two-ray propagation model will be utilized. The received signal strength power at the receiver is determined by [41][42][47]

$$P'_{rx} = \frac{P'_{tx} G_t G_r h_t^2 h_r^2}{d'^{(4)} L} \qquad d' \geq d'_{ref} \tag{3.12}$$

3.5 Proposed Methodology

Consider a wireless Ad-hoc network, which consists of a complete directed graph $G' = (V', E')$, where V' represents the set of nodes in the Ad-hoc network and E' represents the set of directed links (x, y, z) given that $x, y, z \in V'$. The network is made up of a set V' such that $|V'| = S_n$, where S_n is the number of wireless static nodes in the network. Each node has the capability to adjust its transmission power between zero and maximum transmission power value. The complete directed graph will be examined with a non-negative optimum transmitting power function $P : E' \rightarrow R^+$. This function designates the optimum transmission power required by node x to transmit a data packet to another node y and vice-versa. The non-negative power level assignment $P_l : V' \rightarrow R^+$ is the function that specifies the transmission power level to each node $x \in V'$ in the network. In a real life network scenario, the distance between any two nodes depends on the terrain, weather condition and interference level, whereby some links are within short range while some are far from each other. Therefore, a conclusion is drawn that the distance between nodes is different, and the links between the nodes will be asymmetric i.e. $d'(x, y) \neq d'(y, z)$ If the power level allocated to node x is the least transmission power of the link(x, y), then $P'_l(x) \geq P(x, y)$ and if the power level assigned to node y are enough to transmit data packet within link(y, z), then $P'_l(y) \geq P(y, z)$.

Given that

$$E' = \{(x, y, z) : (x \in V') \wedge (y \in V') \wedge (z \in V') \wedge \left(P'_l(x) \geq P(x, y)\right) \wedge \left(P'_l(y) \geq P(y, z)\right)\} \tag{3.13}$$

Let $P'_l(x)$ be the power level assigned to node x. The neighbouring nodes around node x is the set of

$$N_{P'_{l(x)}}(x) = \{y \in V' : (y \neq x) \wedge (P(x, y) \leq P'_l(x))\} \tag{3.14}$$

The dynamic transmission power level is a set of pairs P'_{l_i}, d'_i, where i ranges from $1, \ldots, t \ \forall \ P'_{l_i} : V' \rightarrow R^+$ and each d'_i is the distance between a pair of nodes with respect to the transmission power level. In the proposed energy model, each transmission and reception of data packets results in the decrease of the battery energy. The primary battery energy is represented as a function $B_{IE} : V' \rightarrow R^+$. The Remaining Energy (RE) in the battery of the nodes can be represented as a function $B_{RE} : V' \rightarrow R^+$. The total energy, E_T consumed in a node due to transmission and reception of data packets is given by $E_{tx} + E_{rx}$, where E_{tx} is the amount of energy consumption at each node during transmission and E_{rx} is the amount of energy consumed in each node during reception of data packets.

The proposed algorithm is expected to work in a dynamic way. The source node will use the beacon message (known as the control signal message) to learn about their environment as shown in Figure 3.3. The beacon message will be sent to all the neighbouring nodes (which include the intermediate node/sink) in the Wireless Ad-hoc Network. Through the beacon message, the received signal strength of each node will be detected which will be used in turn to determine the distance and location of each node respectively. Each node that receives the beacon will send an acknowledgement (ACK) with a topology updates (which consist of both address and the route updates). With this, all the nodes in the Ad-hoc network will know about each other with respect to the distance between a pair of nodes. Each node will select the optimal transmission power level based on the information received to establish a reliable communication between a pair of nodes without affecting the throughput of the system. The flow chart algorithm for the proposed TPC is shown in Figure 3.4.

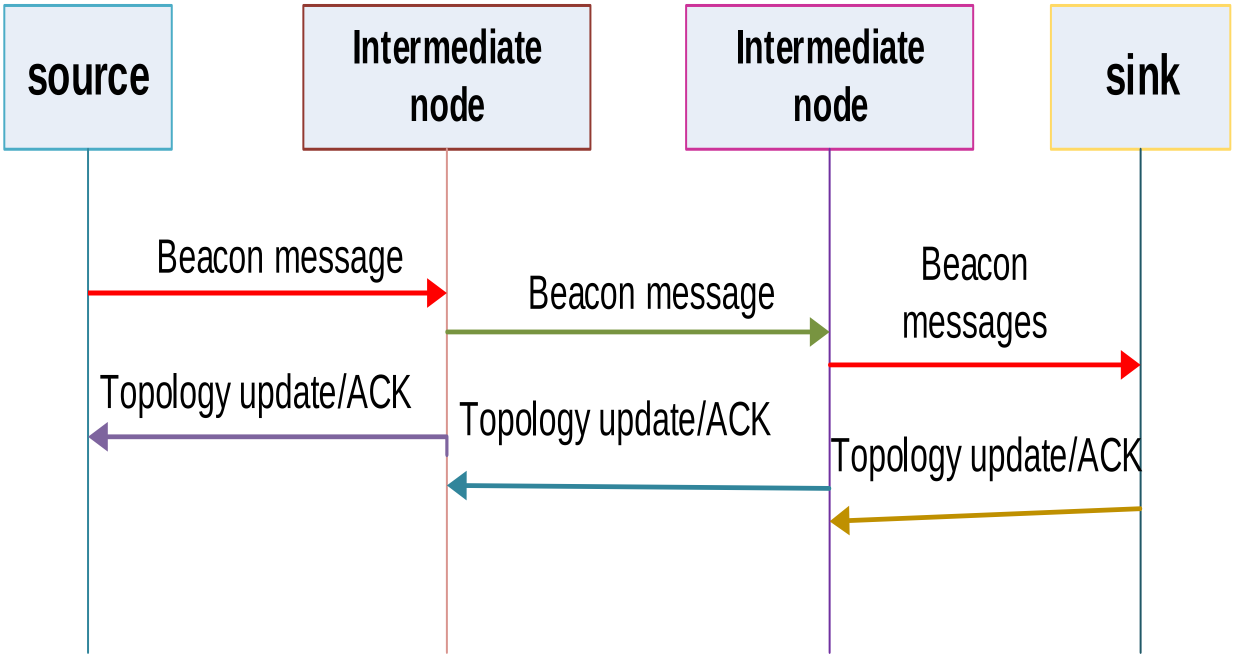


Figure 3.3. The beacon message transfer (The Received Signal Strength and distance will be learnt through the transmission of control messages known as Beacon messages)[32]

Each node will send data packets with an optimal transmission power level to its neighbouring nodes or intermediate nodes and it will use a Multihop Technology to convey information to the destination node. With this proposed algorithm, energy consumption will be minimized in transmission of data packets from the source to the destination using short range hops which uses less transmission power with respect to distance than a longer distance which uses a high transmission power. The flow chart for the proposed algorithm is given in Figure 3.4 with the five different power levels depicted as well.

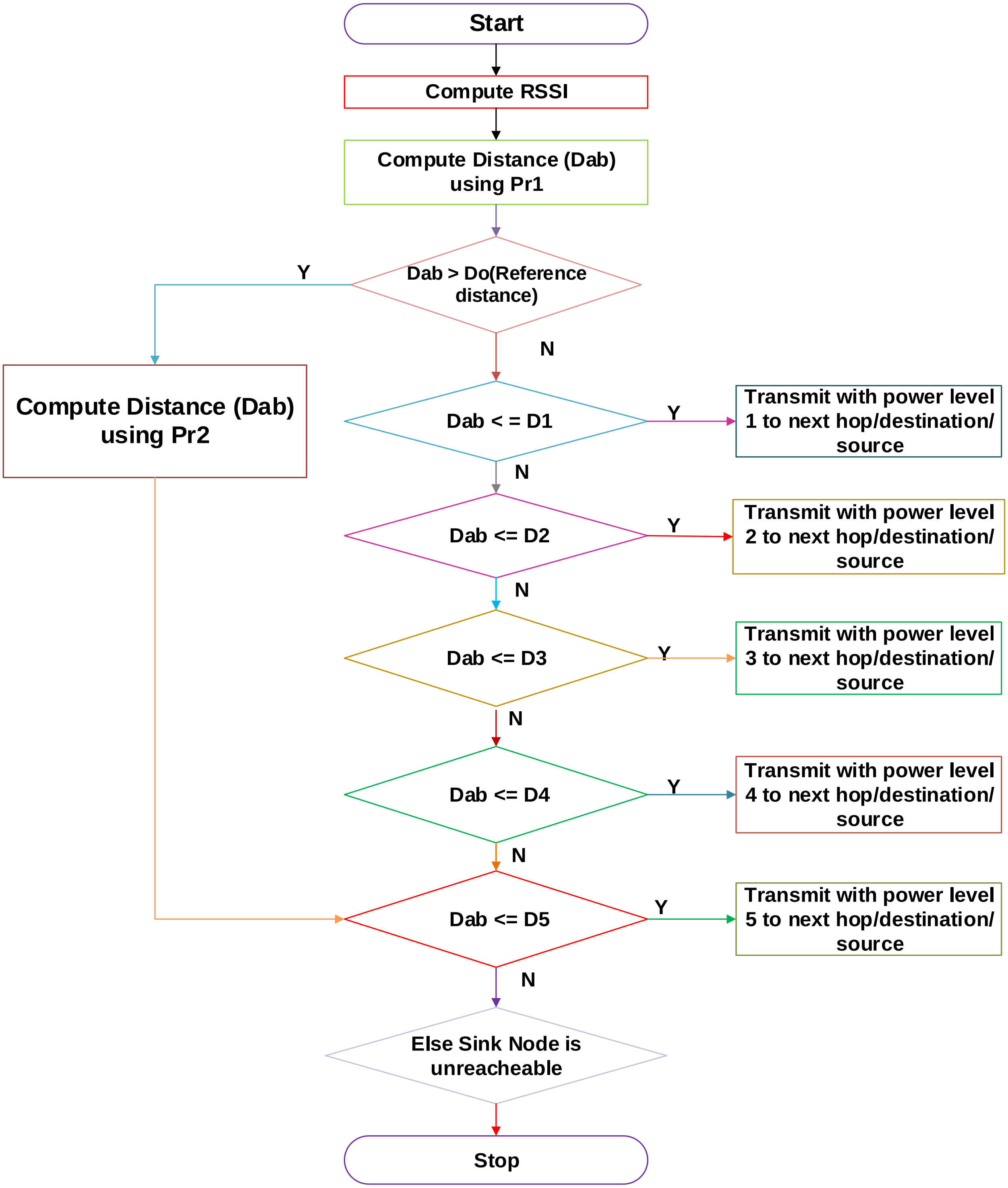


Figure 3.4. Flowchart of the proposed scheme for TPC

3.6 The Energy Model

Each node in Wireless Ad-hoc network comprises a radio communication section that has transmission and reception sub-sections. This could be further divided into the transmitter electronics, receiver electronics, transmitting power amplifier, and antenna (for transmitting and receiving). In this research, the radio model similar to that used in [47] and [48] was adopted as illustrated in Figure 3.5 below to illustrate the energy consumption of each node. The total energy E_T consumed by each node for transmitting m bits data packet over a distance d' consists of energy consumed by the transmitting node E_{tx} and the energy consumed by the receiving node E_{rx} and is given as

$$E_T = E_{tx} + E_{rx} \tag{3.15}$$

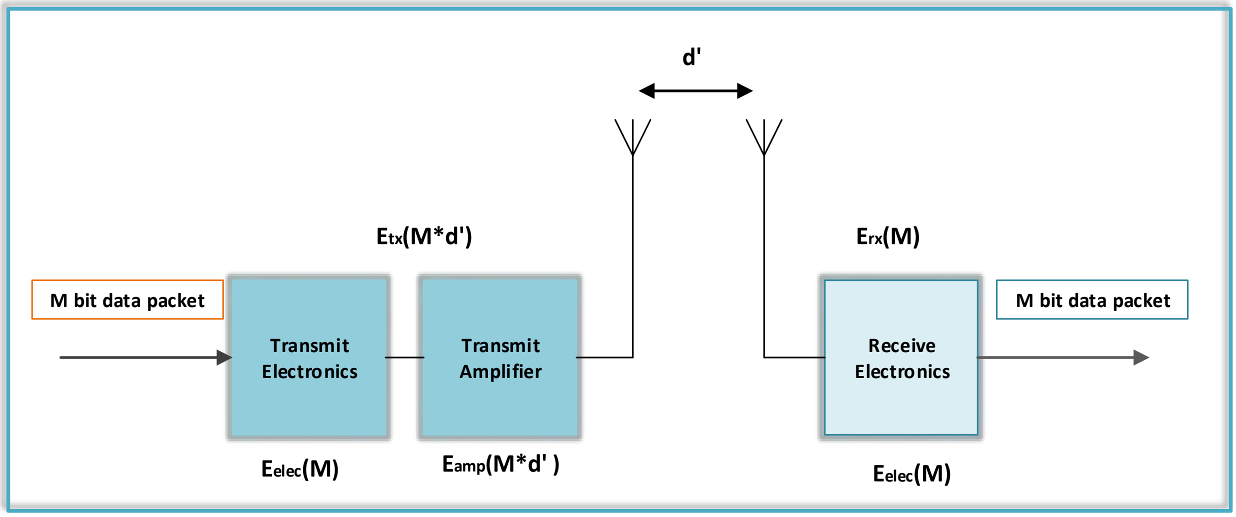


Figure 3.5. Radio Energy Model adapted from [48]

The energy dissipated by a transmitting node is due to the radio frequency (RF) power amplifier, which drives the antenna to radiate signal at a particular transmission power, which is in respect to the distance between two nodes and the electronic components in the node. Therefore, the transmission energy E_{tx} required to transmit an m-bits data packet is the sum of the energy consumed by the electronic components $E_{elec(tx)}$ and energy dissipated by the RF power amplifier $E_{amp(tx)}$ with respect to the distance d' between two nodes that could be the source and destination or source and intermediate node. Thus, the transmission energy needed to transmit m bits data packets with respect to distance is obtained as

$$E_{tx}(m, d') = E_{elec(tx)}(m) + E_{amp(tx)}(m, d') \tag{3.16}$$

Equation (3.16) is re-written in terms of the total transmission power P' required to transmit m data packet over distance d' between any two nodes and the transmission time t'_{tx} and given as

$$E_{tx} = \left(P'_{elec(tx)} + P'_{amp(tx)}\right)t'_{tx} \tag{3.17}$$

The transmission time t'_{tx} required to transmit the m data packets is

$$t'_{tx} = \frac{m}{R'_b} \tag{3.18}$$

where m is the number of data packet and R'_b is the nominal bit rate.

The energy consumed in receiving the m data packets over distance d' between two nodes is the energy dissipated by the receiver's node. Therefore, the energy consumed at the receiver E_{rx} is obtained as

$$E_{rx}(m) = E_{elec(rx)}(m) \tag{3.19}$$

The $E_{amp(tx)}(m, d')$ in equation (3.16) changes with respect to the distance between the transmitting node and the receiving node. Short distance requires low amplification of signal and vice versa. This can be expressed in terms of friis free space and Two-ray ground propagation models. These two propagation models depend solely on the transmitting node amplification mode. Taking the distance into consideration, friis free space propagation model is used when the air interface between the transmitter and receiver has a clear and unobstructed direct line of sight (LOS)[53][54] and the distance d' is less than the reference distance d'_{ref} (Threshold transmission distance), that is $d' < d'_{ref}$. Therefore, propagation loss (power loss) is inversely proportional to the square of the distance d' between transmitter and receiver. If the distance between the transmitter and receiver is greater or equal to the reference distance i.e. $d' \geq d'_{ref}$, two-ray ground propagation model will be considered as it takes care of the reflected signal loss and the propagation loss is inversely proportional to $d'^{(4)}$ between the transmitter and receiver. The amplifier energy consumption is given as

$$E_{amp(tx)}(m,d') = \begin{cases} \gamma'_{fs} d'^{(2)} & : d' < d'_{ref} \\ \gamma'_{trg.} d'^{(4)} & : d' \geq d'_{ref} \end{cases} \tag{3.20}$$

where γ'_{fs} is the friis free space propagation model and γ'_{trg} is the Two-ray propagation model. Equation (3.16) can be re-written as follows:

$$E_{tx}(m,d') = \begin{cases} E_{elec(tx)}(m) + \gamma'_{fs} d'^{(2)} & : d' < d'_{ref} \\ E_{elec(tx)}(m) + \gamma'_{trg.} d'^{(4)} & : d' \geq d'_{ref} \end{cases} \tag{3.21}$$

By equating $d' \equiv d'_{ref}$ in the equation (3.21)

$$\gamma'_{trg.} d'^{(4)} = \gamma'_{fs} d'^{(2)} \tag{3.22}$$

Therefore,

$$d'_{ref} = \sqrt{\frac{\gamma'_{fs}}{\gamma'_{trg.}}} \tag{3.23}$$

The transmitting power can be expressed in terms of the product of amplifier energy and the radio bit rate as

$$P'_{tx} = E_{amp(tx)}(m,d') R'_b \tag{3.24}$$

where R'_b is given in (3.18). Therefore, equation (3.20) can be substituted into equation (3.24) to give

$$P'_{tx} = \begin{cases} \gamma'_{fs} d'^{(2)} R'_b & : d' < d'_{ref} \\ \gamma'_{trg} d'^{(4)} R'_b & : d' \geq d'_{ref} \end{cases} \tag{3.25}$$

Using the radio propagation models discussed formerly, the receiving power is given as

$$P'_{rx} = \begin{cases} \frac{\gamma'_{fs} R'_b G_t G_r \lambda^2}{4\pi^2} & : d' < d'_{ref} \\ \gamma'_{trg} R'_b G_t G_r h_t^2 h_r^2 & : d' \geq d'_{ref} \end{cases} \tag{3.26}$$

If the receiver sensitivity is known, then γ'_{fs} and γ'_{trg} can be calculated from equations (3.26) to yield

$$\gamma'_{fs} = \frac{P'_{rx\_resv}(4\pi)^2}{R'_b G_t G_r \lambda^2} \tag{3.27}$$

$$\gamma'_{trg} = \frac{P'_{rx\_resv}}{R'_b G_t G_r h_t^2 h_r^2} \tag{3.28}$$

The transmitting power with respect to the receiving power and the propagation models can be expressed by considering the distance between the source and the destination

$$P'_{rx} = \begin{cases} \frac{P'_{rx\_resv}(4\pi)^2 d'^{(2)}}{G_t G_r \lambda^2} & : d' < d'_{ref} \\ \frac{P'_{rx\_resv} d'^{(4)}}{G_t G_r h_t^2 h_r^2} & : d' \geq d'_{ref} \end{cases} \tag{3.29}$$

Equation (3.29) can be re-written as follows:

$$P'_{tx} = \begin{cases} \beta_1 P'_{rx\_resv} d'^{(2)} & : d' < d'_{ref} \\ \beta_2 P'_{rx\_resv} d'^{(4)} & : d' \geq d'_{ref} \end{cases} \tag{3.30}$$

where

$$\beta_1 = \frac{(4\pi)^2}{G_r G_t \lambda^2} \tag{3.30.1}$$

$$\beta_2 = \frac{1}{G_t G_r h_t^2 h_r^2} \tag{3.30.2}$$

3.7 Chapter Summary

This chapter described an energy efficient algorithm called VariableTransmission Power Control (VTPC) for reducing the consumption of energy in data transmission. The proposed algorithm can be implemented on the physical layer of the OSI model. This chapter analysed the power control (using graph theory) and the radio model energy. The TPC algorithm will reduce the energy consumption by using the optimal transmission power level needed to establish a connection for data transmission.

The proposed TPC algorithm discussed in this chapter will be implemented using OMNeT++ simulator tool that will be described in the next chapter.

Chapter 4

4 Experimental Approach

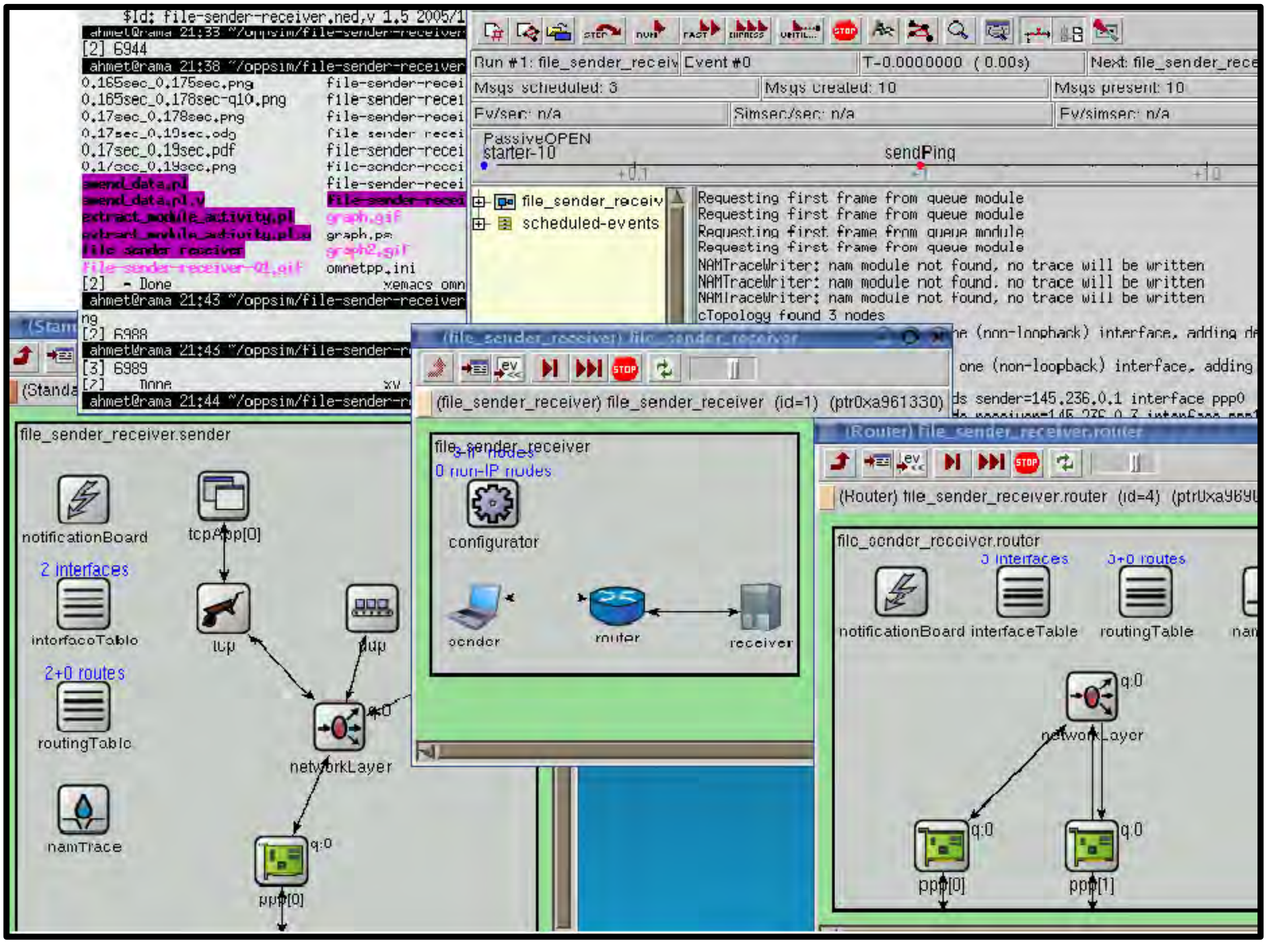
4.1 Introduction

The Network Simulator tool used in the investigation of transmission power control in this research will be discussed in this chapter. The features of the Network simulator, the advantages of using the tools, and the limitations of the network simulator tool, will be discussed. The postulation, network design, performance metrics and simulation parameters are also discussed in this chapter.

4.2 The Network Simulator

To investigate the impact of transmission power control on wireless nodes, Objective Modular Network Test Bed (OMNeT++) in C++ was utilised. The OMNeT++ is a general purpose, public-source, discrete event simulator (DES) tool that is written in C++. The OMNeT++ has an extensive Graphical User Interface (GUI) that displays network topologies with a colourful animation. Figure 4.1 shows the screenshot of the GUI of OMNeT++ environment. The OMNeT++ can run on Mac OS, windows and Linux operating system. The OMNeT++ could be used for both academic and educational purposes. The OMNeT++ can be used to simulate communication networks (such as queuing networks, hardware architecture, wireless and mobile networks)[49][50][51][52].

The OMNeT++ has some unique features that distinguished it from other open source Network Simulation tools. The features, advantages and limitation of OMNeT++ will be discussed in the following sections.



```
$Id: file-sender-receiver.ned,v 1.5 2005/1
ahmet@rama 21:33 ~/oppsim/file-sender-receiver
[2] 6944
ahmet@rama 21:38 ~/oppsim/file-sender-receiver
0.165sec_0.175sec.png          file-sender-recei
0.165sec_0.178sec-q10.png      file-sender-recei
0.17sec_0.178sec.png           file-sender-recei
0.17sec_0.19sec.odg            file-sender-recei
0.17sec_0.19sec.pdf            file-sender-recei
0.17sec_0.19sec.png            file-sender-recei
amend_data.pl                  file-sender-recei
amend_data.pl.v                file-sender-recei
extract_module_activity.pl     graph.gif
extract_module_activity.pl.v   graph.ps
file-sender-receiver           graph2.gif
file-sender-receiver-01.gif    omnetpp.ini
[2]  - Done                             xemacs omn
ahmet@rama 21:43 ~/oppsim/file-sender-receiver
ng
[2] 6988
ahmet@rama 21:43 ~/oppsim/file-sender-r
[3] 6989
[2]    Done                             xv
ahmet@rama 21:44 ~/oppsim/file-sender-r
```

```
Run #1: file_sender_receiv   Event #0   T=0.0000000  ( 0.00s)   Next: file_sender_rece
Msgs scheduled: 3            Msgs created: 10                   Msgs present: 10
Ev/sec: n/a                  Simsec/sec: n/a                    Ev/simsec: n/a
```

```
Requesting first frame from queue module
Requesting first frame from queue module
Requesting first frame from queue module
Requesting first frame from queue module
NAMTraceWriter: nam module not found, no trace will be written
NAMTraceWriter: nam module not found, no trace will be written
NAMTraceWriter: nam module not found, no trace will be written
cTopology found 3 nodes
ne (non-loopback) interface, adding de
one (non-loopback) interface, adding
ds sender=145.236.0.1 interface ppp0
```

(file_sender_receiver) file_sender_receiver (id=1) (ptr0xa961330)

(Router) file_sender_receiver.router (id=4) (ptr0xa969

Figure 4.1. OMNeT++ graphic user interface (GUI) [53]

4.2.1 Features of OMNeT++

The OMNeT++ is developed to accommodate component-based module, hierarchical and extensible architectures. The module can be categorised into simple, compound modules which are durable and reusable, and as illustrated in Figure 4.2, the simple modules assemble into compound modules. The entire model is known as the Network module. The Network module consist of both simple and compound modules. The data packets are sent through the input and output interfaces called the gates. The large module is organised using a high-level language called Network Description (NED)[49][52][54]. The NED includes the modules (simple / compound modules with the connectivity).

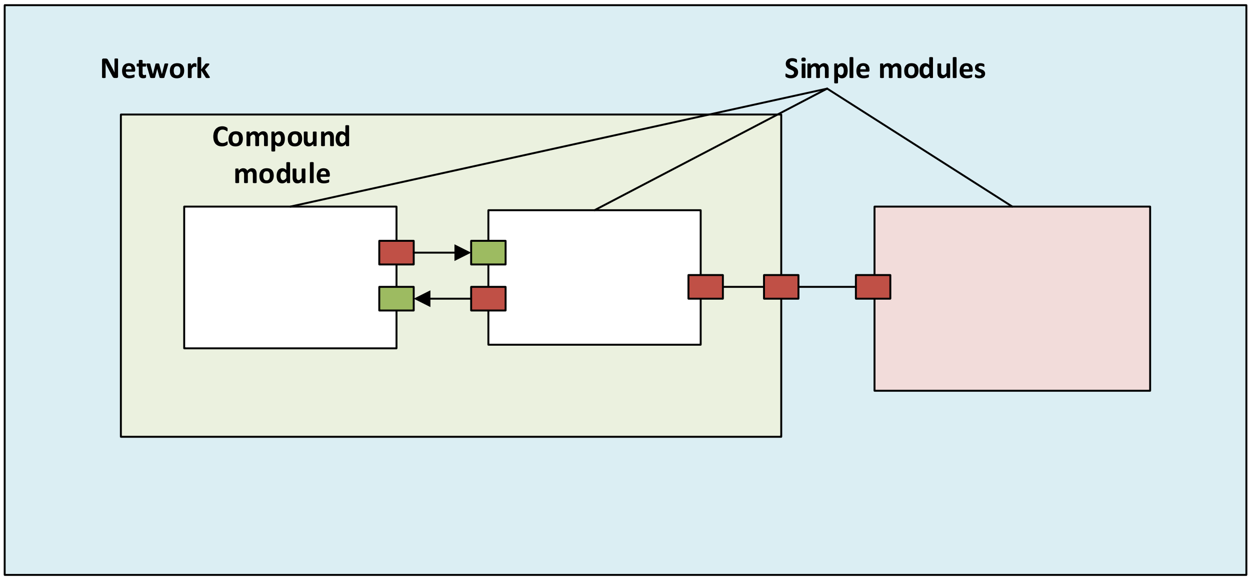


Figure 4.2. The simple andcompound modules of OMNeT++ [49][54]**.**

Other components include internal architecture of OMNeT++ (as shown in Figure 4.3), which are the Simulation kernel Library, NED topology compiler (Nedc), graphical user interface for simulation (Tkenv), graphical network editor for NED files (GNED), command line user interface for simulation execution (Cmdev), graphical output scalar visualisation tool (Scalar), graphical output vector plotting tool (Plove), utilities (such as random number generation (RNG) and make-file creator tool), documentation, etc. The simulation kernel and utilities are responsible for generating the components for simulations. The GNED supports creating a graphical representation of the Network scenario. Tkenv is used to trace, debug and begin/end simulation[3][4] [49][50][52] [54].

The OMNeT++ supports other frameworks such as INET, INETMANET, MIXIM, etc. which can be used to model both wired and wireless (which includes Ad-hoc, mobility, routing protocols, etc.) networks. The OMNeT++ is designed as a platform for other simulations whereby users can create his or her own simulation platform[49][54].

4.2.2 Advantages of Using OMNeT++

The OMNeT++ has a cogent GUI which makes the tracing and debugging more accessible than similar network simulation tools. The hardware devices and the physical appearance were modelled in an exceptional manner[52]. These make OMNeT++ stand out among the likes of Network Simulator (NS-2), Network Simulator (NS-3), etc.

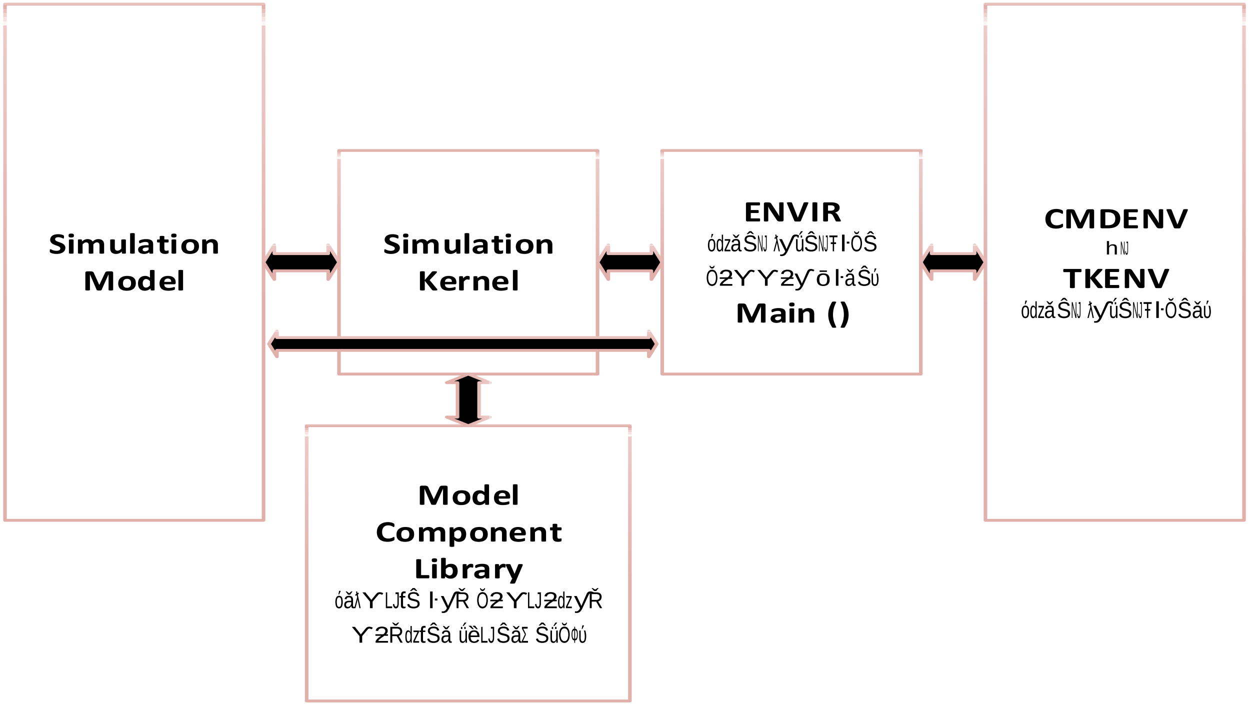


Figure 4.3. Architecture of OMNET++ [50][54]

4.2.3 Limitations of OMNeT++

It has inadequate documentation and scanty analytical measures of the communication networks performance evaluation. It has only few protocols developed for full implementation, while some protocols are still in the process of development, reducing the variety of protocols. This will in turn make the users to work on the background if they would like to try their own designed protocol in various platforms. There is a partial development of the mobility extension[52].

4.3 Comparison of OMNeT++ with other Simulators

Like OMNeT++, NS-2 and NS-3, GloMoSim and NCTUns are open source network simulators. Table 4.1[52] below describes each network simulator with the similarities and differences with OMNeT++.

Table 4.1 Comparison of OMNeT++ with other network simulators

Main streams	**Network Simulators**			
	NS-2	**OMNET++**	**NCTUns**	**GloMoSim**
License	**Open Source**	**Open Source**	**Open Source**	**Open Source**
GUI	**No**	**Yes**	**Yes**	**Limited**
Interface	**C++, OTcl**	**C++, NED**	**C**	**C**
Available Modules	**Wired, Wireless, Ad-hoc and Wireless Sensor Networks**	**Wired, Wireless, Ad-hoc and Wireless Sensor Networks**	**Wired, Wireless, Ad-hoc and Wireless Sensor Networks**	**Wired, Wireless, Ad-hoc and Wireless Sensor Networks**
Documentation and user support	**Excellent**	**Medium**	**Good**	**Poor**
Scalability	**Small**	**Large**	**Medium**	**Large**
Extendable	**Yes**	**Yes**	**Yes**	**Yes**
Emulation support	**Limited Support**	**Limited Support**	**Yes**	**No**
Simulation Technique	**Discrete Event Simulation**	**Discrete Event Simulator**	**Discrete Event Simulator**	**Discrete Event Simulator**

4.4 Network Design and Postulations

Some assumptions were made concerning each node in Wireless Ad-hoc network and the network scenario/topology in this research project. Cisco Aironet 802.11a/b/g Wireless CardBus Adapter data sheets parameters were used for each node on the setup of the network. The following were made:

- Network planning and optimisation would have been carried out. Network planning and optimization can be categorised into four essential categories which are Capacity planning, Coverage planning, Parameter planning and Optimisation planning.
- Each node in the network is a static node. The nodes are placed in an optimal position(s). This will negate the issue of interference, shadowing and multipath fading problems in the wireless communication channel.
- The nodes in the network are randomly placed i.e. the distance between a pair of node in the network varies. Therefore, there are various transmission range among the nodes.
- Each node has the ability to route data packets and control the transmission power with respect to the distance between nodes.
- For the performance analysis, the wireless link is a bi-directional link. The energy consumption measurement is based on the transmission of data packet.

The wireless technology considered in this research is WLAN IEEE 802.11 standard. This is because it has proved to be a successful technology in wireless ad-hoc networks. The Network Interface Card (NIC) for each node is IEEE 802.11g standard. The receiver sensitivity threshold will have to be taken into consideration. The receiver's sensitivity threshold is -90dBm, i.e., any signal that is below -90dBm is regarded as noise signal.

4.4.1 The Network Design Parameters, Calculations and Values

- The maximum transmission power setting will vary from 20dBm (100mW) at 1, 2, 5.5 and 11 Mbps (based on Cisco Aironet 802.22 b/g datasheet).
- The battery capacity is set at 2600mAH.
- The maximum voltage is 3.8v
- The maximum transmit power energy in WH is 2600mAH × 3.8v = 9.88WH

- The maximum energy is 9.88WH × 60s = 592.8Ws. This will be the total value of the battery energy at the start of the simulation.
- The transmission power level ranges from 20dBm (100mW) – 13dBm (20mW) with their respective transmission range.

Table 4.2 Transmission power level with respective distance

Power Level (PL)	Transmission power in dBM/mW	Transmission range (m)
PL 1	8 dBm (6.25mW)	27 (90ft)
PL 2	11dBm (12.5mW)	48 (160ft)
PL 3	14dBm (25mW)	54 (180ft)
PL 4	17dBm (50mW)	91 (300ft)
PL 5	20dBm (100mW)	124 (410ft)

The network model was designed in the Network Description (NED) module of the OMNeT++ simulator. The NED module creates the graphical representation of the network scenario. The variable transmission power control algorithm was designed in the physical layer and initiation module of the simulator.

4.5 Performance Evaluation Metrics and Simulation Parameters

The performance of the proposed TPC algorithm is analysed with some given parameters. Therefore, the performance evaluation metrics and the simulation parameters used in this research will be discussed in this following section.

4.5.1 Performance Evaluation Metrics

Quite a number of performance metrics exist in wireless communication networking. However, the performance metrics that will be focused on are those that are needed to analyse the performance of the each node in terms of energy consumption and general network performance. The performance metrics are Throughput, Node lifetime, and Energy consumed per node.

Throughput: As discussed in Chapter 3, the TPC algorithm, which involves varying the transmission power with respect to distance between the nodes, must not affect the total network performance of the system, i.e., the throughput of the system. In order to analyse the throughput of the system, the following routing protocols were considered:

- Best Approach To Mobile Ad-Hoc Network (B.A.T.M.A.N) routing protocol
- Optimized Link State Routing (O.L.S.R) protocol
- Ad-hoc On-Demand Distance Vector (A.O.D.V) routing protocol

Node lifetime: The node lifetime in this thesis is the total amount of time it takes the node to remain active in the network until the remaining energy is less than or equal to the amount of energy required to transmit or receive a data packet.

Energy consumed per node (during transmission and reception): The energy consumed per node depends on what the node executes in the Wireless Ad-Hoc Network, i.e., it could act as a transmitter, receiver, or relay node. This will in turn affect the consumption of energy in the network.

4.5.2 Simulation Parameters

Table 4.3 given below summarises the parameters used in the simulation with their respective values. These parameters include the Network area size, number of nodes involved, receiver sensitivity, radio propagation model, the amplifier energy consumption to send data packets at both long and short distances amongst others.

Table 4.3 Simulation parameters summary

Parameters	Value
Network area size	500m x 500m
Number of wireless nodes	5 wireless routers
Radio propagation model	Friis Free space and Two-ray Ground
frequency	2450MHz
Transmission power level	8, 11, 14, 17, 20dBm
Transmission range	27, 48, 54, 91, 124m
Receiver sensitivity	-90dBm
Simulation time	3300s
Node operating voltage	3.3v
Data rate	1, 2, 5.5, 11Mbps
Antenna direction	Omnidirectional
Wireless Network standard	IEEE 802.11 b/g
Amplifier energy consumption to send information at short distance	$\gamma'_{FS} = 9.64733 \times 10^{-16} J/bit/m^2$
Amplifier energy consumption to send information at long distance	$\gamma'_{TRG} = 9.09 \times 10^{-20} J/bit/m^4$

4.6 Chapter Summary

In this chapter, the Network simulator that was used to investigate the effect of transmission power control in wireless Ad-hoc networks was discussed, together with the reason for selecting the network simulator, advantages, limitations and the comparison with other related network simulators.

The network scenario, the performance evaluation parameters and the simulation parameters were looked into. The network scenario, experimental results and the analysis will be dealt with in the Chapter five.

Chapter 5

5 Experimental Results and Analysis

5.1 Introduction

This chapter presents the results obtained from simulation using the proposed Transmission power control technique in which transmission power is varied with respect to the distance between the transmitter, receiver and the neighbouring nodes. The results obtained were analysed with energy consumed per node and node life time performance metrics. The throughput of the network was analysed using B.A.T.M.A.N, OLSR and AODV routing protocols to show the effect of routing packets from source to the destination using variable transmission power with respect to the distance between the nodes.

5.2 The Network Scenario

The wireless nodes are distributed randomly with variation in distance between as shown in Figure 5.1. The distance ranges between 27m – 124m as given in the simulation parameters in Chapter 4. The transmission range of each node is based on the distance between its neighbours. The optimal transmission power of each wireless node is based on the distance between the transmitter and receiver or transmitter and the intermediate nodes in the network. The network used Multihop Technology, whereby nodes that are out of transmission range send packets to intermediate nodes that are within its transmission range and then, the intermediate nodes forward it to the destination or the node closer to the destination. The source (node 1) sends information to the sink (node 4) through the intermediate nodes 2 and 3. The B.A.T.M.A.N, OLSR, AODV routing protocols were used to route the data packets from the source to the destination. The beacon message is sent to all the nodes involved in the Ad-hoc network as a control signal. The beacon message learnt about the network topology so that the received signal strength will be known in order to determine the appropriate transmission power that will be used to route the packet from source to the sink before the data signal is established.

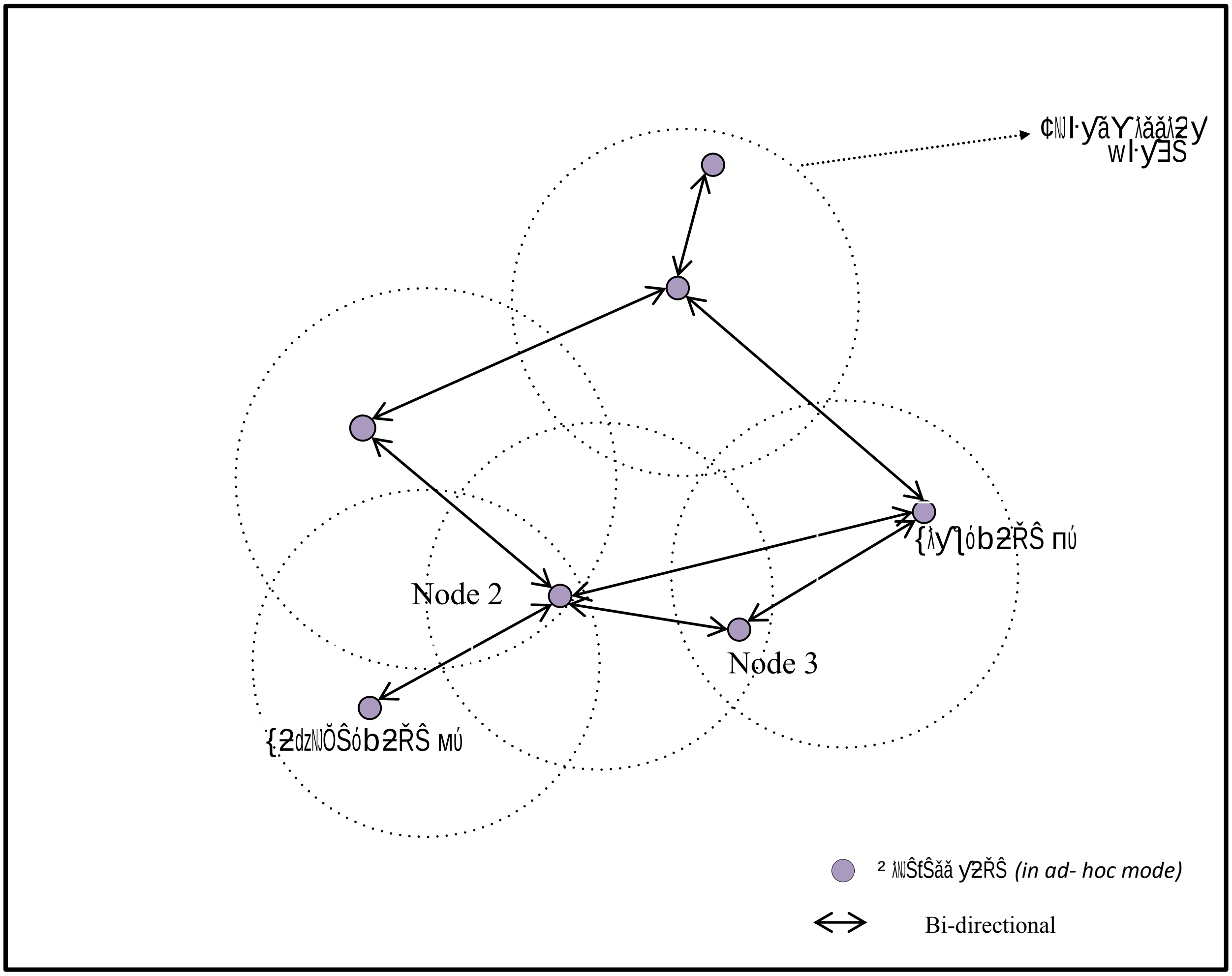


Figure 5.1: Network topology of the experiment

The investigation of the impact of transmission power control in wireless Ad-hoc network was carried out at three different stages, in which each experiment has the same network scenario. The energy analysis, node lifetime and throughput of the network were done separately. In sections 5.3 to 5.6, network simulation experiments are carried out and the results obtained from the simulation are analysed.

5.3 First Simulation Experiment: Comparison Between Constant Transmission Power and Variable Transmission Power

Figure 5.2 shows the energy consumption of five nodes (source, sink, neighouring and intermediate nodes) in the network. The aim of this simulation is to compare the energy consumed using constant transmission power 20dBm (100mW) to those consumed using variable transmission power that ranges between 8dBm to 20dBm.

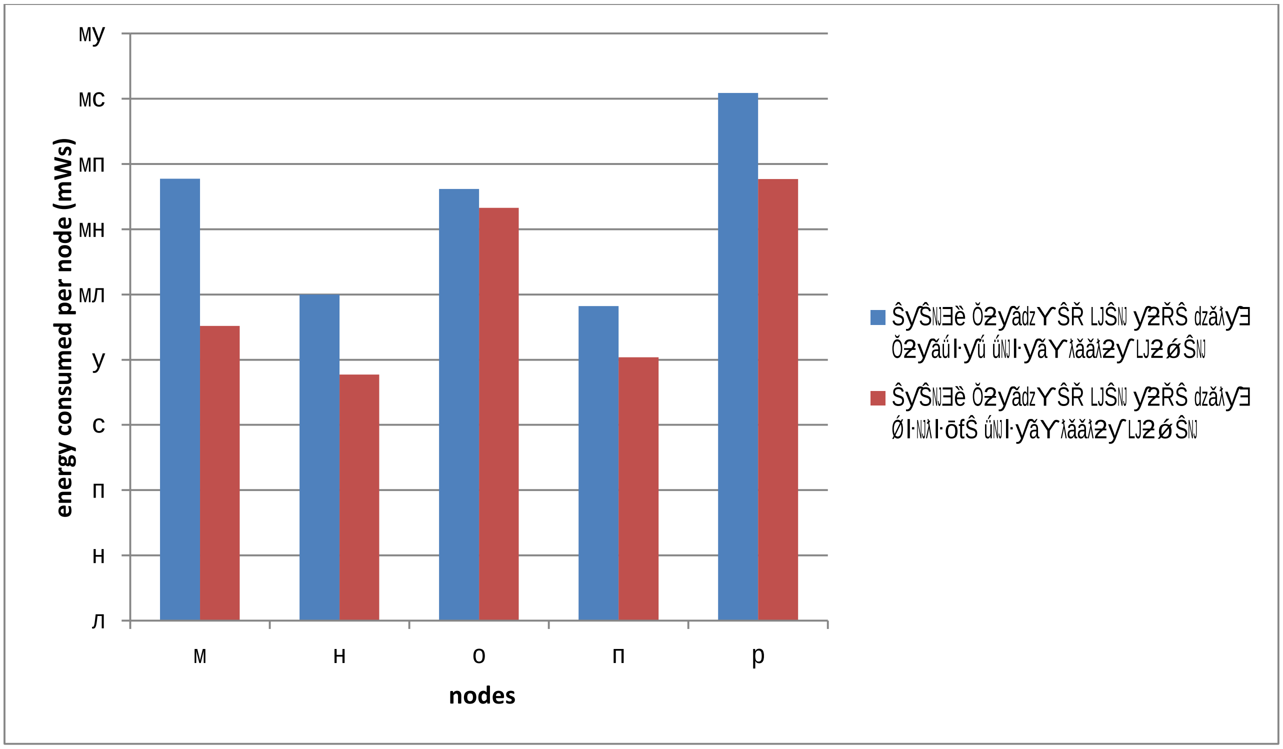


Figure 5.2: Comparison between constant transmission power and variable transmission power

Each node consumed same energy at 3.07098mWs for sending beacon messages within the network. After the each node established the control signal in the network, the packets were transmitted at different transmission power levels with respect to the distance from the source to the destination. In Figure 5.3, the energy consumed by each node at time t = 0.01776s for both constant transmission power and variable transmission power is shown. From this result, the Constant transmission power consumed more energy at time t = 0.0176s than variable transmission power. This shows the level of energy consumption at time t = 0.0176s.

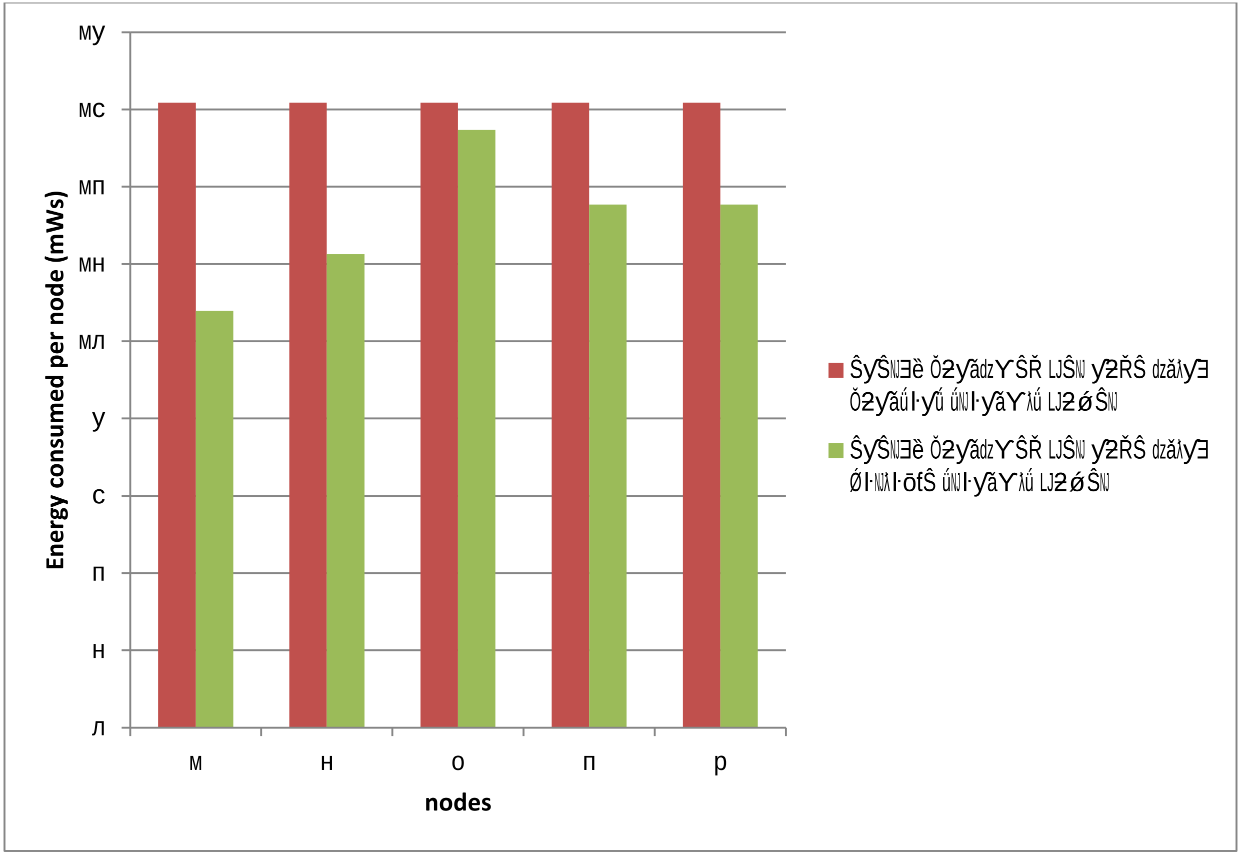


Figure 5.3: Energy consumed per node at time t =0.01776s

5.4 Second Simulation Experiment: Node Lifetime

In Figure 5.4, the total amount of time that is required of a node to remain active (i.e. sending and receiving data packets) in the network is shown. This can be regarded as the lifetime of each node in the network. Using variable transmission power with respect to distance between nodes reduces the energy consumption per node in the network compared to using a constant transmission power. The wireless node tends to stay longer in the network if a variable transmission power control is used as seen in Figure 5.4. The effect of energy consumption in the lifetime of each node is one of the main objectives of this thesis and in Figure 5.4, it is proved that varying the transmission power with respect to distance between nodes will increase the lifetime of an autonomous node in a network. This will in turn affect the network lifetime as well.

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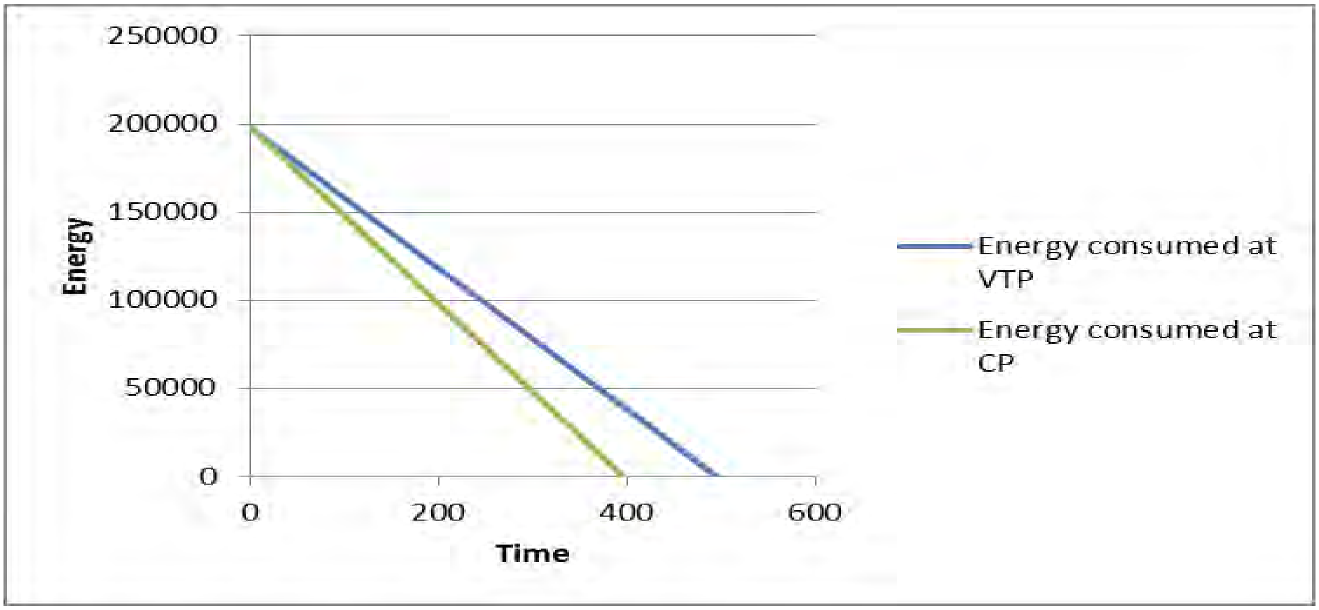

Figure 5.4: Node lifetime

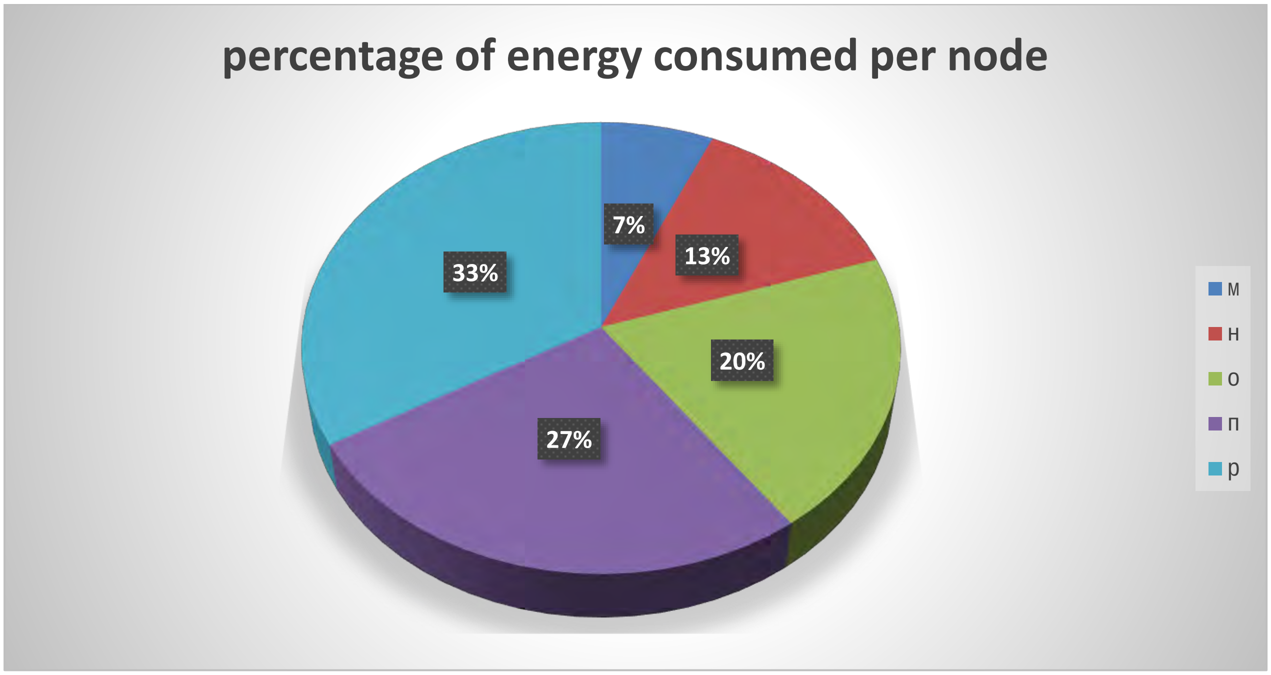

Figure 5.5: Percentage of energy consumed per node

Figure 5.5 shows the percentage of the energy consumed per node using a variable transmission power with respect to the distance between nodes.

5.5 Third Simulation Experiment: Comparison of Throughput analysis using B.A.T.M.A.N, OLSR and AODV routing protocols.

One of the objectives of this research is that the variation in transmission power must not be detrimental to the throughput of the system. In order to achieve that, B.A.T.M.A.N, OLSR and AODV routing protocols were used to analyse the throughput of the system. These routing protocols were compared with each other using variable transmission power control. The throughput is the sum of the data rates that are transmitted and received successfully per second. The throughput was analysed using User Datagram Protocol (UDP) apps.

5.5.1 Simulation Result for B.A.T.M.A.N. routing protocols

Figure 5.6 shows the throughput result obtained from node 1 (source node) using B.A.T.M.A.N routing protocol.

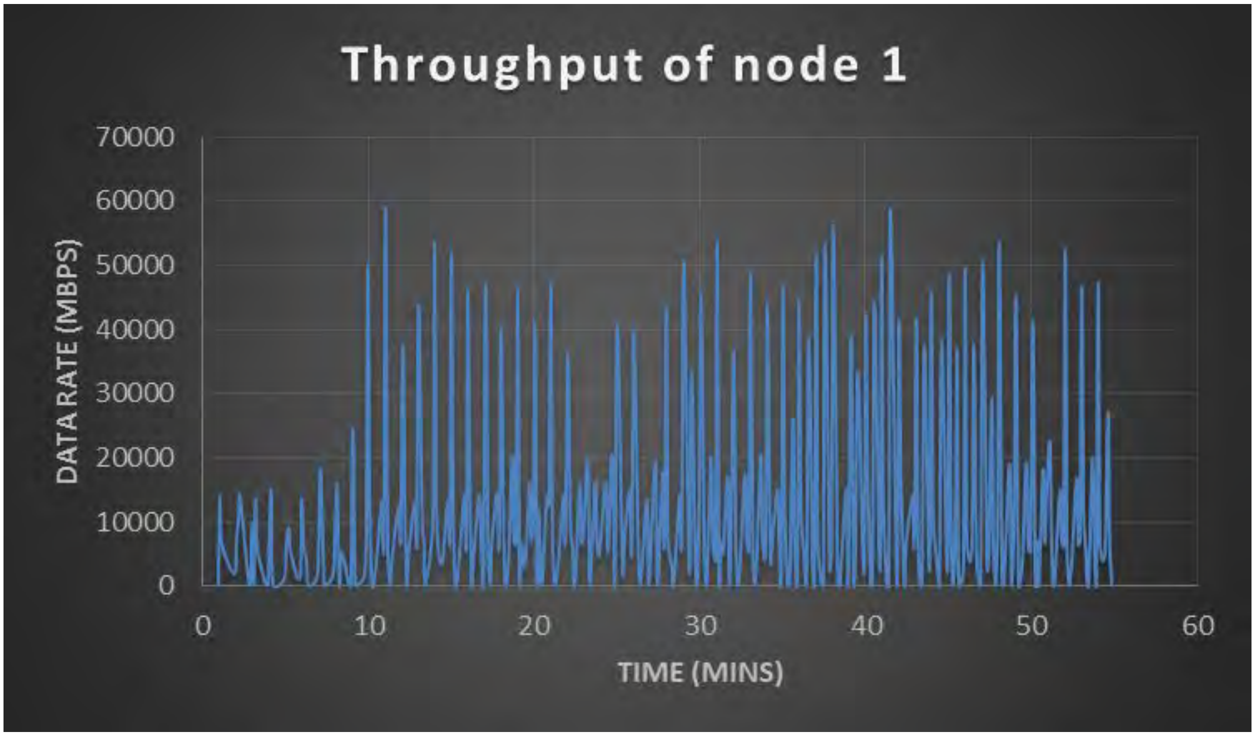

Figure 5.6: Throughput of node 1 (Transmitting node) using B.A.T.M.A.N routing protocol

Figure 5.7 shows the throughput result obtained from node 4 (Sink node) using B.A.T.M.A.N routing protocol.

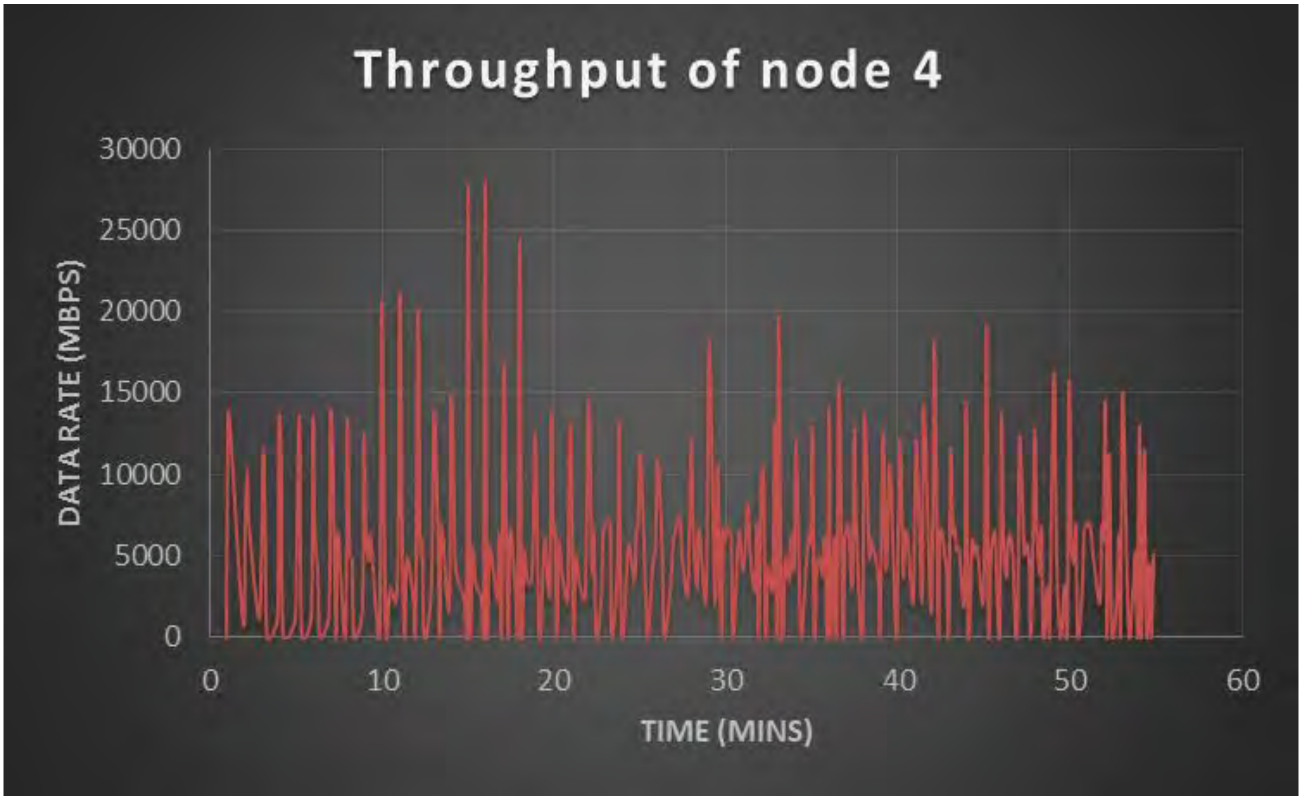

Figure 5.7: Throughput of node 4 (Receiving node) using B.A.T.M.A.N Routing Protocol

For packet flowing from the source node (node 1) to the destination node (node 4) as depicted in Figure 5.1, the source node sends a message called Originator Message (OGM) to the next hop node. This OGM contains the sequence number, the type of data to be sent and destination node information. Since the OGM contains the information regarding the destination node and the data packets, no delay is experienced during the transfer of the packets as shown in the Figure 5.6 from the source to the destination nodes. Variation in the throughput signifies the continuous flow of the successive packets from the source node to the destination node. In addition, as shown in Figure 5.7, node 4 received data after 60 seconds into the simulation. However, the continuous variation in the throughput of node 4 signifies the successive packets received from node 1. The B.A.T.M.A.N routing protocol experiences gradual decrease in the throughput from node 1 to node

4 due to the number of hops and the number of nodes in the network. It only relays control messages if requested. The average throughput value for the data transmission is 20000bps.

5.5.2 Simulation result for OLSR

Figure 5.8 shows the throughput result obtained from node 1(source node) using OLSR routing protocol.

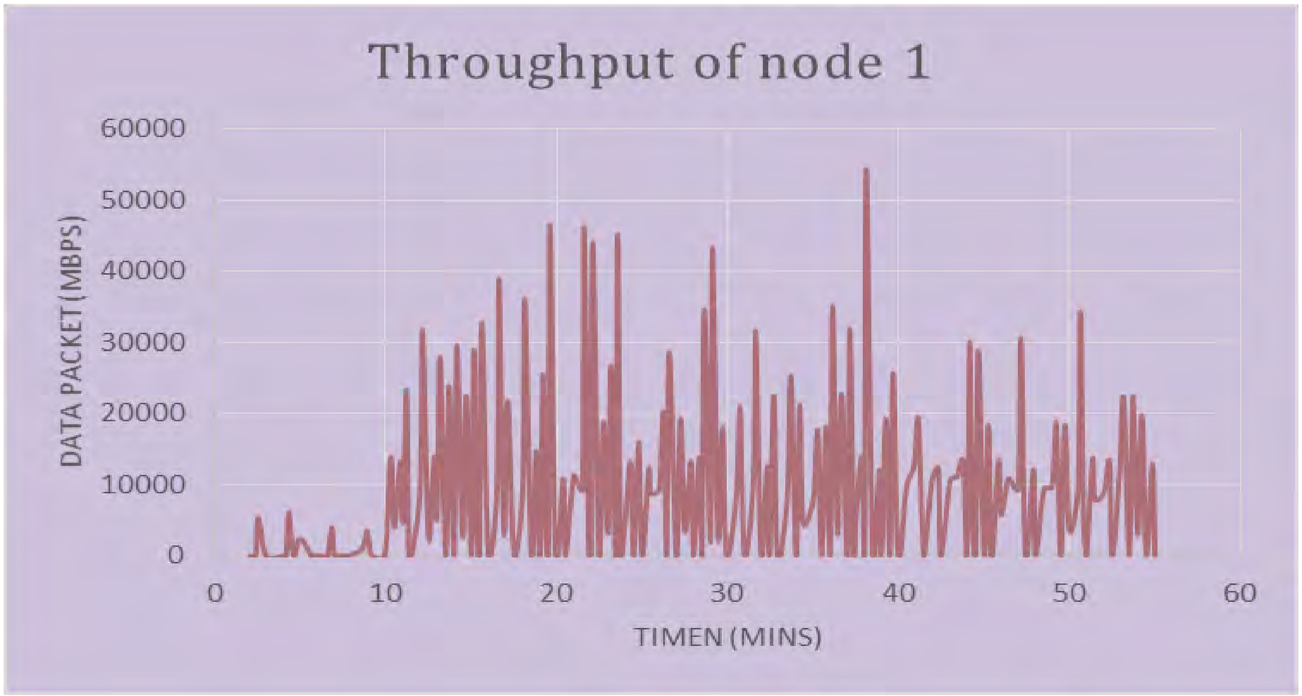

Figure 5.8: Throughput of node 1 (Transmitting node) using OLSR Protocol

A two minutes delay was experienced while the optimal route was established in the network topology as shown in the Figures 5.8 and 5.9 owing to creation of optimal path that was needed to be established before sending the data packets to the destination node. At 10mins, the throughput of the nodes in the network improved resulting in the successful delivery of packets in the network because of the optimal path that has been established. The average throughput value of the data transmission using OLSR protocol is 10000bps. This accounts for the optimal path established before data transmission compared to B.A.T.M.A.N routing protocol, which does not require establishment of optimal route.

Figure 5.9 shows the throughput result obtained from node 4 (sink node) using OLSR routing protocol.

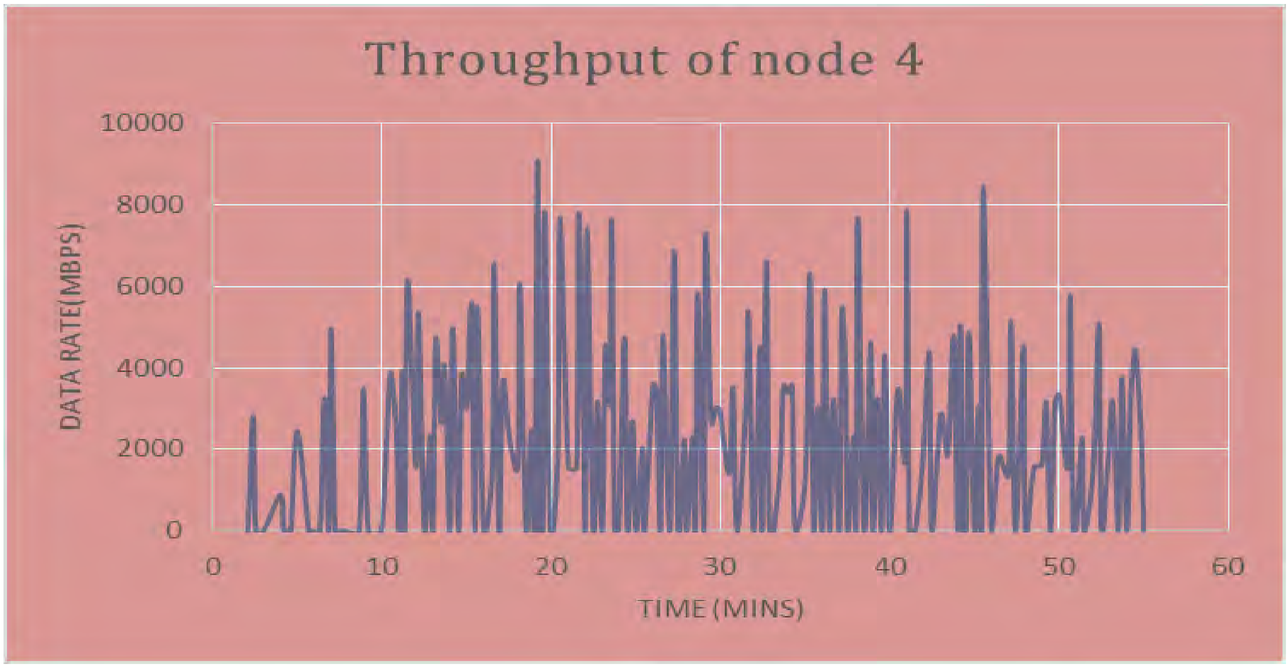

Figure 5.9: Throughput of node 4 (Receiving node) using OLSR protocol

A delay was experienced at the receiving node as well due to the initial establishment of optimal path. The nodes also experience gradual decrease in throughput due to number of hops. However, the throughput of the nodes was lower than B.A.T.M.A.N routing protocol.

5.5.3 Simulation result for AODV

Figure 5.10 shows the throughput result obtained from node 1 (source node) using AODV routing protocol.

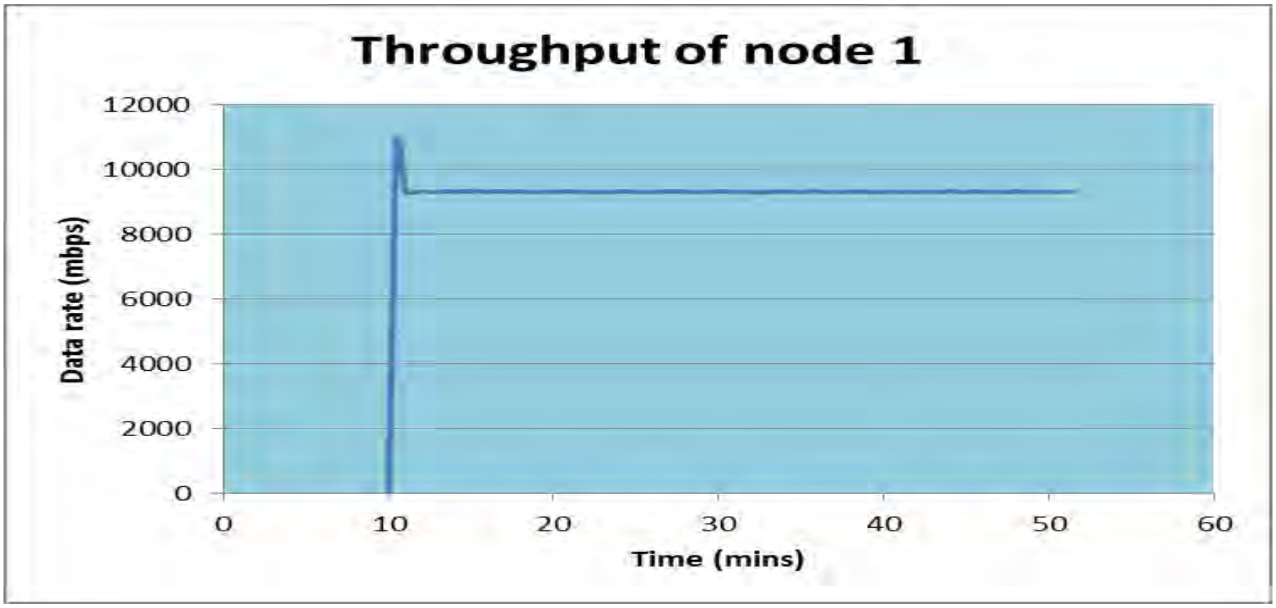

Figure 5.10: Throughput of node 1 (Transmitting node) using AODV Routing Protocol

Figure 5.11 shows the throughput result obtained of node 4 using AODV routing protocol.

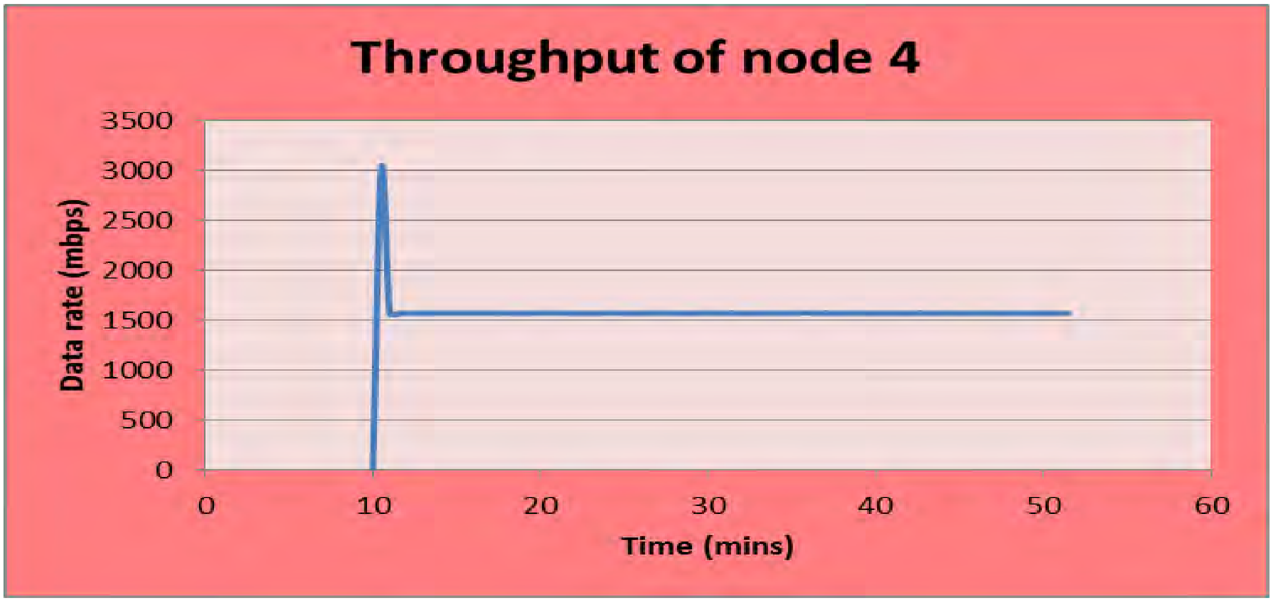

Figure 5.11: Throughput of node 4 (Receiving node) using AODV routing protocol

In AODV, each node sends a Route Request (RREQ) message (flooded messages) to all the nodes in the network. When a path to the destination is found, a Route Reply (RREPLY) message will be sent back to the source before establishing a data communication link between the source and the sink. This makes AODV to experience delay in throughput graph between 0-10mins, i.e., there was no data transmission for 10 minutes. This results in a poor performance of AODV and it has an average throughput of 5000bps.

Owing to the above discussion made on the B.A.T.M.A.N, OLSR and AODV routing protocols, it is observed that the reason behind the better performance of B.A.T.M.A.N routing protocol compared to OLSR and AODV routing protocol is that, B.A.T.M.A.N protocol chooses the best route between nodes in the network topology. It encloses and forwards the data/network traffic until it gets to the sink. Each node in the network only discovers and sustain the information of the optimal route to other nodes in the network through the best next hop. Using Variable Transmission Power Control with B.A.T.M.A.N. routing protocol, the battery power will be highly optimised because retransmission of data packets and control messages would have been minimised, which will reduce unnecessary consumption of energy at each node and increase the node lifetime and network lifetime. Therefore, the B.A.T.M.A.N routing protocol experiences a better network performance in its throughput as compared to OLSR and AODV routing protocols.

5.6 Comparison of End-To-End Packet Delay analysis using B.A.T.M.A.N, OLSR, AODV routing protocols.

In Figs 5.12 - 5.14, the end-to-end packet delay in the B.A.T.M.A.N, OLSR and AODV routing protocols is shown. End-to-End delay is the time taken for a packet to be transmitted across a network from source to destination. The end-to-end delay between the nodes in B.A.T.M.A.N, OLSR and AODV routing protocols is almost the same with the Transmission Power Control technique. They follow similar trend in the nature of the delay i.e. a linear graph.

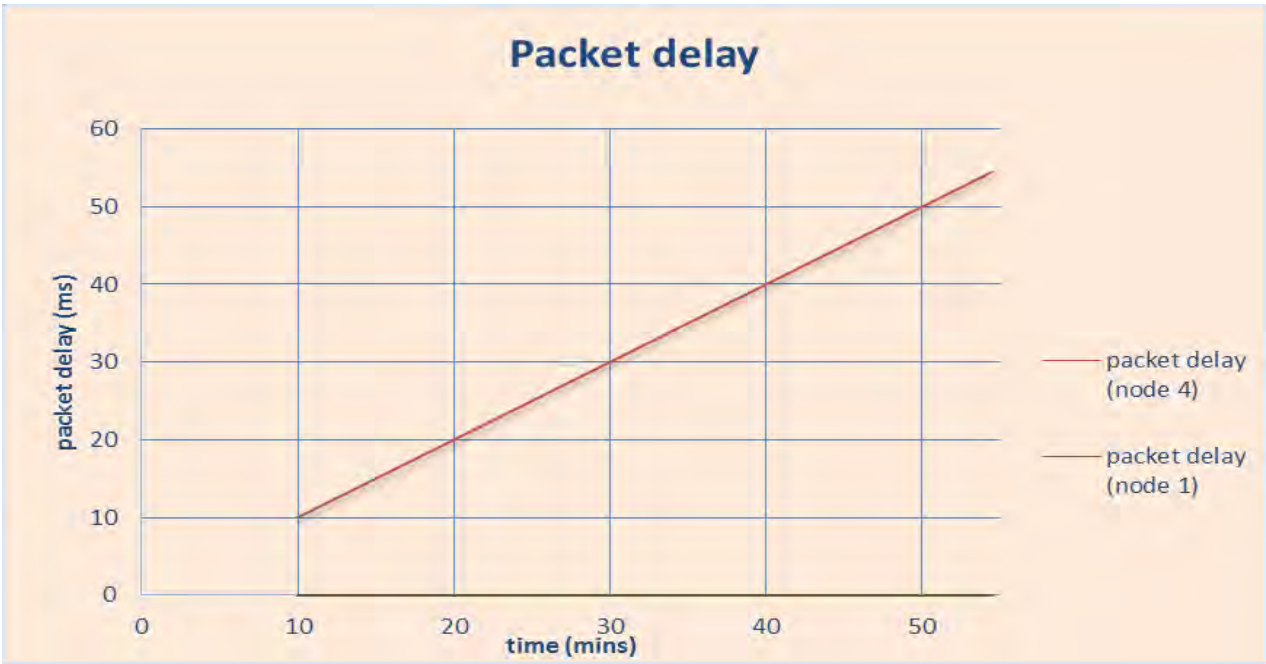

Figure 5.12: End-to end packet Delay of node 1 and node 4 using B.A.T.M.A.N Routing Protocol

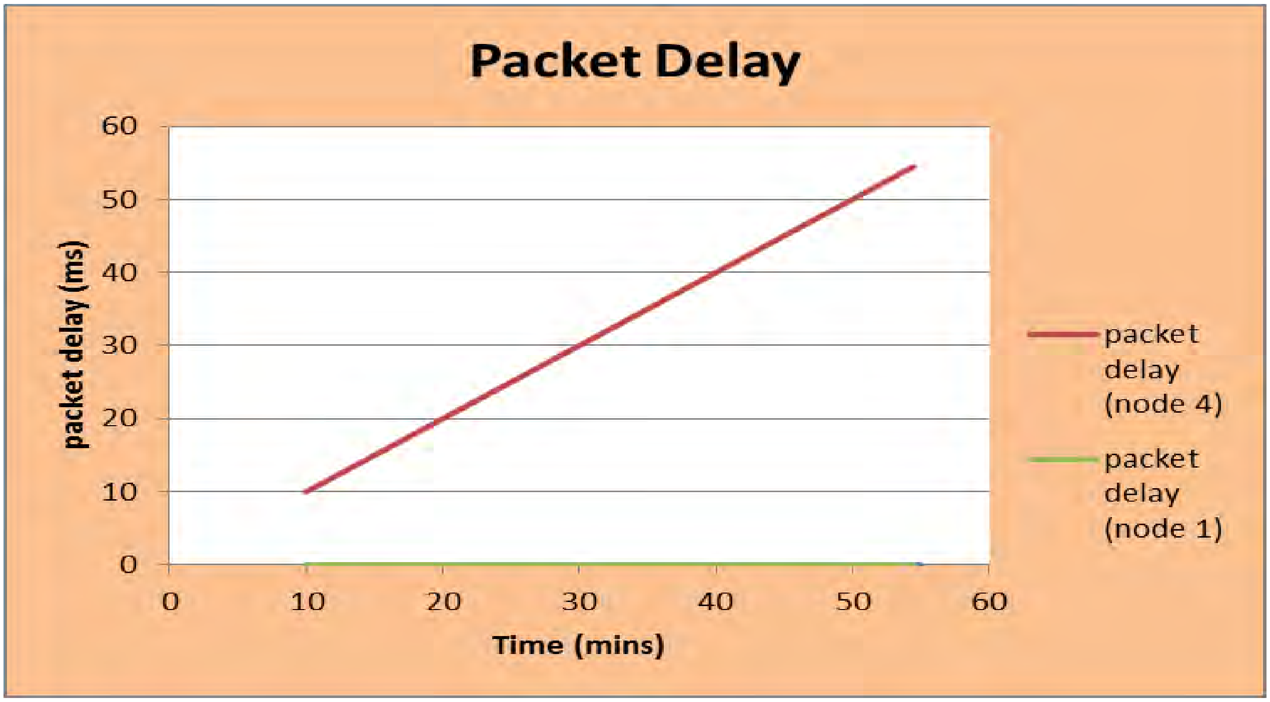

Figure 5.13: End-to end packet Delay of node 1 and node 4 using OLSR Protocol

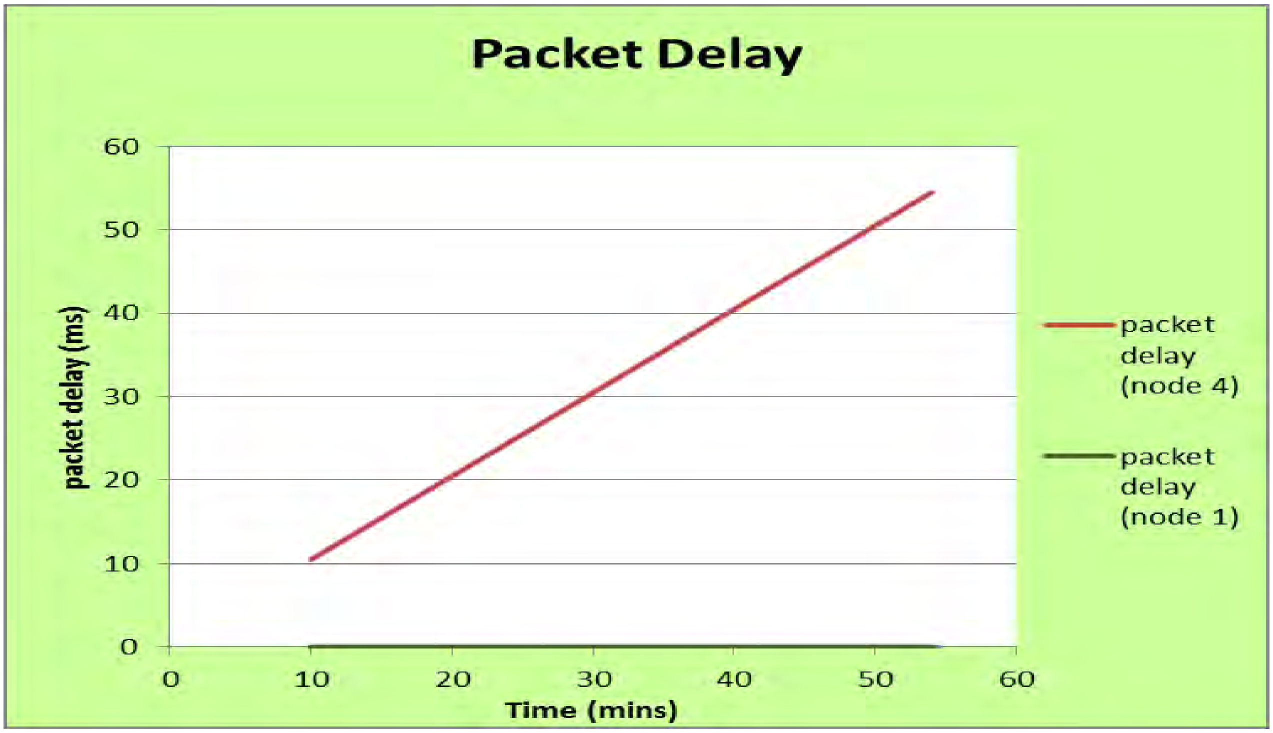

Figure 5.14: End-to end packet Delay of node 1 and node 4 using AODV Routing Protocol

5.7 Conclusion

The simulation results accomplished in this research experiment show that the transmission power control technique can reduce the energy consumption of each node involved in the wireless Ad-hoc network topology. Transmission power should be based on the distance between a pair of nodes and the node should be optimally placed in a location that will negate the effect of fading, multipath, etc., to bring out a better network performance of the system. Reduction in energy consumption will increase the node and network lifetime of the system. The proposed TPC algorithm reduces the consumption of the energy in each node and network up to 25% compared to constant transmission power. The throughput of the system was not affected which is part of our objectives.

Chapter 6

6 Conclusion, Contribution and Recommendations

6.1 Conclusion

The control of energy consumption at each node in Wireless Ad-hoc Network is inevitable considering the node lifetime and the network lifetime. The independent nature of the node in Wireless Ad-hoc Network made energy consumption to be one of the major factors to be considered. The variable transmission power method is the approach considered in order to reduce energy consumption per node. This thesis proposed an algorithm for controlling the transmission power based on the distance between the nodes involved in the Wireless Ad-hoc Network. The proposed Transmission Power Control algorithm was implemented at the physical layer of the node. The Variable Transmission Power Control algorithm chose the optimal transmission power level required to send data packets between a pair of nodes with respect to the distance between the nodes. The optimal transmission power must be able to provide a reliable network connection between the nodes without affecting the throughput of the network. Using OMNeT++ to implement the algorithm, the proposed Transmission Power Control was evaluated with different routing protocols such as OLSR, AODV and B.A.T.M.A.N. From the result obtained in the simulation, it shows that the variable transmission power control consumed less energy compared to using a constant or fixed transmission power based on the distance between nodes. The received signal strength was used to determine the level of transmission power that was required to transmit a packet of information from the source to the intermediate node and to the destination. As expected the constant transmission power consumed more energy than variable transmission power. This is because changing the transmission power level between nodes with respect to the distance results in slow and gradual decline in the transmission energy consumption compared to constant transmission power. The routing protocols were used to analyse the throughput of the network performance. The different results show that varying the transmission power with respect to distance between the nodes reduces the consumption of energy, increases the node lifetime in each node and also increases the network lifetime. The obtained results were discussed and conclusions were reached based on the result obtained in the simulation in the Chapter 5.

6.2 Research Contribution

The simulation results explained in the Chapter 5 signified that the Transmission Power Control algorithm designed in this dissertation contributes to the body of knowledge in Wireless Ad-hoc Network.

This dissertation has reported a well-structured algorithm for varying transmission power with respect to distance in Wireless Ad-hoc Networks. The Variable Transmission Power Control minimised the energy consumption rate by varying the transmission power with respect to the distance between nodes. The node lifetime was increased as well as the network lifetime. This was achieved through the proposed Variable Transmission Power Control algorithm. The fixed transmission power consumed more battery energy of the each node. This will reduce both the node lifetime and network lifetime. The proposed algorithm did not affect the throughput of the system.

Therefore, it can be deduced that the proposed Transmission Power Control Algorithm in Wireless Ad-hoc Network is energy efficient.

6.3 Recommendations

The proposed algorithm for transmission power control in this dissertation is demonstrably a good solution to energy efficiency in Wireless Ad-hoc Networks. However, a more efficient and robust Transmission Power Control can be designed using a cross-layer technique. The cross-layer technique design involves joint activities and cooperation among the physical layer, medium access control layer and the network layer. Future work could be carried out by using this technique to create interaction among the OSI layers mentioned earlier to bring about better performance of the Ad-hoc network in the aspect of energy consumption and network lifetime.

In addition, an accelerated method of dynamic mobility of nodes should be considered in the Transmission Power Control for mobile nodes in Ad-hoc Network. This will accommodate mobile nodes involved in Ad-hoc Network, which will help to characterise the position and location of the mobile users. Mobility pattern that should be considered for the performance analysis are Gauss-Markov mobility model, Manhattan mobility model, etc. More prototype-based

Transmission Power Control technique should be developed so that it can be deployed in real-time network scenario in the industry.

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$$deg(n)_{min} = min\{deg(n)|n \in N\}. \qquad óнΦnú$$

CORRECTION:

$$deg(n)_{min} = min\{deg(n)|n \in N\}Σ \qquad óнΦoú$$

ǿKλƒŜ ŭKŜ ϒI·ÈλϒdzϒŘŜƎNJŜŜ 2Ŧ y2ŘŜ 2Ŧ I·y !ŘπK2Ŏ yŜŭǿ2NJʅ λă ƎλǿŜyʹōè

$$deg(n)_{max} = max\{deg(n)|n \in N\}. \qquad óнΦnú$$

/2ϒϒŜyŭϒLJI·ƎŜ opϒ I· ŘλI·ƎNJI·ϒ ǿ2dzƒŘ KŜƒLJ ŘŜăŎNJλōŜ нΦто ¢KŜ ƎNJI·LJK ŭKŜ2NJè I·LJLJNJ2I·ŎK

CORRECTION:

{ŜŜ LJI·ƎŜ op Ŧ2NJ ŭKŜ ŘλI·ƎNJI·ϒ Ŧ2NJ ŭKŜ DNJI·LJK ŭKŜ2NJè I·ă ădzƎƎŜăŭŜŘΦ

/2ϒϒŜyŭϒ LJI·ƎŜ opΣ[м άΦLJI·è2ŦŦΦ ăK2dzƒŘ ōŜ άLJI·è2ŦŦăέXΦά DI·ϒŜ ŭKŜ2NJè λyǿ2ƒǿŜă I· ăŜŭ 2Ŧ LJƒI·èŜNJăΣ I· ăŜŭ 2Ŧ ăŭNJI·ŭŜƎλŜă I·yŘ I· ăŜŭ 2Ŧ LJ2ăăλōƒŜ LJI·è2ŦŦΦ

CORRECTIONϒ άDI·ϒŜ ŭKŜ2NJè λyǿ2ƒǿŜă I· ăŜŭ 2Ŧ LJƒI·èŜNJăΣ I· ăŜŭ 2Ŧ ăŭNJI·ŭŜƎλŜă I·yŘ I· ăŜŭ 2Ŧ LJ2ăăλōƒŜ LJI·è2ŦŦăέΦ

/2ϒϒŜyŭϒ ¢KŜ ŎI·yŘλŘI·ŭŜ ăK2dzƒŘ ŭNJè ŭ2 ƎŜŭ ¢I·ōƒŜ oΦм 2yʹ2yŜ LJI·ƎŜΦ

CORRECTIONϒ {ŜŜ LJI·ƎŜ пс ¢I·ōƒŜ oΦм KI·ă ōŜŜyʹNJŜŘdzŎŜŘ ŭ2 I· LJI·ƎŜ I·ă ădzƎƎŜăŭŜŘΦ

/hAa9b¢ϒLJI·ƎŜ сфΣCλƎΦpΦнϒ¸πI·ÈλăπϒF ² λă Ŧ2NJ t2ǿŜNJΣ y2ŭ 9yŜNJƎèΦ

CORRECTION: [illegible]

[illegible]

CORRECTION [illegible]

Chapter 1

[illegible]

Correction: [illegible]

Chapter 2

[illegible]

Chapter 3

[illegible]

Correction: [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Chapter 4

[illegible]

[illegible]

Chapter 5 and 6

Comment: Figure 5.2 vertical and horizontal axis unit. Difference between figures 5.2 and 5.3. Fihure 5.4, node lifetime unit not defined.

Fig 5.2 has been corrected. Nodes on the horizontal analysis represents the nodes involved in the network which includes the sender, receiver and the intermediate nodes. Figure 5.2 and 5.3 shows the overall energy consumption between constant transmission power and variable transmission power at different time t. Figure 5.4 node lifetime has been defined as seconds (secs). Figure 5.5 shows the percentage of the energy consumed per node using a variable transmission power with respect to the distance between nodes.

Figs 5.5.1 – 5.5.3 explained performances of different ad-hoc routing protocols used in the network to evaluate the throughput of the network. The results obtained show different throughput of the network with each routing protocol. It was deducted from the result that B.A.T.M.A.N routing protocol outperformed other routing protocols.

The conclusion has been modified as suggested by the examiners on page 78.

Student: OJUETIMI IFEDAYO AKINSOLU

Signed: AKINSOLU

Date: 20/05/2015

Supervisor: Mqhele E. Dlodlo (Associate Professor)

Signed: ______________________

Date: ________________________

Head of department: Professor E.Boje

Signed: ______________________

Date: ________________________