ROUTE DISCOVERY BASED ON ENERGY-DISTANCE AWARE ROUTING SCHEME FOR MANET

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Abstrak

Proses penemuan laluan di dalam sesebuah Rangkaian Ad hoc Bergerak (MANET) adalah mencabar disebabkan kekangan tenaga pada setiap nod rangkaian. Keterbatasan tenaga mengekang hayat hubungan rangkaian, oleh itu menjejaskan proses penghalaan. Justeru, adalah perlu bagi setiap nod dalam rangkaian mengira faktor penghalaan dari segi tenaga dan jarak dalam menentukan calon nod penyampai optimum bagi penghantaran paket. Kajian ini mencadangkan satu mekanisme penemuan laluan baharu yang dipanggil Penghalaan Peka Tenaga-Jarak (EDRA) yang menentukan pemilihan nod ketika proses penemuan laluan bagi menambahbaik hayat hubungan rangkaian. Mekanisme ini mengandungi tiga skema iaitu Peka Faktor Tenaga-Jarak (EDFA), Strategi Penghantaran Tenaga-Jarak (EDFS), dan Pemilihan Laluan Peka-Tenaga (EARS). Skema EDFA bermula dengan mengira tahap tenaga (e_i) pada setiap nod dan jarak (d_i) ke semua nod yang berjiran untuk menghasilkan nilai faktor tenaga-jarak yang digunakan bagi pemilihan nod penyampai. Seterusnya, skema EDFS menghantar paket-paket permintaan laluan dalam kawasan penemuan nod penyampai berdasarkan bilangan nod. Kemudian, skema EARS memilih laluan penghalaan yang stabil meggunakan maklumat status terkini dari EDFA dan EDFS. Mekanisme penilaian EDRA dibuat menggunakan penyelaku rangkaian Ns2 berdasarkan set tentuan metrik prestasi, senario, dan kebolehskalaan rangkaian. Keputusan eksperimen menunjukkan EDRA mencapai kemajuan yang ketara dari segi hayat hubungan rangkaian berbanding mekanisme yang serupa, iaitu AODV dan DREAM. EDRA juga mengoptimakan penggunaan tenaga dengan memanafaatkan penentuan penghantaran yang cekap pada skala nod-nod rangkaian yang berbeza. Juga, EDRA memaksimakan hayat hubungan rangkaian disamping menjaga truput dan nisbah kehilangan paket. Kajian ini menyumbang ke arah pembangunan satu mekanisme penghalaan peka-tenaga yang cekap bagi menampung hayat hubungan rangkaian yang lebih lama dalam persekitaran MANET. Sumbangan ini adalah penting bagi mempromosi penggunaan teknologi rangkaian generasi hadapan yang mesra alam dan lestari.

Kata kunci: Rangkaian ad hoc bergerak, Penghalaan peka-tenaga, Penemuan laluan penghalaan, Pemilihan nod penyampai, Protokol penghalaan.

Abstract

Route discovery proses in a Mobile Ad hoc Network (MANET) is challenging due to the limitation of energy at each network node. The energy constraint limits network connection lifetime thus affecting the routing process. Therefore, it is necessary for each node in the network to calculate routing factor in terms of energy and distance in deciding optimal candidate relay nodes needed to forward packets. This study proposes a new route discovery mechanism called the Energy-Distance Routing Aware (EDRA) that determines the selection of nodes during route discovery process to improve the network connection lifetime. This mechanism comprises of three schemes namely the Energy-Distance Factor Aware (EDFA), the Energy-Distance Forward Strategy (EDFS), and the Energy-Aware Route Selection (EARS). The EDFA scheme begins by calculating each nodes energy level (e_i) and the distance (d_i) to the neighbouring nodes to produce the energy-distance factor value used in selecting the relay nodes. Next, the EDFS scheme forwards route request packets within discovery area of relay nodes based on the number of nodes. Then, the EARS scheme selects stable routing path utilising updated status information from EDFA and EDFS. The evaluation of EDRA mechanism is performed using network simulator Ns2 based on a defined set of performance metrics, scenarios and network scalability. The experimental results show that the EDRA gains significant improvement in the network connection lifetime when compared to those of the similar mechanisms, namely the AODV and the DREAM. EDRA also optimises energy consumption by utilising efficient forwarding decisions on varying scale of network nodes. Moreover, EDRA maximizes network connection lifetime while preserving throughput and packet drop ratio. This study contributes toward developing an efficient energy-aware routing to sustain longer network connection lifetime in MANET environment. The contribution is significant in promoting the use of green and sustainable next generation network technology.

Keywords: Mobile ad hoc network, Energy-aware routing, Routing path discovery, Relay node selection, Routing protocol.

Declaration

Some of the works presented in this thesis have been published as listed below.

[1] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, “Node Selection Based on Energy- Distance Factor in Mobile Ad-Hoc Network,” in Proceedings of the *International Postgraduate Conference on Engineering (IPCE2011)*, Universiti Malaysia Perlis (UniMAP), Perlis, MALAYSIA 22 - 23rd October 2011.

[2] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, Mohammad Firdaus, “Node Selection Based on Energy Consumption in MANET,” in Proceedings of *International Arab Conference on Information Technology(ACIT2011)*, Naif Arab University for Security Science (NAUSS), Riyadh, Saudi Arabia, 11st – 14th December 2011.

[3] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, “Probability based Method for Node Selection in MANET,” in Proceedings of *International Engineering Education Conference (IEEC2011)*, Madinah, Kingdom of Saudi Arabia, 25th -27 December 2011.

[4] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, “Concept of an Energy-Efficient with Probability based Method for Node Selection in route discovery of MANET,” in Proceedings of 3rd *International Conference on Network Applications, Protocols and Services; (NetApps2012)*, IEEE, Sintok, Kedah, Malaysia, 2012.

[5] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, “Energy efficient with Location Forward Strategy in MANET,” in Proceedings of 3rd *International Conference on Network Applications, Protocols and Services; (NetApps2012)*, IEEE, Sintok, Kedah, Malaysia, 2012.

[6] Jailani Kadir, Osman Ghazali, Suhaidi Hassan, .”Node Discovery Based on Energy-Distance Factor in MANET,” in *International Journal of Engineering Research & Technology (IJERT)* Vol.1, Issue 7, September 2012.

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List of Abbreviations

ABR	Associatively Base Routing
AODV	Ad-hoc On-Demand Distance Vector
AOMDV	Ad-hoc On Demand Multipath Distance Vector
AREC	Average Rate of Energy Consumption
ARQ	Automatic Repeat Request
BP	Beacon Packet
BPIT	Beacon Packet Interval Time
CBPM	Communication-Based Power Management
CBR	Constant Bit Rate
CPU	Central Processing Unit
CTR	Control Routing
CTF	Clear to Forward
DBEEP	Distance-Based Energy Efficient Placement
DEAR	Distance Energy Aware Routing
DSR	Dynamic Source Routing
DREAM	Distance Routing Effect Algorithm for Mobility
EARS	Energy Aware Routing Selection
EC	Energy Conserving
EDRA	Energy Distance Aware Routing Protocol
EDFA	Energy Distance Factor Aware
EDFS	Energy Distance Forward Strategy
EELAR	Energy Efficient Location based Routing

EM	Electromagnetic
ELT	Entry Lifetime
FEC	Forward Error Correction
FS	Forward Strategy
GPS	Global Position System
GRS	Greedy Routing Scheme
HCB	Hierarchical Cluster based Routing
HREC	High Rate of Energy Consumption
LAMOR	Lifetime Aware Multipath Optimal Routing
LAR	Location Aided Routing
DREAM	Localised Energy Aware Restricted Neighbourhood
LET	Link Expiration Time
LREC	Low Rate of Energy Consumption
MAC	Media Access Control
MANET	Mobile Ad-hoc Network
MAP	Maximum Available Power
MFR	Most Forward Radius
MN	Mobile Node
MRE	Minimum Route Energy
NFP	Nearest Forward Progress
PAMAS	Power Aware Multi-Access
PAMOR	Power Aware Multicast On-demand Routing
PAMP	Power Aware Multi Path
PAOD	Power Aware on Demand
PARAMA	Power Aware Routing Algorithm Mobile Agent

PBMA	Probability Based Method Algorithm
PDA	Personal Digital Assistant
PMRP	Power-Aware Multicast Routing Protocol
PNR	Position Neighbourhoods based Routing
PSR	Power-aware Source Routing
PTPSR	Power Traffic Path Selection Routing
Q-DIR	Quadrant Directional Routing
QoS	Quality of Service
RD	Random Direction
RE	Remaining Energy
REAR	Residual Energy Aware Routing
REC	Rate of Energy Consumption
RET	Route Expiration Time
RREP	Route Reply
RREQ	Route Request
RSSI	Received Signal Strength Index
RTF	Request to Forward
SIFS	Short Interframe Space
VANET	Vehicular Ad-Hoc Network
WMN	Wireless Mesh Network
WSN	Wireless Sensor Network
ZHLS	Zone-Based Hierarchical Link State
ZRP	Zone Routing Protocol

CHAPTER ONE

INTRODUCTION

1.1 Overview

This dissertation proposes a new extension for the current AODV protocol in the Mobile Ad-hoc Network (MANET). In this chapter, Section 1.2 provides a general background, while Section 1.3 presents the motivation and research problem. Sections 1.4 and 1.5 present the research objective and the research scope respectively. Meanwhile, Section 1.6 presents the research assumptions and key research steps respectively. Finally, Section 1.7 presents the organisation of this dissertation.

1.2 Background

Development and advancement of communication technology, especially the wireless communication system, has witnessed very rapid changes in technology, in particular the development of communication technologies. One of the fastest growing applicable technologies in the communication sector is wireless communication, such as the Mobile Ad-hoc Network (MANET). MANET technologies is infrastructure-less and substantially different from conventional wireless technology.

The concept of infrastructure-less communication refers to the wireless communication system. This means that all devices in the system are autonomous within the network system which is connected by wireless links. All processes of sending and receiving data between source to destination are through a wireless interface [1].

Mobile nodes in MANETs usually consist of mobile wireless equipment that can communicate and can be deployed within an environment where wireless base station coverage is strictly limited. One advantage of MANET is that it has very dynamic connections and can form links spontaneously according to changes in topology. Nodes in MANET are able to connect with each other using the limited bandwidth radio link [2, 3]

The mobile nodes in MANET characteristically function as a router to connect a source node to destination node while utilising limited resources, such as battery power and bandwidth [1]. The process of establishing a routing path on mobile nodes while using limited resource necessarily requires an efficient scheme to ensure that limited resources can be used effectively in route discovery [1, 4]. Figure 1.1 below shows a schematic illustration of MANET.

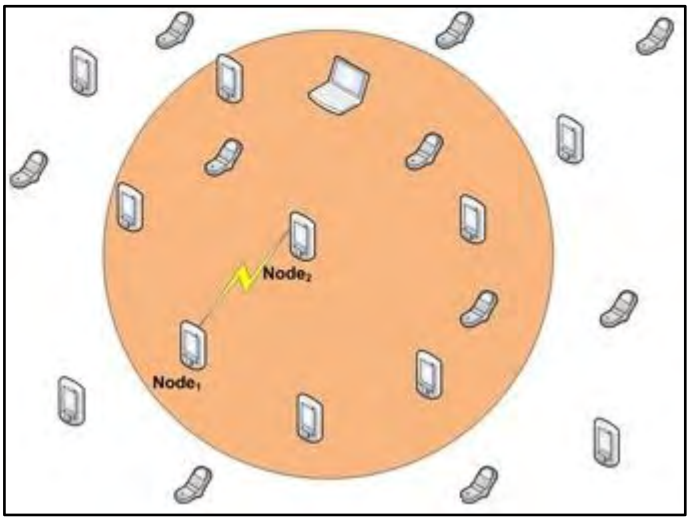

Figure 1.1. An example of mobile ad-hoc wireless network topology.

Due to this dynamic mobility feature, MANET is considered to be a valuable network topology for its flexibility and availability for various applications. The robustness quality associate with MANET allows it to be subjected to additional complications and also challenges [5]. Besides these features and complexities of traditional wireless networks, the unpredictability and frequent topology changes, limited resource, bandwidth constraints, multi-hop nature, and network scalability are new added challenges to implementing MANET successfully [6]. In conclusion, the main challenge in MANETs is ultimately to establish a stable routing connection in a condition of limited resources on every node within the network [6].

1.3 Motivation and Research Problem

The issue of a lifetime connection in MANET is basically due to energy constraints, and there have been efforts in overcoming this problem by proposing particular energy efficiency routing protocols for resolving the unstable connection problem in the MANET network. The proposed methodology in routing protocols is to make a reliable routing protocol with a highly stable connection between nodes and optimised by using limited resource effectively [7, 8, 9]. Node failure in MANET is generally due to node inability to have sufficient energy, which not merely has an impact on the node itself, but its failure would retard the progress of packets to other relay nodes. This would affect the network lifetime connection in MANET. For many specific purposes, a lot of research was carried out discover more efficient routing protocol algorithms. However, these algorithms were observed to be not specific enough and showed that the methods used in a particular protocol can solve the same problems by other protocols. This is because the technique used may be suitable according to the parameters set for specific protocols.

Therefore, it is necessary to ensure the efficient consumption energy at each node to be evaluated more effectively by taking into account the computational energy distance efficient for the next node. A number of routing protocol techniques by previous research efforts [10, 11, 12, 13, 14] had been proposed based on the energy efficiency or energy awareness. A lot of proposed energy awareness metrics had been defined as a function for the lifetime connection of the node [15, 16] as well as function in calculation of the remaining energy for node lifetime [10, 12].

Previous research had used the method of energy-efficiency on routing protocols based on their own goals with different assumptions and parameters set according to their particularly established network environment. The efficient energy on the nodes would be capable of increasing the lifetime of the relay nodes in packet forwarding multi-hop conditions. This means that efficient energy is required to be the main consideration in packet forwarding of wireless links inside most trusted means. The energy effective proposed in one research [17] had focus based on residual energy and node position within the network.

The routing mode using maximum energy level to achieve the maximum transmission distance per packet to intermediate relay nodes by previous studies [10, 18, 19] had the advantage, where the node will transmit to its neighbour with the largest forward progress to destination. However, when communication distance increases over a long time period, it would cause the sender node to run out of energy quickly and be incapable of transmitting any further.

The short transmission mode in packet forwarding can save energy consumption by using an appropriate transmission power control algorithm, as described previously

[20, 21, 22]. This will save energy and thus can increase the life of the relay node connection. However in the event that a power failure occurs, the power control established in the node needs to adapt the energy according to the distances of neighbour nodes, which will cause all routes to be uniform to all neighbour nodes, even though they are at different distances. This would decrease the sender node's lifetime. Thus, the nodes with lower remaining energy would quickly expire and shut down, which would cause packet lost. Therefore, if a sender node with lower energy capacity and the next relay-node has the same capacity, then the link between the two will have a short lifetime and would break network connection [21, 23]. Therefore, ignorance of energy level status in nodes in forwarding decision-making would ultimately result in severe packet loss.

Meanwhile in order to retain node stability connection as well, load distribution method can be used to balance the energy usage among nodes by avoiding over-utilised nodes when selecting a routing path [22, 24]. Protocols based on this approach do not necessarily provide the lowest energy route, but prevent certain nodes from being overloaded, and thus would ensure longer connection lifetime. Woo K et al. in [24] proposed the LEAR algorithm with modifies the route discovery procedure for balanced energy consumption to occur. LEAR is a distribution algorithm where each node makes its routing decision locally without considering its residual energy of packet forwarding to neighbour nodes [25, 26]. The consequence is that, if the next selected relay node is one of those considered to be an ineffective node, the forwarded packet would be dropped. As a result of the dropped package, this would lead to the re-transmission process and rerouting of the dropped packet, which would result in increased communication cost. Therefore, a key factor for good performance of an energy efficiency protocol in the MANET environment is the knowledge in the forwarding decision process to next relay nodes in the neighbouring nodes list.

To conclude, motivated by the reasons behind short lifetime connection of nodes failures in MANET and the weaknesses of current proposed solutions, the demand for an efficient solution is obviously needed. This research proposes a new extension to the existing routing protocol based on energy and distance to the next node hop. The purpose of this scheme is to propose a newly formulated method to improve the routing discovery mode with forwarding strategies, and to further optimise the energy-distance routing protocol in the MANET environment.

1.4 Research Goal and Objectives

The main focus of this thesis is to develop an Energy-Distance Routing Aware (EDRA) protocol by introducing an algorithm aimed at improving the technique of node selection, establish a stable path connection, and thus ultimately sustaining the network lifetime connection. These improvements sought to make EDRA compatible with the various MANET features, to decrease failure rates, and to reduce the need to use recovery modes. In order to fully accomplish this goal, a set of concrete objectives have been formulated, which is to design a technique of Energy-Distance Routing Aware protocol with an algorithm based on the energy distance factor. In order to achieve this objective, the following sub-objectives have been formulated, which are:

a. to formulate an algorithm that determines the optimum energy and distance effective of the nodes in the network,

b. to design an algorithm for reduce flooding in network by implement quadrant technique, and

c. to implement an algorithm that uses the Energy-Aware Route Selection (EARS) in the routing path.

1.5 Scope of Research

This research focused on dealing with the main function of node selection in the routing protocol within the MANET environment. Since energy efficiency in routing protocol of a wireless environment is closely related to how data is going to be transmitted over the network, this would involve the network, physical, and data link layers in the routing protocol. The node selection in these layers is based on the energy of the node and effective distance of packet transmission to the next nodes in the network. This thesis focuses on sustaining a lifetime connection, which is known as the energy-distance efficient mode. This research considered improving the route discovery mode to optimise the necessity of using energy and distance parameters. The first recommended solution focused on node selection of effective relay nodes. This proposed solution highlighted an approach based on the probability of energy distance factor of candidate node in the network. The second recommended solution focused on the next relay-node discovery with projection quadrant progress technique, which would always find a better neighbour and thus resulting in a reliable routing decision. The third recommended solution emphasised on the route selection based on projection of two schemes. This solution revealed an energy aware approach with a metric of maximum residual cost that can assist in maximising the path lifetime.

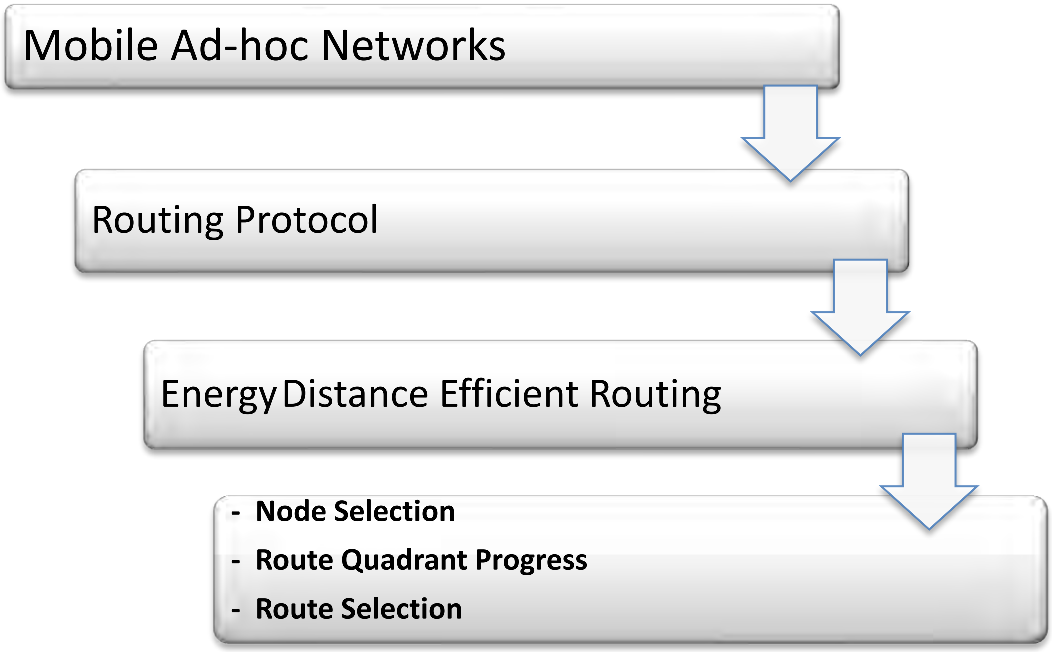

Figure 1.2. Research scope and key contributions.

1.6 Research Assumptions

In this dissertation, the assumption taken is that the process of communication between nodes within the network occurs in a bidirectional process. This means that two neighbouring nodes can send and receive packets from each other simultaneously. This research assumed that all nodes will run the self-positioning calculation and stores its coordinates at the particular nodes themselves. The source node can obtain the position coordinates (x, y) and direction movement to destination node using an available and efficient location-based service, such as the hierarchical location service (HLS) [27]. All nodes used in this study were equipped with the Global Positioning System (GPS). Therefore, the current status information of each node position can be shown in its coordinate (x, y) form, velocity, and motion direction, with reasonable accuracy by the location algorithm service.

1.7 Dissertation Organisation

The dissertation is structured as follows. Chapter One is an introduction that defines the scope of the thesis. Chapter Two presents the background and related works. Chapter Three explains the proposed method with solutions for route discovery in the routing protocol. Chapter Four describes the implementation of algorithm in the route setup. Chapters Five describe the performance evaluation of the study, while Chapter Six presents the conclusion of the thesis and recommendations for future work.

CHAPTER TWO

BACKGROUND AND RELATED WORK

The first part of this chapter introduces the background of issues and challenges related to the routing efficient technique by illustrating some examples of current research efforts in enhancing routing protocols. Then, the related intensive studies are explored in order to provide an overview of the area and domain of this research. Then, routing energy-efficient techniques are discussed in greater detail as the focus of this research. Each technique is discussed along with the corresponding related work. The analysis of the features and limitations on the state-of-the-art routing strategies is also presented.

The problems related to the routing path of energy constraints on nodes have been discussed in general in Chapter One, which will be elaborated upon further in this chapter. In addition, the various techniques developed for wireless network and mobile ad-hoc networks are also described in this chapter.

2.1 Overview

In this chapter, the routing issues are investigated from the routing layer point of view. The focus is more on the combination domain based on distance issue and energy routing. In recent years, some researchers have focused their attention on this problem. This study has attempted to perform an in depth survey of the published literature concerning the state-of-the-art routing efficient and energy efficient routing approaches for an ad-hoc network.

Firstly, the position-based routing is a method for selecting an appropriate intermediate node based on position distance between nodes. This technique was created to offer successful efficient routing by means of minimising the flooding associated with control messages, while considering restricted energy associated with mobile nodes in addition to making use of suitable power transfer capacity to the communication. Secondly, a review is performed on protocols related to energy routing influence on node selection for sustaining connection lifetime. And finally, a new function was proposed to select intermediary nodes which consider both distance and energy factors of each node.

To overcome the problems identified in the conventional routing protocol, several approaches had been proposed as potential solutions previously [28][29][30]. The potential of these approaches is that it can help establish the foundations of a conceptual framework for the thesis in this study, so that it can produce a more efficient routing protocol compatible with the MANET environment.

2.2 Routing in Mobile Ad-hoc Networks

Efficient routing protocol in the MANET environment is the important issue in determining the stability of the connection as well as the connection lifetime. The ability of the protocol to correctly adapt to the capacity of nodes in the network environment, which would have either sparse or dense capacity of the nodes, will ensure a more stable connection. As mention by previous researchers [31, 32], there is a need for the ability to perform routing protocols for rapid response to frequent topology changes, and thus adapt to resource constraints at the nodes in MANET environments [33]. From the conducted literature review, several approaches had been introduced to address this problem with varying degrees of success. In this dissertation, the emphasised techniques considered the issue of energy–distance aware protocol with due regard to energy efficiency at the node and the effective distance of the position of the relay nodes. For position of efficient nodes, it can be divided broadly into position-based routing protocols and topology-based routing protocols.

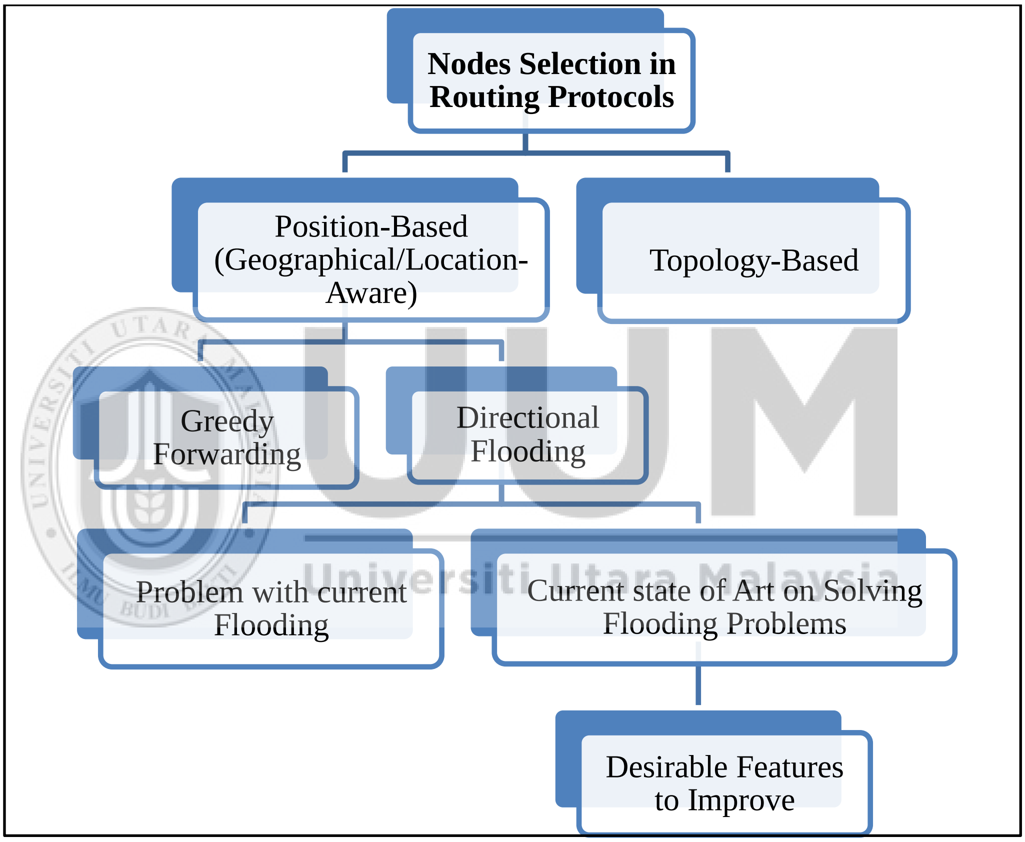

Figure 2. 1. Literature review framework of node selection in routing process.

This chapter is organised according to two focuses, firstly the node selection technique and secondly the energy efficiency technique. An introduction and brief knowledge presentation of the routing protocol process in MANET are presented in Section 2.2, as well as issues behind node failure in MANET and their associated reasons. Section 2.3 highlights the constrained conditions of mobile nodes. The techniques of node selection are presented in Sections 2.4 and 2.5, while Section 2.6 describes the overview of route discovery routing in MANET. Section 2.7 presents the related works in routing point of view which influences the life of the network. Section 2.8 presents the existing energy routing techniques in wireless ad-hoc networks, and finally the chapter's summary is presented in Section 2.9.

The need for knowledge information on a node within the network is a major subject for maintaining continuous communication between nodes. The geographic information of mobile nodes, such as the source and relay node, is kept with the information of each the other neighbourhood node status. The transmitting node must have knowledge information of the next nodes so that packets can be sent directly toward them. Assuming a routing protocol equipped with the location server or service exists, then adjacent node information can easily be obtained. The limited power capacity of the nodes is one of the reasons for failure of intermediate nodes in maintaining a connection to the other nodes. Failure of any relay nodes would affect the others in terms of the ability to send packets to the destination node. In addition to this problem, many researchers have opened up an investigation on the development associated with an efficient routing protocol. Many algorithms had been developed in recent years [24, 32, 34, 35], while some basic methods had been proposed about 15 years ago. Most of the algorithm routing protocols had been proposed with the ability to establish routes and to send the packet forwarding information to next node in a timely manner. Secondly, the path to be established must have minimised energy consumption, bandwidth, and overhead costs.

2.3 Node Constrained Conditions in MANET

The efficiency of a routing protocol is closely linked to the reliability of nodes and communication performance process of the whole network. To ensure that the node operates correctly and reliably, several factors need to be considered. Among the factors that are important include the conditions of participating nodes in the path of such energy recovery and the exact node position information [19, 36]. Without regard in accounting for these factors, it would lead to decreased performance of network connection between relay nodes in MANET.

2.3.1 Nodes Involved in Route Path

Existing routing protocols are engaged while taking into account the shortest route as the main characteristic in the route selection criteria without taking into account other factors of relay nodes in forming the route plan. Therefore, even if the shortest route is the route selected, sometimes it would suffer higher packet loss in the delivery of packets. As plotted in Figure 2.2 below, which used the short path selection method, in the occurrence of high node density and high traffic congestion (hot-spot area), it would eventually lead to problems in the network condition [37].

High traffic load in hot spot areas compared with other regions can reveal some issues that will adversely affect the performance of MANET [38, 39]. Firstly, the probability of any collision of packets would be too high, and this can result in a lot of packet losses. Secondly, the position of the node in hot-spot areas would make them subjected to higher traffic levels, thus the related node must process more frequent packets as compared to other nodes. Thirdly, the nodes involved would probably suffer from rapid loss of battery power due to high power consumption.

Consequently, packets going through these nodes in hot-spot areas would likely lose or create end-to-end delay of packet transmission.

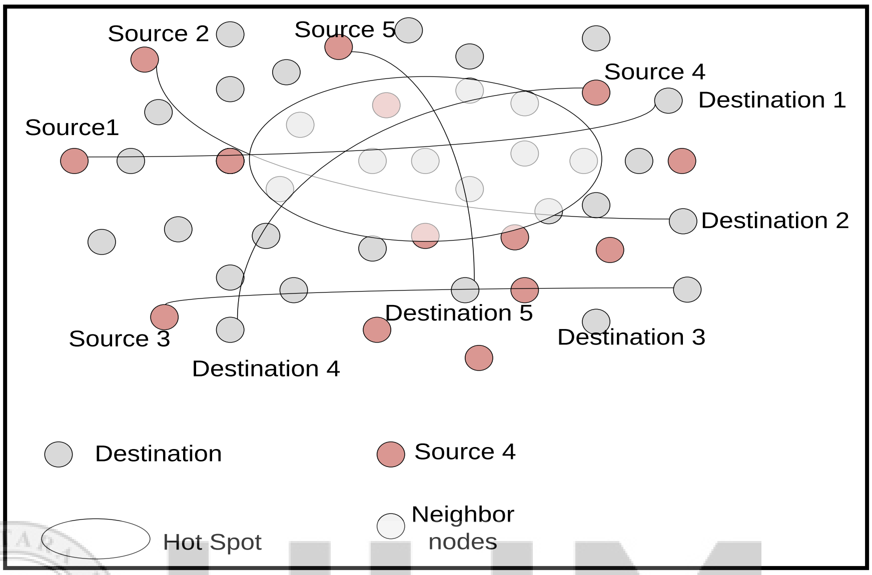

Figure 2. 2. Example of a hot-spot area over routing in MANET.

2.3.2 The Problem of Candidate Nodes in Path

In mobile devices, the limited power capacity on each node makes the processing power to be fairly limited [10, 40, 41, 42]. As long as the node is considered alive, the MANET routing protocol would be considered operational [41]. Lifetime of mobile nodes in the MANET is determined by two factors. The first one is the quantity of energy a mobile node consumes over time. The second one is the residual amount of energy that is available for a mobile node to use [42].

Normally, the relay node involvement would increase with an increase in the density of nodes within the network [43]. This would also increase the number of links to the destination node. A short or long route in packet forwarding would affect the power consumption levels in routing protocols. Usually, the distance parameter would affect power consumption at each node [42].

Meanwhile, topology changes that occur frequently in MANET may be due to two main reasons. Firstly, this could refer to nodes that are running out of battery as mentioned in the previous section. Secondly, this would refer to nodes that are not adjacent to node coverage due to changes in speed and direction [44].

Most of current routing protocols do not put high priority on the position and distance of adjacent nodes. Possible selected relay node does not lead the packet to the destination. This would have implications on the selected node whether the packets are carried through a longer route or along routes that are not optimal. It would increase end-to-end delay of the packet transmission [43, 44]. In conclusion, the use of density information and positive direction of adjacent node as parameters in the selection of relay node as forwarding nodes would certainly boost the performance of MANET routing protocols.

2.3.3 Relay Node Connection Lifetime

In the position-based routing protocol, the fitness of the node in the neighbouring-list is high priority to be selected since the relay nodes forward packets. If the information listed in the neighbouring-list in the routing table is inaccurate, it would lead to a wrong decision being made on the relay node selection and thus have a devastating impact on MANET resources [45].

Neighbourhood Entry Lifetime (ELT) (i.e., entry timeout) is usually determined as a fixed threshold as described previously [46]. However, the pre-threshold setting ELT would affect the listed nodes that have out-dated entries. To give clarity to this situation, the following scenarios would perhaps provide a clearer picture on this subject. In the first case, some nodes cannot receive the latest beacon packet (BP) from its neighbours due to congestion. This would cause the node to have a statement that it has an expired date. In this condition, the node that has an entry with an expired date would be removed from the list of neighbouring nodes, but it is still within the transmission range [45]. To give more explanation to this claim, the following two scenarios are assumed. In the first scenario with a small threshold, if a node transmits its up-dated BP to its neighbour and the BP could not reach a neighbour's node due to a congestion problem, then the neighbour would remove this node's entry from its neighbouring-list, while in fact, the node is still within its transmission range.

In the second scenario due to the length of ELT threshold, it would cause in the entry waiting time to be too long before the BP is removed. Due to the fact, as provided in previous research [47], the algorithm forwards packets to nodes close to the destination, consequently the selected neighbour is close to the border of the node's transmission range, and thus there is a higher probability to have more relay nodes. Therefore, due to the long threshold value and the case of a high mobility environment, a node would still hold a neighbour's entry BP, when in fact the neighbour has already left the node's transmission range.

From both of these scenarios, it would affect the performance of the forward strategy routing protocol performance, while the packets that are sent would be lost [46, 48]. This would increase delay and increase the energy consumption at the related nodes. Consequently, to increase the performance of data routing in MANET, hence there is the need for an ELT with sufficient frequency assigned to ensure the updating of BP information.

2.4 Topology-based Routing

Topology-based routing protocols would need information regarding inbound links that exist within the network. Such information is used to establish and maintain routes to perform packet forwarding [38]. These protocols discover routes either proactively such as demonstrated by the work presented previously [40], or reactively, as shown before [40]. In route discovery, network topology changes in MANET are usually influenced by the effects of node mobility and mortality of the node due to high overhead. For proactive route discovery, it cannot maintain the route when the two factors mentioned above increases. Whereas, in the reactive route discovery, it depends on the capacity of flood in either route network congestion, high delay, or scale node within MANETs [49, 50].

2.5 Position-Based Routing

Position-Based (Geographical or Location-Aware) routing is the task of delivering a data packet to a specific position within a MANET [51, 52]. These protocols utilise the geographical location information of participating nodes to deliver packets over a network. Thus, as in all proposed position-based routing protocols, the underlying principle is to send the data packet ahead from the sender node to a neighbour within its transmission range that it is closer to the destination than itself. With this principle, they make positive progress toward the destination [42].

The simulation results by previous research [50, 53] showed that position-based routing protocols are better than other routing protocols when utilised within the

MANET environment. Moreover, the simulation results presented that position-based routing protocols offer a number of advantages over topology-based routing protocols. Also, as reported previously [52], position-based routing algorithms could eliminate some weaknesses of topology-based routing protocols.

There are three main packet-forwarding strategies used for position-based protocols, namely greedy forwarding, restricted directional flooding, and hierarchical approaches. Greedy forwarding protocols do not establish and maintain paths from source to destination; instead, a source node includes the approximate position of the recipient in the data packet and selects a next-hop relay node depending on the optimisation criteria of the algorithm. In enabling nodes to periodically make decisions, node position information carried by the beacon would announce the current status of the nodes in the routing table of the neighbouring node. While beaconing frequency can be designed toward the adaption of flexibility, the fundamental problem of inaccurate (out-dated) position information often provides that a new neighbour determined to be a potential next-hop node may no longer be within transmission range. This would lead to a substantial reduction in the packet delivery rate with increasing node mobility. To cut back the inaccuracy associated with location data, it is possible to boost the beaconing volume. Nonetheless, this would enhance the load within the network through the occurring range of congestion, and increasing the probability associated with having data packets and having node strength [50, 54, 55].

Focus also had been given to the complete framework for position-efficiency of intermediate node selection based on the communication medium. Three main design factors had been identified with respected to the development of protocols for MANET.

The first problem was to resolve the intermediary nodes as applicant nodes *en route*. Another concern would be the progress of an effective forwarding technique that would lessen the opportunity associated with broadcast related to the flooding zone. The final problem is always to develop an efficient routing path to destination with regard to lifetime connection.

Since the scope of this research is concerned with position-based routing protocols, this research does not address any topology-based routing protocols for MANET. A survey of topology-based routing protocols can be found in previously published research outputs [51, 56]. The following section presents more details about the position-based routing protocols.

2.5.1 Forwarding Strategies

In the position-based routing protocol, two main techniques have been used regularly, i.e., geographic routing process and route location service, as described in previous research efforts [21, 57, 58]. The geographic routing technique is used to discover nodes and establish communication paths between nodes. Meanwhile, the route location services are used to determine the location of the relay nodes to the destination. The main challenge in the method based on node position is related to the updating of information associated with the sender and recipient. This strengthens the proposal to make use of geographical location nodes as a parameter to forward packets throughout the entire network. The power of sender node is useful information for routing on acquired location facts to the adjacent node, having a chance to retain up-to-date facts connected with their neighbours, and also having a chance to recover the position facts from the precise location. With position-based routing, the mobile nodes estimate their particular position. There are a couple of methods to achieve this. The nodes may also use the Global Positioning System (GPS) unit to get a node's self-position information [59], or they estimate their (x, y) position using the distance formula $d = \sqrt{(x_2 - x_1)^2 - (y_2 - y_1)^2}$. The angle is calculated using the inverse tangent function.

$$\theta = \frac{tan^{-1}(Y_2 - Y_1)}{X_2 - X_1}. \quad [2.1]$$

The second way is to use a direction antenna approach based on directional arrival and signal strength [26, 60].

The Location-Service within the network functions to inform the position of the current node location in mobility mode. Each node can be determined accurately with the actual position within each node to its neighbours by the following methods, namely flooding-based and location-server based [56, 60, 61].

2.5.2 Structure and Operations

Mobile nodes in MANET must have local information about the location of neighbour nodes within the network, so that the developed routing algorithms can determine the short path for the packet to be delivered to the destination. Usually, the short path to the destination will be selected, i.e., the minimum number of hops to get low overhead would reduce the use of resources within the network [59, 62, 63].

Any position-based routing protocol is made up of two principal factors, which are a location service and geographic routing process [29, 55]. The location service is needed to determine the position of the packets' destination. The geographic routing process is needed to discover and establish concerning interacting nodes in the network.

2.5.3 Nodes Position Information and Location Service Methods

The capability of the sender node to create an efficient routing decision is based on the next relay node information, as described in previous research [61]. This consideration is related with node position info which forms the main difficulty for reaching any node with position-based route forwarding throughout the MANET. Therefore, the node needs to have the following characteristics:

- the capability to obtain its own position information,
- the ability of nodes to update information from neighbouring nodes, and
- the ability to know the position of the nodes targeted destination node.

Meanwhile, the Global Positioning System (GPS) [64] functions in order to obtain the actual self-position details, as well as by employing location-sensing process [63]. Every time it receives a unique position detail, a new node emits an update packet in order to enlighten many neighbourhood nodes of its presence and adds information regarding the actual place. The actual node that is provided with the actual update packet, will certainly update the neighbouring-list in connection with the node routing the actual update packet [65].

Position-based protocols would always require the location detail knowledge about the qualified node within the network. The determination of the node position in the network is the responsibility of the location-service function, which can plot and dynamically maps a node's ID to its graphical information. The function of location services is to inform the location of the node. This can be used to detect the position of the geographical location of the nodes that participate in the route discovery, and thus can quickly answer any location queries [66].

Existing location services in MANET can be categorised into two principle types, which are flooding-based and location-server based methods [66]. The first category can be further classified into two classes, namely reactive flooding-based and proactive flooding-based location services [51]. Inside the proactive class, every node occasionally floods its geographic information to all other nodes in the network. So, many nodes can update their location table. The flooding sending rate can be optimised in line with the distance result or node mobility [67]. Distance Routing Effect Algorithm for Mobility (DREAM) Location Service (DLC) is an example of the proactive flooding-based location service in the distance routing DREAM [32] routing protocol. In the reactive class, a node sends its location information when it receives a location request. Reactive Location Service (RLS) [68] is an example of the reactive flooding-based location service. Proactive flooding-based service incurs heavy loads because of the use of periodical flooding for updating locations. Additionally, if a nodes' mobility is considered as part of the criteria to determine the interval of flooding sending rate, a broadcast storm problem could occur in the case of high nodes' mobility. Therefore, the proactive class can be inefficient with regard to scalability as well as dangers connected with over-crowding. Even though the reactive class mitigates particular overheads connected with useless areas, faults within the proactive class could add large latency periods not suitable in the event of mobility within MANET [33, 69, 70].

2.6 Overview of Route Discovery

Once a source node has a packet to be sent to a target, it will try to set up a route from the source to destination nodes. In general, the flooding technique utilised in the reactive or proactive protocol for route request (RREQ) process occurs on each node. Generally, it is not ready to perform route discovery on a different scale network. In this dissertation, the implementation of limited flooding protocol is used as a route discovery method because it can reduce the optimum route discovery zone as described in previous research [26, 71, 72, 73, 74, 75, 76]. In the route discovery method, the source node will send a short RREQ message directly to the next hop through a unicast procedure. Once the neighbour node receives this RREQ message, it will send the associated acknowledge (ACK) message to its previous (source) node. Then, it will add its own location information into the RREQ message and send it to its next hop neighbour in an iterative manner similar to its previous node. Finally, the RREQ message together with the complete route information will reach the destination node. The RREP message will then be sent back in a reverse way by an intermediate node to the source node based on the symmetric link method.

The packet traffic can begin once the source node gets the RREP message with complete route information. After the traffic session is closed, each node on the route will update its routing and neighbouring tables. For example, if there are some nodes running out of energy, their relevant neighbouring nodes will delete them from their neighbouring table. On the other hand, if there are some new nodes joining the network, the relevant neighbouring and routing tables should be updated on time.

During the routing process, each packet that will be delivered has the following message structure, as illustrated in Table 2.1. The first column in the structure, “Type”, designates the property of the message which can either be a control or data messages. For a control message, the packet length is short and requires a small amount of energy, while for the data message with long data length, more energy is necessary. This type of data message is attached in the latter part of the message structure. The “Dest_Addr.” can be omitted if there is only one intermediate node. If there are several intermediate nodes, it is necessary to specify the target destination of the node message.

Table 2.1.

Message Structure

Type	Source_Addr.	Previous_Addr.	Next_Addr.	Dest_Addr.	TTL	Data_length	…

For the purpose of exchanging the energy information in the network, the existing control packets in AODV is modified for adding new control packets, namely HELLO to enable the transmission of the required energy information [77, 78, 79].

HELLO packet: The neighbouring nodes in the EDFA utilises the HELLO packet in the AODV to exchange the information of their remaining energy. In order to store such information, a new field called Remaining Energy (RE) is added to the HELLO packet, as shown in Table 2.2. With the support of the HELLO packet, a Remaining Energy Table, which records the remaining energy of all one-hop neighbours, can be maintained by those nodes.

Table 2. 2.

HELLO Packets with Remaining Energy Field

8 bits	16 bits	8 bits	
Type	Flag and Reserved	Hop Count	1
Destination ID			2
⋮			⋮
Lifetime			6
Remaining Energy (Added)			7

RREQ packet: The EDFA also utilises the RREQ in the AODV which is forwarded in the route discovery process to accumulate the local average remaining energy information along the backward path. A new field denoted as E_{sum} is added to the RREQ packet as shown in Table 2.3. Each intermediate node will update the E_{sum} field by cumulating its own local average energy. As the RREQ packet is being forwarded, the local energy information of all the intermediate nodes is spread through the backward path. Note that both R_E and E_{sum} fields only occupy four bytes in a 28 byte HELLO packet and a 32 byte RREQ packet, respectively.

Table 2.3.

Modified Format of the RREQ Packets

8 bits	16 bits		8 bits	
Type	Flag and Reserved		Hop Count	1
Broadcast ID				2
X_s	Y_s	X_d	Y_d	3
⋮				⋮
Source sequence Number				6
E_{sum}(Added)				7

2.7 Related Work

The majority of the work revealed in the literary works concentrates on the protocol design and performance evaluation in terms of energy conservation, residual energy, energy consumption, and traditional metrics such throughput, delay, and overhead.

However, lack of focus was given to the energy effectiveness in routing protocol based on the assessment of effective power value of data packet when forwarded through the distance to the next hop. Most researchers performed work on routing protocols based on energy and often assess the ability of nodes depending on power conservation, residual energy, power consumption, and etc. Most processes of the relay node selection in the route discovery within MANET usually have different selection criteria. These selection techniques will affect the overall network performance. Some algorithms for achieving efficient routing has recently been proposed [58, 80, 81]. However, the difference between those algorithms is in the approach used for searching and selecting nodes based on forward progress. In this dissertation, the proposed algorithm is to select the relay nodes based on parameters related to energy and distance in route discovery. Methods of selecting relay nodes during the route discovery will affect the performance of the routing network, especially to extend the lifetime of a wireless mobile network.

2.7.1 Node Selection

Each node within the network is selected as relay nodes and will be interconnected with a neighbour node with information transmitted and received between them. The strength of this relationship will determine the links between nodes to become stable or otherwise.

2.7.1.1 On-Demand Multicast Routing Protocol (ODMRP)

Previous research [82] had proposed On-Demand Multicast Routing Protocol (ODMRP), where the selection of intermediate node is based on the calculation of residual energy over the transmission packet to the next hop as weightage for relay node candidate. It considers minimum energy consumption per transmission without evaluating the next hop.

2.7.1.2 Energy Balance-Based Routing Protocol (REB-R)

Meanwhile, other research [83] considered the Energy Balance-Based Routing Protocol (REB-R) by broadcasting the information of energy levels on each node and capacity of data to their neighbours. The nodes will choose among them as their parents who have the highest level of energy that can receive and send. It creates two types of packages by each node. The first is FWD_ROUTE and the other is DATA. It uses a bit to distinguish packet’s type. For “energy” part, number of residual packets could be used.

2.7.1.3 Most Forward within distance Radius (MFR)

Other authors [80][84] proposed a protocol known as the Most Forward within distance Radius (MFR). The MFR is a greedy position-based routing protocol that minimises hops by selecting the farthest node from its neighbours. The MFR forwards a packet to the neighbour that is the farthest from the source in the direction of the destination within the transmission range. Due to the distance between the nodes, the MFR may sometimes lose packets in a highly mobile environment.

2.7.2 Directional Routing

Directional routing methods that rely on the destination direction to select the next forwarding node had been discussed previously in the literature [85, 86, 87, 88, 89]. The Location Aided Routing (LAR) [84][90] is a position-based protocol that uses restricted direction flooding to enhance route discovery. The LAR proposes the use of position information to enhance the route discovery phase of reactive ad-hoc routing approaches. Ko and Vaidya [86] demonstrated, with their LAR protocol, how the utilisation of location information can improve the flood mechanism of route discovery messages and hence reduce the routing overhead. In LAR, the source node defines the zone where the destination is expected to be based on the location information of the destination and the speed to which the destination can be reached. The source node only broadcasts the discovery request within the request zone, which is the smallest rectangle formed by the expected zone and the source node's position. Two LAR algorithms had also been presented previously [86], namely the LAR scheme-1 and LAR scheme-2.These differ in the manner in which the request zone is specified in the request message. In scheme-1, the zone is specified explicitly by the source node, while in scheme-2 it is implicitly specified as the source includes additional information about the destination coordinates and the distance to the destination in the request message. Although LAR reduces the routing overhead as it reactively discovers a route to the destination, it still requires the maintenance of an explicit path between every source and destination prior to data transmission. In a previous publication [87], a Location Aided-Routing algorithm challenge was discussed and an improved version of the protocol was presented. Although the destination node receives a request from different routes during the route discovery phase, it only responds to the earliest request received. Therefore, any later route breakages will lead to a new route discovery process. The author proposed selecting a back-up route as a secondary route in case of failure in the primary route. Takagi et al. [79] proposed the Energy Efficient Location Based Routing Protocol (EELAR), that can reduce the energy consumption by decreasing the size of the discovery area and dividing it into small zones. The base station concept was also introduced, which divides the network into six zones. These base stations manage the network and maintain a position table. The significance of this approach is that it is able to send a smaller number of packets which can reduce energy demand. Location Aided Knowledge Extraction Routing (LAKER) [88] utilises a combination of a caching strategy in Dynamic Source Routing [91] and limited flooding in Location-Aided Routing [86]. The idea of LAKER is to DREAM the topological characteristics of the network and use this information to guide the route discovery more precisely in the request zone. Simulation results showed that LAKER saves up to 30% more of the broadcast messages than LAR. A variant of the LAR protocol is Multipath Location Aided Routing in 2D and 3D, referred to as MLAR [91], which was designed to work efficiently in three dimensions by using an alternate path caching strategy. The Distance Routing Effect Algorithm for Mobility (DREAM) was proposed by Basagni et al. [32]. DREAM represents an all-to-all location service that disseminates and updates nodes' locations throughout the entire network. The frequency of updates is determined based on the distance between the nodes and the mobility rate. Data packets are transmitted to all one-hop neighbours that lie in the direction of the destination, represented by the angular range that includes the node's position, the destination's position, and the zone that the destination is expected to be in. The same procedure is applied at every node until the destination has been reached. Although transmitting data packets through multiple paths may increase the probability of reaching the destination, the protocol lacks scalability due to the communication overhead and data message redundancy.

2.7.2.1 Quadrant-based Direction

A limited flooding technique, Quadrant Directional Routing (Q-DIR), was proposed by A. Latif et al. [92, 93]. In Q-DIR technique, the focus on quadrant zones is used to find candidate relay nodes using location services. This technique uses the node's coordinate information obtained from its own self-positioning system [94] and modification capabilities of geo-casting [95]. In Q-DIR operation, the position information of the source and destination nodes is piggy-backed in the route request (RREQ) packet. Figure 2.5 shows the network with participating nodes in a fully flooding algorithm, while the Q-DIR's method to minimise flooding is shown in Figure 2.3.

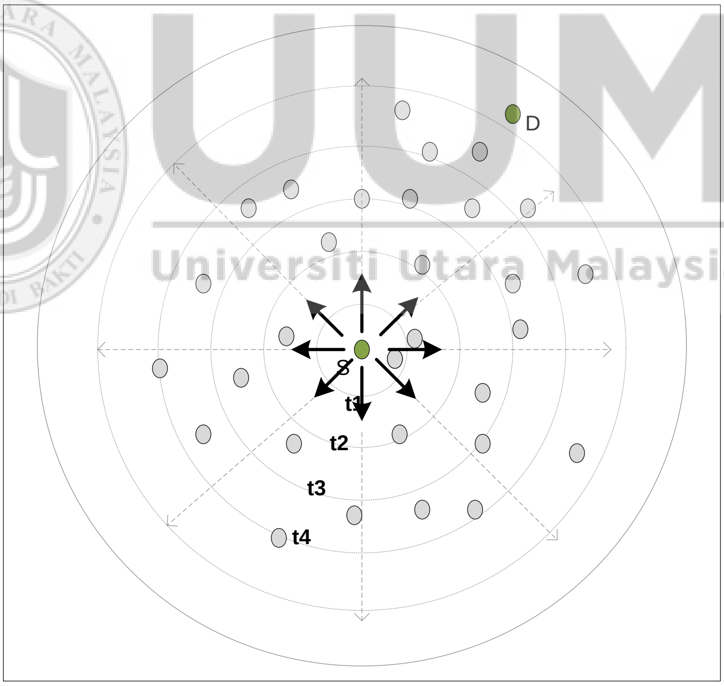

Figure 2.3. Participating nodes in fully flooding algorithm.

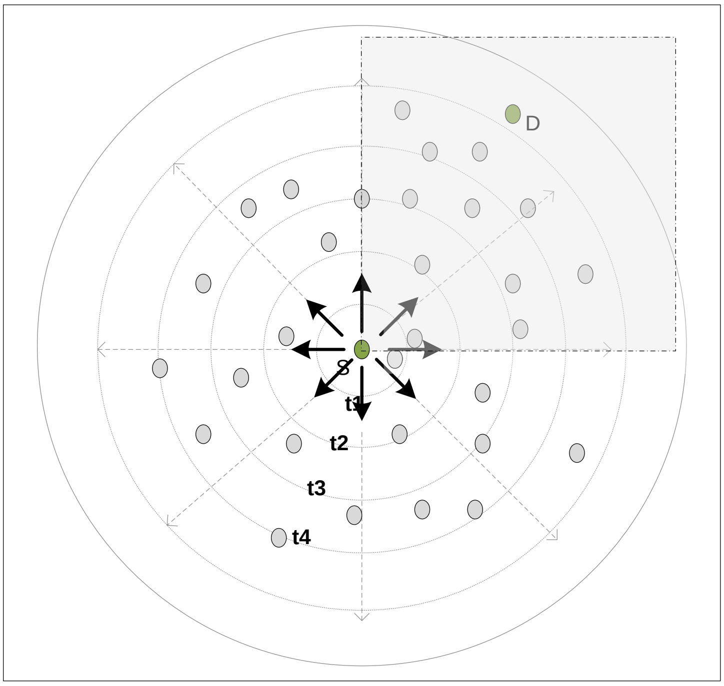

Figure 2.4. Less participating nodes in Q-DIR algorithm.

Inside Q-DIR, the details of nodes can determine the actual quadrant both source and destination nodes are located in addition to intermediate nodes in which they can examine their location compared to source and destination, and then decide to broadcast or otherwise. However in Q-DIR, consideration is not given to the degree of network density in the route discovery, since it determines the quadrant discovery without adjustments to the angle of the discovery whether the capacity nodes are high or low. Thus both overhead and end-to-end delay will increase in the routing path.

2.7.2.2 Distance Routing Effect Algorithm for Mobility (DREAM)

Distance Routing Effect Algorithm for Mobility (DREAM) [32] is an example of nodes using restricted directional flooding routing protocols, where the sender will broadcast the frontward packet to nodes within a limited sector on network, or to single hop neighbours toward the destination. DREAM algorithm is a proactive protocol that uses a limited flooding of location update message [50]. In DREAM, each node maintains a position database that stores position information of all neighbour nodes which is connected directly to the relay node within the network. It has a location service database and can therefore be classified as an all-for-all approach. Thus, each node regularly floods packets to update the position information of other neighbour nodes [96].

In DREAM, the concept is sent to all others who live nearby whose routes are supposed to be the area that is likely to contain the place *D*, known as the predicted area. The expected area is identified by the tangents from the resource *S* to the group based at *D* and with distance similar to a maximum possible activity of *D* since the last place update. The others of a nearby hop will do again this process while using their details on *D* position.

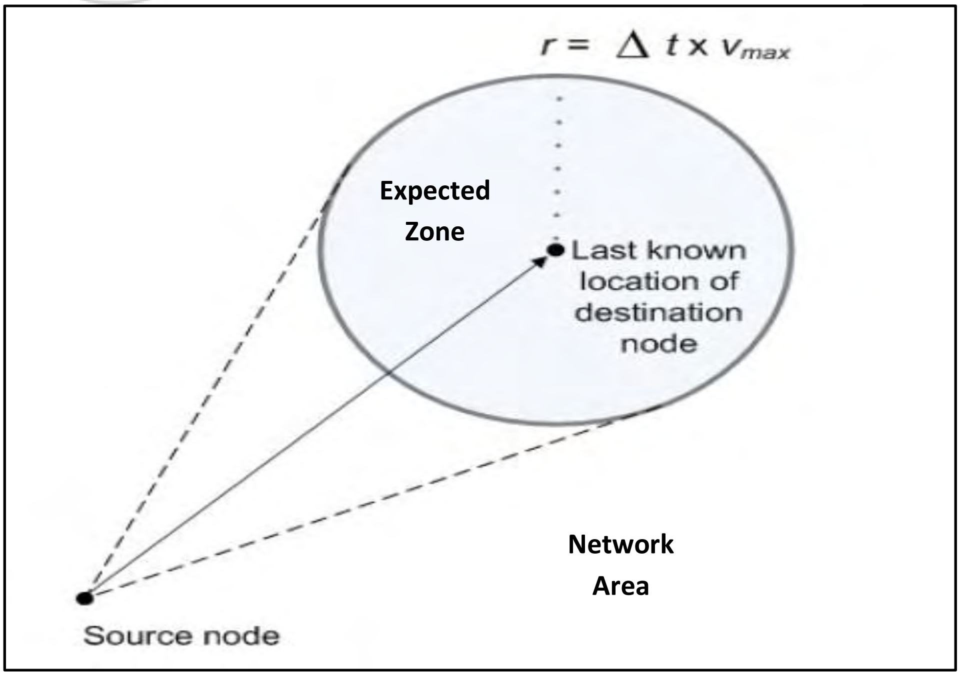

Figure 2.5. Illustration of progress with DREAM.

Figure 2.5 gives an example for the predicted area in DREAM. If a node does not have a one-hop next door neighbour along the required route, a restoration process would begin. However, this process is not an aspect of the DREAM requirements [56].

Due to the fact that DREAM uses limited directional flooding to forward information packets, there are several duplicates of each packet at the same time. This improves the prospect of using the maximum path; however, it reduces its scalability to large systems with a higher volume of information signals and makes it more suitable for programmes that require a higher stability and fast message distribution for infrequent information signals.

2.7.2.3 Location-Aided Routing (LAR)

Location-Aided Routing (LAR) [86] is an example of a limited searching discovery routing protocol; however, limited flooding is used in LAR for direction finding purposes, as in DREAM, for packet sending. Hence, LAR suggests the route discovery stage of reactive ad-hoc routing techniques. The predicted area is set from the source based on the available position information (e.g., from a route that was established earlier). A request zone is determined as the set of nodes that should forward the route discovery packet. The demand zone generally contains the projected area [96]. Two demand area techniques have been suggested. The first plan is a rectangle-shaped geographical area. In this case, nodes will send forward the packet to a direction finding only method if they are within that specific area. This type of demand area is shown in Figure 2.6.

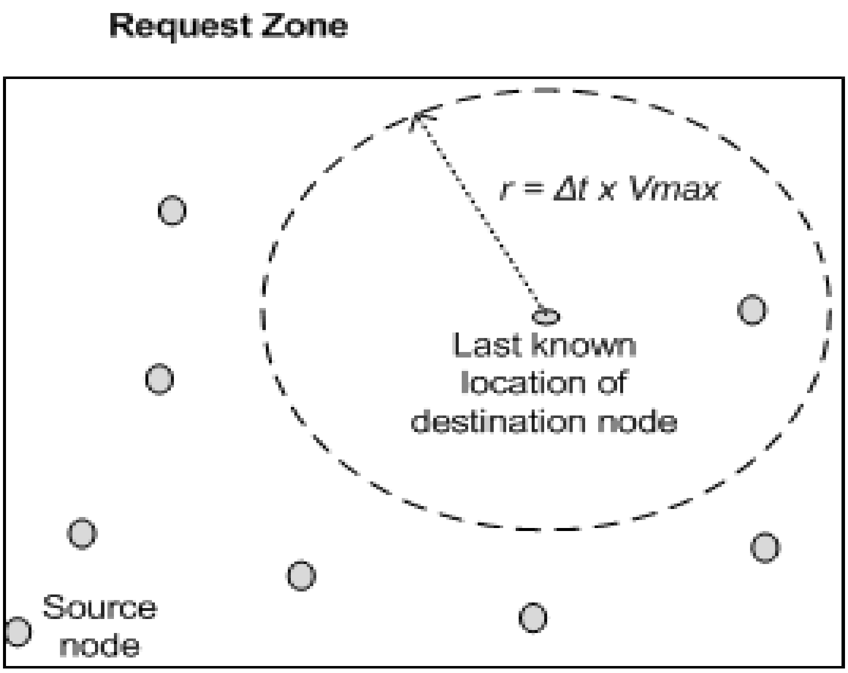

Figure 2.6 . Source node within the expected zone.

In LAR plan 2, the resource or an intermediate node will forward the message to all nodes that is frontward to the location other than itself. Thus, the node that gets the direction demand message will examine if it is nearer to the location and it will retransmit the direction demand message; otherwise, it will drop the packet. To find the quickest direction within the network, instead of choosing only one node as the next hop, several nodes would be chosen for handling the direction route request and each of them will put its identification (ID) while dealing with the header of the request packet. Therefore, the direction through which the direction route request is approved will be stored in the header of the message; route path will be established through being far from the resource and the routing overhead will be increased.

Figure 2.7 illustrates a transferring of node S, where the improvement of a node A is determined as the projector screen onto the range linking S and the ultimate location of transferring node S and getting node A next door neighbour is in ahead route if the improvement is beneficial (for example, for transferring node S and getting nodes A, C, and F in Figure 2.7).

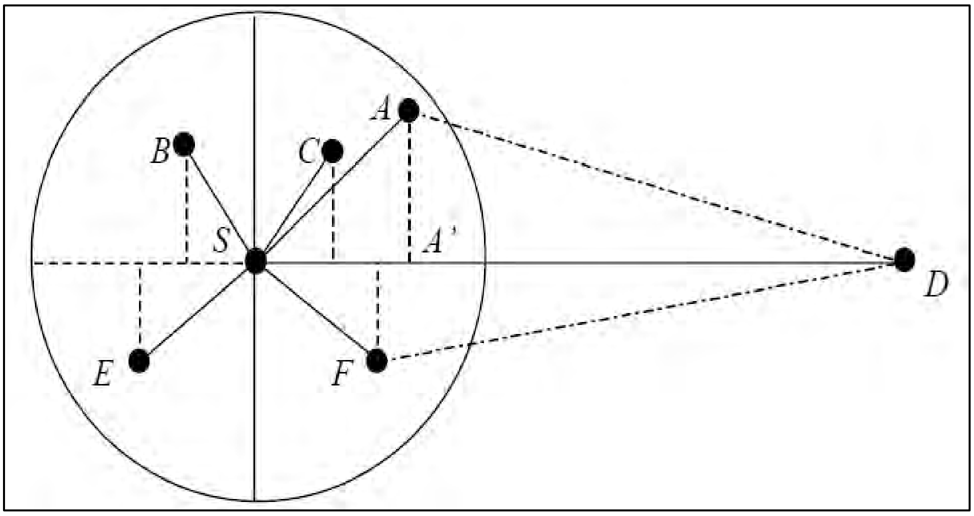

Figure 2.7. Positive and negative progress: C, A, and F are in forward direction, with a positive progress (for example, A'D < SD); nodes B and E are in backward direction, with a negative progress.

Thus, in all suggested position-centred routing protocols, the actual concept is to deliver the information packet forward from sender node to a next door neighbour within its transmitting range that is nearer to the location then itself. With this strategy, good improvement is achieved when forwarding to the location [58, 97]. Primary Range, Progress, and Route Based Methods use these ideas to choose among others which nodes live nearby the next redirecting step.

2.7.3 Energy-Aware Route Selection

To maximise the network lifetime, some consideration should be given to the mechanism that is efficient in route selection. In the basic routing protocols [98, 99, 100], shortest-hop metric is used to select the best route. Most of these relay nodes will be used repeatedly for data transmission, causing this node to lose energy rapidly and thus leading to lost network connections. Therefore, route conversion needs to be performed to balance the traffic load at a node so that it would not experience rapid energy decline. In nature where node behaviour is dynamic, its capability to adjust power based on link distance often leads to the formation of a path with larger number of hops. A link cost that includes the receiver power as well is presented in previous research [101]. Researchers dealing with energy-aware routing had also considered the battery capacity of individual nodes, such as battery-aware routing algorithm that typically aims to extend the lifetime of the network by distributing the transmission paths among nodes that currently possess greater energy/battery resources. Such algorithms are based on the observation that minimum-energy routes can often unfairly penalise a subset of the nodes, e.g., if several minimum-energy routes have a common node in the path, the battery of that node would be exhausted quickly. Among such battery-aware algorithm, a node metric was formulated [102], where the capacity of each node was a decreasing function of the residual battery capacity. A minimum cost path selection algorithm then would help to evaluate routes where many of the intermediate nodes are facing battery exhaustion. Since this mechanism could still lead to the choice of a path having a node that is nearing energy depletion (especially if the other nodes on the path has high residual energy), the basic MMBCR algorithm and its CMMBCR variant [103] would formulate path selection as a min-max problem. In this approach, the capacity of a route is defined as the battery level of the critical (most drained) node; the algorithm then selects the path with the highest capacity. The proposed strategy in this thesis introduces some new metrics that can prevent short node death due to the ineffective remaining battery power of its neighbour nodes.

The strategy is the combination of (trade-off between) two metrics; energy-distance factor in deciding which neighbour the packet should forward to. In the proposed strategy, the packet sender of the forwarder node selects some neighbour nodes which have forward progress toward the destination node. It will again select some of them which have more similar rho (ρ) with its own capacity.

2.8 Existing Energy Routing Techniques

Development of efficient algorithms must take into account several factors to ensure the set objectives are achieved. Some energy-aware techniques for achieving energy efficiency in maintaining network connection lifetime are long and complicated. Among the proposals is to broaden the energy at the nodes (remaining, conservation, and utilisation) while considering the energy costs at the nodes during the formulation of the route between the source and destination nodes. However, there is still a gap that needs to be filled in guaranteeing a more constant network relationship lifetime. In this thesis, various techniques investigated to overcome those highlighted inadequacies, which will be further elaborated upon through compare and contrast of algorithms.

M. Azim et al. [104] performed research and recommended the use of brief variety and non-distance communications between indicator nodes. Figure 2.8 represents the way of getting the required energy during transmitting.

determine the variety of nodes to signify the relay node. Moreover, it can also figure out the most possible node to be the node nearest to the direct link from n to the relay nodes. However, the DEAR algorithm is not able to evaluate the available residual energy of the chosen node. This measurement is necessary to ensure that the node does not run out of power during function.

In a related investigation, L. Ren. et al. [106] suggested the Distance-Based Power Effective indicator Positioning (DBEEP) for life-time maximisation that would together improve link stability, interaction range, and system size in a time-driven straight line WSN. The visitors fill controlling is a crucial problem that must be resolved at each node in a healthy visitor's circulation on a particular node which can increase the network lifetime. The writer came up with a power design with a supposition that the available nodes are toward the range except when that particular node is missing. In this design, establishing the agreement of nodes is relevant to the range implemented along the range nearby node range, which is designed as $d_1 > d_2 \ldots > d_n$, to ensure linking protection. In the same way, another research [107] described a way of managing power consumption by managing the best possible router location. The number of nodes should also be taken into account as well as the interaction costs and the quickest path.

Several techniques were developed to reduce power/energy utilisation [18, 105, 106]. For example, Yi Zang, et al. [108] suggested a new power-aware routing algorithm depending on mobile agent (PARAMA). The purpose of using an agent is to provide information about each specific node to all nodes in the system (including their link states). In order to do this with least overhead cost, the node selection is in accordance with the staying battery power potential (i.e., above the threshold) and shortest path. However, the value of the remaining energy cannot be performed to evaluate the real value of each node's energy in network functions. Nen-Chung Wang and Yu-Li Su [109] suggested a power-aware multicast routing protocol (PMRP) with flexibility forecast for addressing this issue. The suggested method contains a route discovery and maintenance process. In the proposed PMRP, the authors defined three parameters, namely the total power consumption of transmitted data packets (Pprediction), the Link Expiration Time (LET), and the Route Expiration Time (RET). The PMRP uses remaining power to forward a packet to a neighbour node using the Pprediction calculation. This is to ensure that the intermediate node would have enough power to deliver the information packets. If not, the packet will be decreased and rebroadcasted to another nearby node. Meanwhile, path servicing uses regional procedure of restoration. Maleki et al. [17] suggested the Power-aware Resource Redirecting (PSR) criteria strategy would improve the DSR. The purpose of the PSR is to improve the useful support lifestyle of a MANET. In the PSR, route finding and servicing are more complex in comparison to their alternatives in the DSR. In the PSR, all nodes except the location node determine their link price for route finding by making reference to the staying (threshold available) power on the nodes. The PSR uses the source node to initiate the route finding whenever route error happens. Ching et al. [24] presented an on-demand power-aware routing protocol that enhances the overall system lifetime by processing the possible remaining energy after information transmission. This method chooses the most possible direction that can transmit a great deal of information. The authors used the link bandwidth usage and possible link lifetime between two mobile nodes to estimate the quantity of information passed on along the link. Subsequently the quantity of information passed on through a direction can be obtained. This enhances the overall system lifetime based on the predicted remaining energy.

In a similar vein, Banerjee and Misra [110] developed a transmitting energy flexible algorithm to discover the minimum energy routing path. This is done by using systematic methods to discover the best possible transmitting energy on each individual direction in a multi-hop wireless network. The study only focused on the energy cost suffered at those nodes that are within the receiving range, but not the location nodes. The results indicated that the number of packets has a greater impact on energy consumption than the packet size. Moreover, the energy consumption of non-productive method is high. Routing in a wired network depends on the quickest direction and tiniest delay. In a wireless network, the metrics vary since the energy restriction is only an issue found in the mobile ad-hoc network. In this case, redirecting through the nearest node could speed up the power failure of that node. Therefore, other actions should be considered in alleviating this issue.

In a further development, Power-Aware Multi-Path Routing Protocol (PAMP) [111] is an extension of the Ad-hoc On Demand Distance Vector (AODV) which focuses on establishing multiple paths by introducing four features, namely (i) energy adaptable information with modified control packet and routing table, (ii) duplicate Route Request (RREQs) management, (iii) energy-based route selection at the destination, and (iv) energy management during date delivery.

In the PAMP, the location node decides the tracks to set up several tracks in such environment and finish information distribution. In this example, three paths are recognised. Each of those three paths has smaller power than the source's demand. However, the sum of the efforts meets the demand. The benefits of PAMP is that it facilitates more stability and longer system lifetime with the development of paths that have high power based on the available power and arranged power of the node and direction. However, the inadequacies of the PAMP consist of improved redirecting expense and inattentiveness because the chosen node has greater power available for the RREQ sending to the next node until it gets to the location. Moreover, the PAMP might cause a link relationship to fail when typical nodes break. Gradually the other paths will also be harmed.

Effective usage of power on a node in the MANET environment is required as these mobile nodes have restricted lifetime. K. Miskin et al. [112] suggested the Energy Control Energy-Aware with low overhead and topology scheme. The main aim of this suggested routing protocol is to increase the lifetime of a network with low overhead cost while accomplishing many preferred features of redirecting method of MANET. It chooses the maximum routes using power conscious measurement and maximises the ability intake, expense, and data transfer usage. It facilitates stability by offering node disjoint routes that provides the balance (increasing nodes lifetime) by circulating the load of routing and congestion control.

This strategy would achieve a stable relationship with enhanced power consumption, overhead, and bandwidth usage. However, the suggested strategy does not take into account the lowest depended hop or shortest path to ensure the lowest node participation with the best possible energy cost. This could impact the network lifetime efficiency.

Similarly, the Power-Aware on-Demand (PAOD) routing protocol was proposed by Wang Kun et al. [113] with the objective of maximising the system lifetime of MANET. The idea of PAOD includes; (i) traffic anticipation (i.e., the source is able to anticipate the traffic of the request), (ii) energy reservation (the node on the route should make energy reservation for the request according to the anticipated traffic); (iii) energy threshold (a node could participate in route discovery only when it has logical residual energy), and (iv) a new path cost function (this is used in route selection which considers both the shortest-hop and maximum lifetime).

Meanwhile, J. Chenl et al. [27] had suggested the Amount of Power Consumption (REC) strategy to accomplish enhanced node lifetime. In the REC, there are three different prices of node consumption levels, namely Low Amount of Power Consumption (LREC), Regular Amount of Power Consumption (AREC), and Great Amount of Power Consumption (HREC), which are depending on two thresholds: thresh1 and thresh2. For each stage (Low, Regular, and High) of consumption rate, the writer distinguished the rest of the energy of a node into low (indicates node is critical) as well as recurring energy (indicates node is not critical). The weak points of REC are the failing of specified variety of recurring energy in the limit value, cost operation of each node, and build-up of take part nodes in the route path. The node chosen in the first stage of determining limit value might not take the burden to successfully pass on the packet.

Another research [114] presented a redirecting method known as Energy Visitors Direction Choice Routing (PTPSR) that takes into consideration the ability preservation and traffic stability. The PTPSR redirecting method uses certain implementations from Ad-hoc On Requirement Multipath Range Vector (AOMDV).

For example, it creates use of the cycle independence guidelines and disjoint path requirements from AOMDV to find several loop-free and disjoint routes. Apart from executing path finding responsibilities, the RREPs and RREQs also collect the ability and traffic information needed for the path selection. However, the bottle-neck node with lowest residual power in a path was not regarded, which may cause the network to be disconnected.

Meanwhile, Banerjee et al. [115] suggested the Energy Conscious Multicast On-demand Redirecting [PAMOR] as a method that views the current power in each mobile location before making the routing decision. The protocol tries to get over the malicious actions of the current node taking part in a specific path between the source and destination by supposing that every node understands about the lowest energy (threshold value) required for delivering or getting the data packet. This suggested protocol also guarantees a better efficiency with regard to data transfer usage. However, the expense decrease can be more effective by considering the lowest depended hop or shortest path in the path selection choice.

In another development, W. Kun et al. [113] suggested a Power Aware On Demand routing protocol (PAOD) with the objective of maximising the MANET system lifetime. The method refers to the sufficient time a node uses up for its power initially. It uses logical residual power returned by the limit function, and rebroadcasts the packet out only if the rest of the power is greater than the limit power. The PAOD makes the path choice in accordance with the physical recurring power, shortest-hop, and maximum-lifetime. The path choice is in accordance with the information of the intermediate nodes. This method makes routing connection more reliable on path finding.

Next, Liansheng Tan et al. [116] suggested the highest possible amount allocation specifications, known as Lifetime-Aware Multipath Maximum Course-plotting (LAMOR) as a potential solution. This solution specifies the lifetime for several paths to avoid when using the same paths for any given guest specification, which would cause a fast exhaustion of nodes power, criminal activity of the links, and untrustworthy information transferring. PAOD [30] and LAMOR [31] recommended an energy-aware redirecting technique that provides the power of the nodes along the route. However, these techniques only use the nodes which have enough power to meet with the source requirement.

Similarly, Anjina et al. [112] recommended a routing protocol that can increase a network lifetime with low overhead cost while achieving many desired features of MANET. It selects the optimal paths using power-aware metric and optimises the power consumption, overhead, and bandwidth. Kee-Young Shin et al. [117] came up with REAR to set up routing paths by considering residual energy potential of each indicator node that supports multi-path routing protocol for efficient data transmitting in Wireless Sensor Network (WSN). The REAR views current energy of indicator nodes when it determines routing routes from source to location. In REAR, the staying energy of the intermediate nodes is rationally separated into two parts; arranged and available energy. Figure 2.9 shows a sensible energy partition in an advanced node. Energy is arranged during path setup for service and/or for back-up routes. Therefore, this part of the energy is no longer available unless it is released. The focus is only on the available energy at the node instead of the remaining energy when selecting the node to build a path.

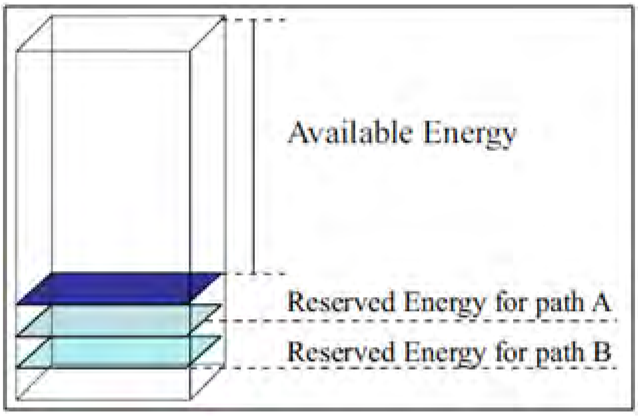

Figure 2.9. Logical energy partitions at intermediate nodes.

In accordance with the literary works, the power-aware or energy-aware strategy has assisted to enhance the network connection of the mobile network lifetime. However, there has not been any focus on the energy owned and operated by an individual node. For example, the suggested strategy only views the average cost value on the path and the energy of the node. This does not indicate the real value of the node potential.

While regarding this issue, Murali et al. [118] described the use of a proactive approach on top of the two route techniques which include information and management routes. The information route is used for transmitting of data packets, while and the management route is for method access. This means that when a node joins the network, its information route is turned off to preserve battery power source. The management route is kept active and ready for transmitting. To reduce the difference of the node energy in the network, the idea of "refresh intervals" is used. With the help of path recalculation at renewed durations, difference of the network can be reduced. If a huge slice of data is passed on over the same nodes, battery power will get used up quicker. The use of renewed period is to ensure that the same nodes do not get used quite often. This helps to specifically preserve battery power resources, and generally increase the network lifetime.

Next, various place conscious protocols were taken into account. Among them is the Location Aware Redirecting (LAR) [62, 116, 117]. LAR is an on requirement routing protocol. In order to decrease the expense of upcoming path finding, LAR delivers place details to all packets. By sending packets to the whole ad-hoc network, LAR floods the packets in its sending area by using its place details. Nevertheless at a lesser rate, the LAR is able to lower the overall end-to-end waiting time and achieve overhead control [119]. This weakness of is addressed by the Distance Routing Effect Algorithm for Mobility (DREAM) [32]. A location node provides distance details regularly to the source node on the foundation that the source node enquires or shows packets in the particular route and decreases the routing load.

Additionally, Yu Wang et al. [120] suggested a Nearby Energy Conscious Limited Community redirecting DREAM to assure the distribution by using face routing as a back-up. In DREAM whenever possible, the node chooses its next door neighbour within a little neighbourhood (defined by a parameter α) that has the biggest energy usage (i.e., the range visited per device energy consumed) as the next hop node. Hypothetically, DREAM is power effective. For example, when DREAM routing finds a direction from the resource to the target node, the complete energy consumption of the discovered path is within the best possible continuous aspect. DREAM also shows that the complete Euclidean duration of the discovered path is within the continuous aspect.

Meanwhile Li et al. [121], presented the Positional Attribute depending on Next-hop Determination Approach (PANDA) that uses positional features (e.g., transmitting energy consumption and residual battery power) to figure out the rebroadcast wait around of each sending node during the path finding stage. A forwarding algorithm is developed where each attribute is considered independently. Another research [12] investigated the efficiency assessment by viewing the previous edition of PANDA-TP (transmission power) [122]. PANDA-TP was designed in accordance with the fact that for a given range, increasing the number of hop matters will reduce the total transmitting energy absorbed. Therefore, the rebroadcast wait around would be smaller if the range between the upstream next door neighbour (immediate sender of path demand packet) and the involved sending node is less. The location will wait around for adequate time period to gather enough path information before determining the path that the source packet should travel.

The important objective of a routing protocol is to keep the network performing as long as possible. As mentioned previously, this objective can be achieved by reducing mobile node energy, not only during effective interaction but also when they are non-active. Transmitting energy control and fill submission are two techniques to reduce the effective interaction energy, and sleep/power-down method is used to reduce energy during lack of transmission. After introducing the current routing protocols, it can be grouped as part of three techniques, as listed in Table 2.4. The methods that are part of each of the three techniques for energy-related metrics that have been used to determine energy efficient routing path instead of the shortest one are mentioned. They are [102]:

- energy consumed/packet,

- time to network partition,
- variance in node power level
- cost/packet, and
- maximum node cost.

Table 2.4.

Classification of Energy Efficient Routing Protocols

Approach		Protocols	Goal
Minimise Active Communication Energy	Transmission Power Control	• Rate of Energy Consumption (REC) [27] • Maximum Available Power (MAP) [104] • Distance-based Energy Aware Routing (DEAR) [105] • Power-aware Multicast Routing Protocol (PMRP) [109] • Flow Argumentation Routing (FAR) [123] • Online Max-Min (OMM) [124] • Power aware Localised Routing (PLR) [125] • Minimum Energy Routing (MER) [126] • Power-Aware Routing Algorithm based on Mobile Agent (PARAMA) [108] • Power-aware Source Routing (PSR) [17] • Power Aware Multicast On-demand Routing [PAMOR] [115]	Minimise the total transmission energy but avoid low energy nodes

		• Residual Energy Aware Routing (REAR) [110]	
		• Power Management Energy-Aware (PMEA) [112] • Retransmission-energy Aware Routing (RAR) [127] • Smallest Common Power (COMPOW) [128]	Minimise the total transmission energy while considering retransmission overhead or bi-directionality requirement
	Load Distribution	• Conditional Max-Min Battery Capacity Routing (CMMBCR) [22] • Localised Energy Aware Routing (LEAR) [24] • Power-Aware on-Demand routing protocol (PAOD) [113] • Distance-Based Energy Efficient Placement (DBEEP) [106] • Power-Aware Multi-Path Routing Protocol (PAMP) [111] • Power Traffic Path Selection Routing (PTPSR) [114] • Lifetime-Aware Multipath Optimal Routing (LAMOR) [116]	Distributed load to energy rich nodes
Minimise Inactivity Energy	Sleep/Power-Down Mode	• SPAN [129] • Geographic Adaptive Fidelity (GAF) [130] • Prototype Embedded	Minimise energy consumption during inactivity

		Network (PEN) [131]	

Here, each wireless link is annotated with the link cost with regard to transmission energy over the link and the minimum-power direction is the one that reduces the sum of the link costs along the direction. The first metric is useful to offer the minimum-power direction through which the overall energy consumption for handling a packet is reduced. However, a routing algorithm using this metric may result in the outcome of uneven energy invested among mobile nodes. When some particular mobile nodes are badly overwhelmed to support many packet-relaying features, they consume more battery power energy and stop running more than other nodes, thus interfering with the overall performance of the ad-hoc network. Therefore, increasing the network lifetime (the second metric) is a more essential objective of an energy effective routing algorithm; given alternative routing paths, the method would choose the one that has an outcome of the lengthiest routing function time.

Due to the difficulty of estimating the future network lifetime, the next three metrics had been proposed to make it happen indirectly. Variance of recurring battery power energies of mobile nodes is a simple indication of power balance and can be used to extend network lifetime. Cost-per-packet metric is similar to energy-per-packet metric, but it includes each node's residual battery power in addition to the transmitting power. The corresponding energy-aware routing protocol prefers the wireless link requiring low transmitting power, but at the same time prevents the node with low residual power with node cost to be considered high. With the last metric, each direction candidate is annotated with the maximum node cost among the intermediate nodes (equivalently, the minimal residual battery power life), and the path with the minimum path cost, min-max cost, is selected. This is also referred to as max-min cost in some protocols because they use the nodes' residual battery power rather than their node cost.

2.8.1 Sleep/Power-Down Mode Technique

In the communication mode of inactivity, most radio communications hardware will switch to use low power. The radio subsystems will change to sleep mode or turn off the nodes to save energy. For example, the *Lucent WaveLAN-II* uses standard power of 250 mA and 300 mA in the process of receiving and transmitting, but only uses 9 mA in sleep mode, i.e., in accordance to the *IEEE 802.11* LAN standard [131, 132]. However, when an apparent node is in sleep mode, the node does not hear the packet to be accepted. This causes the packet to be unable to be transmitted to the destination node. Therefore, there is the need to select a potential relay node as an effective node in order to coordinate the communications process on behalf of the other nodes. Other neighbouring slave nodes can save battery power energy. The slave neighbouring node will periodically wake up and communicate with the parent node to determine if there is any data packet to be received. In MANET, the concept of multi-hop that needs more than one parent node is required to cover the entire MANET communications.

2.8.2 Transmission Power Control Approach

The process of communication between two wireless nodes will basically involve the transmission power control for adjusting the propagation of radio transmission to find the optimal path [19, 132, 133]. When the transmission power can be adjusted on a node, then the node can control the transmission distances. With this, the number of forwarding nodes can be adjusted [19, 134]. Although the increase in transmission power can reduce the number of hops in a path to the destination, when high power transmission is used, the probability of nodes that have low battery power will die prematurely. Meanwhile, weak transmitter power will divide the network topology and cause end-to-end delay due the a larger hop count [13, 134].

2.8.3 Load Distribution Approach

The distribution of the load in the transmission mode is to balance energy consumption at a node by choosing a path with nodes that are not fully utilised and not the shortest route [25, 135]. This causes more time tracks but packets are directed only through energy-rich intermediate nodes. This strategy does not actually provide the smallest power path, but avoids certain nodes from being overloaded, and thus, guarantees more network lifetime [133]. This approach had been used in protocol such as Localised Energy-Aware Routing (LEAR) [24] and Conditional Max-Min Battery Capacity Routing (CMMBR) [22] protocols.

2.8.4 Transmission Power Optimisation

Since all the nodes in the MANET are involved in routing algorithms, the information must be available and distributed at each node, which include link cost and remaining battery energy of the nodes. The methods in this classification are Flow Augmentation Routing (FAR) [123], Online Max-Min Routing (OMM) [124], and Power aware Localised Routing (PLR) [125]. A strategy is used to balance the ability consumption by preventing low power nodes when choosing paths. The primary goal of Minimum Energy Routing (MER) method [126] is not to provide power effective routes but to make the given paths power effective by modifying the transmitting power just enough to reach to the next hop node. Table 2.5 shows the types of information required and the strategy used to improve energy efficiency and avoid low power nodes.

Table 2.5.

Information and Approach to Optimise Energy Efficiency

Routing Protocol	Required information at each node in addition to that obtained during operation	Approach to optimise energy efficiency and to avoid low energy nodes
FAR [123]	Link costs of all links Node costs of all nodes Data generation rate at all nodes	- Use graph optimisation algorithm - Include node cost in the link cost
OMM [124]	Link costs of all links Node costs of all nodes	- Use graph optimisation algorithm - Select the max-min path among a number of best min-power paths
PLR [125]	Link costs of some links (from itself to its neighbours and to the destination) Node costs of some nodes (all its neighbours)	- Use graph optimisation algorithm - Include node cost in the link cost
MER [126]	None (each source node will obtain the link costs through the routing algorithm employed)	- Adjust the transmission power just enough to reach the next hop node in the given routing path

2.9 Summary

Most of the ad-hoc mobile devices for personal communications are powered by a battery. Therefore, a study on energy-efficiency in wireless networks is needed, especially when the issue of energy restrictions has been recognised as the primary hurdle for wireless networks, especially MANET. In order to accomplish interactions within the MANET, an effective routing protocol is needed to discover an appropriate or optimally efficient path between mobile nodes. Performance is one primary problem in the MANET, especially in developing a routing protocol. In this section, this author described the node energy related issues, strategy of packet sending, and categorised a number of energy effective, as well as aware, routing schemes. In many cases, it is difficult to compare them directly since each protocol has a different objective with different presumptions and utilises different means to make it happen. For example, when the transmitting energy is manageable, the maximum modification of the energy is essential not only for energy preservation but also for the disturbance control. When node density or traffic density is far from consistent, a load submission approach must be employed to relieve the energy discrepancy problem. The sleep/power-down method strategy is basically separate of the other two techniques because it concentrates on reducing standby power consumption. Therefore, research is required to merge and incorporate some parameter the methods provided in this section to keep MANETs operation for a more lasting connection lifetime.

CHAPTER THREE

RESEARCH METHODOLOGY

This research was designed at developing and analysing Energy-Distance Aware Protocol (EDRA) and its associated techniques. In this chapter, a research methodology for efficiency assessment of EDRAs is presented.

Following this section, the techniques for analysing network protocols is explained, namely analytical modelling, measurement, and simulation. Section 3.2 explains the technique for evaluating the routing protocol. Section 3.3 describes the selection of network simulator, while Section 3.4 justifies the simulation model used in this research. Section 3.5 explains the network topology used in the simulation environment and Section 3.6 justifies the parameter setting in network simulation. Meanwhile, Section 3.7 elaborates the validation and verification of network simulators and protocol implementation. Next, Section 3.8 describes the performance metric used in this research. Finally, Section 3.9 summarises this chapter.

3.1 Introduction

In a routing protocol, the participation of nodes in paths is the first issue related to the condition of network connection. The connection of nodes within the network environment is highly complex, which in turn leads to difficulty in predicting the behaviour from the first principle [134]. Therefore, implementing a prototype and deploying it on the actual network with the aim of studying the effects of network components (device and site) will cost time and effort. So, the only way this can be achieved is by simulation [135]. It is very important to emulate a routing protocol as realistically as possible and provide some methods of evaluating various strategies that might be used to optimise the routing protocol. Hence, experimental research methodology is the appropriate methodology for such research. Table 3.1 shows the core activities in the methodology used in conducting this research and fulfilling the objectives of the thesis.

Table 3.1.

Research Methodology Phases and Expected Output

Step	Output
Analysing the research problem	**Review of literature:** Criticise the current work and determine the weaknesses and gaps.
Designing the new algorithm	**Identify current mechanism specification for:** • Conceptual framework • Proposed algorithm process
Implementing the new algorithm	• Refining the simulation code • Finalising the algorithm
Evaluating the new algorithm	• Specify simulation environment • Specify performance metrics • Raw data collection • Final result Data analysis and interpret

The core activities are divided into four steps and discussed in detail throughout this chapter.

- The first step aims to perform an in depth study on the design of a new routing algorithm and surrounding issues. In this phase, the strengths and weaknesses of node selection strategies are identified, while areas that should be eliminated and enhanced are explored.
- The second step works with the design of the new routing algorithm. The designs processes involved include determining design requirements, objectives, specifications, and justifications for the new algorithm.
- The third step works with the implementation and verification of the design of the new routing algorithm.
- The fourth step executes a performance evaluation of the new algorithm by comparing it with existing algorithms.

The next sections describe the detail of each step of the adopted research methodology.

3.2 Techniques for Evaluating Routing Protocol Network

Commonly, there are three different approaches that can be used to evaluate the routing protocol in network systems, namely analytical modelling, experiment, and simulation research. However, one research may cover one or more of these methodological research areas [136].

3.2.1 Analytical Modelling

Analytical modelling is the process of developing, fixing, and approval of the analytical design. This method can only be used to research simple techniques, and if it is used to research a complicated system, significant amounts of generality and presumptions are needed [137]. Redirecting methods in network systems are too complex to be reasonably made and analysed with analytical techniques [138]. Using analytical modelling to evaluate performance of a computer network has two major drawbacks [139]. The first is that it makes too many simplifications and assumptions, which inhibit the model from representing the actual behaviour of the system. The second is that it ignores interaction, however; in reality this interaction is the main factor that affects the routing protocol network performance. The drawback limits analytical modelling to evaluate small scale networks with limited network behaviour [140]. Therefore, using analytical modelling to evaluate a complex routing protocol network system will result in inaccurate performance evaluation.

3.2.2 Measurement

The measurement approach for performance evaluation of routing protocol network systems is measuring the performance of a real efficient routing protocol system or the prototype of the routing protocol. Using this technique, a researcher can design prototypes of routing protocol network system and test them in a specific network environment. This can be done in a laboratory using a test-bed (using network emulator) or actual network. The performance of the prototype would be investigated and evaluated during and after the running of the prototype.

The environment (both test-bed and real network) in which the prototypes are to be tested, requires real equipment and programs. Since it uses real equipment and programs, the result of the evaluation reflects the actual performance of the system in an actual network. Therefore, it can be the ideal approach for a routing protocol performance evaluation provided there is sufficient network infrastructure to support the requirements of the performance evaluation. However, efficient routing protocol systems are very complex. The routing path in this work require massive mobile network infrastructure in order to perform measurement of performance evaluation, which is beyond the capacity of this research.

3.2.3 Simulation

Computer simulator is a method for formulating a wide range of designs of real-world techniques by using specific simulator software designed to mimic the techniques, function, or features [141]. Similarly, routing protocol network environment simulation is the discipline of designing a model of a theoretical routing protocol network system, executing the model, and analysing the execution outcome using network simulator software. Using network simulation, a routing protocol network system can be designed and customised easily. Adjustment or difference in the design can be done by renovating and/or modifying certain areas of the design. The customised design can be re-evaluated until the preferred results are obtained. This allows for discovery of complicated circumstances that ensure the correctness of the research and evaluation.

Simulation is an excellent strategy to design and assess a complicated system [142] because real-word systems are too complicated to be designed on a test-bed.

Simulation methods are most commonly used in operations research, control technology, and network efficiency assessment [143, 144]. In the field of redirecting method network systems, simulation has appeared to become the primary analysis technique used by many studies. Therefore, in this analysis, this researcher employed a network simulator to evaluate routing network protocols.

3.3 Network Simulator

There is a wide range of network simulators available for the purpose of investigating the performance of routing networks. Some network simulators are freely available to network researchers, while others are available as commercial simulation packets. In this research, the researcher has designed and implemented a new network protocol. For this reason, it is important that the researcher has full control over the simulation packets that are used in this study. In particular, this researcher is able to write new modules and to modify the existing modules to satisfy the design of protocols. For budgetary reasons, this researcher is more interested in freely available network simulators, but without compromise on the credibility, accuracy, validity, and reliability of the simulation. Ns-2 is a credible network simulator, which is developed as part of the Virtual Internet Test Bed Project (VINT) [145]. Simulation of Ns-2 is a discrete event simulator, and is written in both C++ [146] and the Object-oriented Tool Command Language (OTcl) [144]. Its core modules are implemented in C++ while its interfaces are implemented in OTcl. Implementation of new modules and additional functionality to Ns-2 can be done either with new C++ methods or OTcl procedures. Ns-2 is an excellent tool to study the behaviour of complex and dynamic systems such as the behaviour of protocols in network systems. Currently, Ns-2 is the most widely used for network simulation packets [147], as well as:

- performance evaluation of existing network protocols,
- performance evaluation of new network protocols before real implementation in the Internet,
- running large-scale communication network experiments that are not possible in real experiments, and
- simulation of a variety of IP networks.

Ns-2 is a well-validated and well-documented network simulator. All Ns-2 modules have been validated by Ns-2 validation programs. The validation program contains detailed sets of tests on all modules of applications and protocols. Whenever new modules are developed, a new evaluation will be performed to ensure that the new modules work well with other parts of the Ns-2 base modules. The validation process of Ns-2 enhances confidence in the network simulator [148]. Since it was suggested previously [149] that the validity of simulation studies is very important, Ns-2 would be a good tool for conducting performance evaluations of computer network protocols.

As it has become the most popular simulation packet for network protocol performance evaluation, Ns-2 is very well supported by the research community. The Ns-2 mailing list [150] is very active and discussions go on all the time. Any problem thrown out to the mailing group for discussion receives an overwhelming response from members. With all these features, Ns-2 is the most appropriate simulation packet for this research needs, and Ns-2 was selected as the network simulator for this research. Using Ns-2, this researcher was able to design new modules that incorporate both C++ methods and OTcl procedures for modelling the newly proposed protocol. The new modules were then compiled, so that they could be used together with the other Ns-2 features.

3.4 Simulation Model

The MANET is a huge and complex network. Its infrastructure is highly heterogeneous, in particular the link bandwidth levels, transmission delays, host capabilities, traffic types, applications, and etc. To model the whole MANET in a simulation would be extremely difficult. Nevertheless, simulation was used in this research because there is a need to study particular aspects of the wireless routing protocol, i.e., interaction of energy-distance aware based routing. In designing the simulation model, this researcher tried to closely match the real mobile ad-hoc network environment as well as sufficiently meet the research requirements. Since the main features of MANET are that it has been known to function without an infrastructure and topology changes are not expected, hence there is a need for a rugged and robust routing protocol. Thus proper preparation is needed in conducting research in the MANET environment which requires determination and appropriate assumptions to be used, as was done by similar studies, within the carefully created environment.

3.5 Simulation Topology

The selection of appropriate network topologies in simulating the mobile network routing protocol is very crucial. The appropriate network topologies would ensure that it could represent and thus illustrate the problem under investigation, and the simulation results are as general as possible. In this research, all experiments for analysing the efficient routing protocol were conducted by means of extensive simulation using a well-known scalable node topology. The topology was selected while considering the assumption of MANET features with dispersion of nodes in a two-dimensional setting without barriers to the delivery packages. The node capacity within the network environment was fixed in three scales the number of nodes, where the lowest level of node number was 100 nodes and highest was 500 nodes.

3.6 Simulation Parameters

Parameters recreate the characteristics of a MANET that affects the performance of the system in the simulation. The outcome of a simulation depends heavily on appropriate parameter selection. Therefore, choosing the correct parameters is important in order to obtain the correct behaviour of the investigated efficient routing protocol. In this study, this researcher carefully set parameters for the investigated efficient routing protocol, and most of the settings followed the guidelines published by previous research [154, 155]. The parameter setting in this research is shown in Table 3.2.

Table 3.2.

Parameter Settings

Parameter	Value
Signal frequency	914e+6Hz
Receive power threshold	3.652e-10 watt
Receive power	0.2818 watt
Carrier sense threshold	1.559e11 watt
Default Transmission power[2]	0.2818 watt
Sensing range	550.0 meter
Propagation model	Two-ray ground model used in Chapter 4

	and 5
Path loss exponent	3.0
Reference distance	30.0 metres
Deviation	4 decibels
Antenna	Omnidirectional antenna
Antenna height	1.5 meter
Antenna transmit gain	1.0
Antenna receive gain	1.0
Interface queue length	150
Mac Protocol	IEEE 802.11
Bandwidth	2 Mbps
Traffic	Constant Bit Rate (CBR)
Packet size	512 Byte
Packet rate	4 packet/sec

3.7 Simulation Validation and Verification

As mentioned before, the performance analysis and comparison simulations were conducted using the Ns-2 network simulator as a tool to study the behaviour of the proposed MANET routing algorithm. The proposed EDFA, EDFS, and EARS algorithm protocols were implemented using C++ in the Ns-2 network simulator. This researcher had considered the following assumptions, as explained in the next sections, in order to implement the routing algorithm in Ns-2 network simulator.

3.7.1 Validation of Network Simulators

Validation is a process to ensure that the conceptual model accurately represents the system under study [137], so that the simulation results provide meaningful answers for the questions being investigated [148]. In this research, this researcher is concerned with the validation of network simulators and routing protocol implementation.

Ns-2 is a credible network simulator, which is supported by a large collection of detailed validation scripts. Researchers are encouraged to use the scripts to validate Ns-2. This is usually done after building the processes of Ns-2. During the validation process, the simulator is run using a specific set of input values with known output values. Then, the results obtained from the simulation are compared with the known output. If the results match the known output, then the Ns-2 is considered to be valid. However, if it fails or some of the comparisons do not match, a notification will be sent and the validation process needs to be repeated for the failed components. This process is repeated until the validation process is successful. The Ns-2 used in this study was validated using this validation process.

3.7.2 Validation of EDRA Implementation on Ns-2

This researcher validated the EDRA implementation in the Ns-2 by using run-time trace and incremental implementation. For every simulation that was performed, a checked run-time trace was examined to ensure it had run as expected.

3.8 Performance Metric

The taxonomy of energy efficient routing protocols based on various goals and performance metrics was used to determine an energy efficient routing path. Selecting performance metrics is an important part of the simulation methodology [13]. Throughout this thesis, a wide range of performance metrics were used. The metrics used have been used by other researchers to evaluate other routing protocols. Once the performance evaluation of routing protocols was conducted, a comprehensive comparison with the simulation tool is made by using various published performance metrics. The metrics represent different characteristics of the overall network performance. In most cases, it is difficult to directly compare the protocols with each other because each protocol has its own goal and assumptions. In addition, each protocol employs different mechanisms to achieve the goal. This study indicated that each protocol has different strengths and weaknesses. Due to these differences, no single protocol can be an absolute solution to the energy issues in MANETs. The best way is to design each protocol according to the maximum possible requirements that fulfils certain required scenarios.

The simulation for conducting performance evaluation was implemented using Ns-2.34 [151]. The results were then analysed to observe the difference between the five major performance metrics used in Chapter Four and Five, which are described in detail as follows.

- Total energy consumption rate. It is the energy consumed per byte and computed as follows:

$$\frac{Total\ energy\ consumed}{Total\ throughput} \tag{3.1}$$

  The total energy consumed includes the total energy received and transmitted.

- Average node degrees. It is the computation of the average node degree measuring the effect of the transmission power updates on the interference. The node degree of any node is the number of nodes within its transmission range.

- Throughput. This is computed as the total number of bytes received per second.

- Drop ratio. The packet drop ratio is the ratio between the dropped packets to total packets sent during simulation time.
- End-to-end delay. This is the time a packet takes to be transmitted across the network from source to destination. The average delay for all the received packets is computed.
- Network lifetime. This is defined as the time it takes for the first node to die.

3.9 Summary

This chapter had described the alternatives for conducting performance evaluation of routing protocols, namely analytical modelling, measurement, and simulation. Analytical modelling is not a suitable technique for studying complex systems such as a routing protocol, while to develop a prototype and test-bed for experimenting complex routing protocols for MANET was beyond the resource capacities of this researcher. Therefore, simulation was deemed to be the ideal tool for this research. It can be used to accurately model routing for MANET and costs were within the budget constraints.

Ns-2 was chosen as the network simulator for this research since it incorporates all the routing protocol implementations that are required for this research. Moreover, Ns-2 is a credible network simulator and has passed certain validation and verification processes. In addition, it is a well-supported network simulator and is widely used by many researchers around the world.

The simulation models used in this study were described, along with the reasons why certain network topologies were chosen. In order to have credible simulation experiments, the network simulator (Ns-2) itself and the newly implemented Ns-2 modules were validated and verified. In addition, the performance metrics used in this research were described based on guidelines provided by prominent network researchers and previous research work. Finally, in order to ensure the validity of the analysis, a technique was established to determine the number of simulation runs.

Having establishing the methodology for this research in this chapter, the next chapter shall report the work on the scalar RTT estimation for routing protocol in MANET.

CHAPTER FOUR

THE DESIGN OF ENERGY-DISTANCE ROUTING AWARE (EDRA)

After previously establishing the research methodology for analysing the efficiency of the new designed method in Chapter 3, this chapter presents the design of the protocol method, namely EDRA. The chapter presents the existing obstacles regarding routing protocol on the ad-hoc network and especially how it can be resolved with a new algorithm that is the output of this study. Section 4.1 presents the overview of routing behaviour and routing process which involve moving nodes randomly while communicating. It also discusses the existing obstacles regarding Ad-hoc On-demand Distance Vector (AODV) routing protocol and how they can be solved.

4.1 Introduction

The proposed Energy Distance Aware Protocol (EDRA) protocol is an extension of the popular AODV protocol. The selection of AODV for this research was due to the fact that it has the basic features mentioned in earlier chapters and it is easy to be modified with the techniques used in the proposed algorithms. AODV keeps the basic route-discovery and route-maintenance of DSR and uses the hop-by-hop routing sequence numbers and beacons of DSDV. Therefore, in this chapter, the detailed design of the route discovery based on the EDRA is presented; followed by the design justifications, specification, and objectives for the new algorithm. The chapter ends by presenting the details of the proposed EDRA in route discovery and its processes.

The lifetime connection between the neighbour nodes on a path has real impact on the quality of the communication service discovery, provision service, and network reliability. Network lifetime relates to the time duration before 1) the first node dies, 2) the fraction of active nodes whose power drops below a threshold, or 3) the time until the aggregate delivery rate drops below a threshold. In this thesis, the second definition of the network lifetime was chosen, as this represents a major event that is more important than a single node failure (definition 1) or a drop in data rate (definition 3). Therefore, the proposed protocol utilised for the network lifetime connection, as optimal as possible, included potential node candidates selected from a scheme of Energy-Distance Factor Aware (EDFA), Energy-Distance Forward Strategy (EDFS), and Energy-Aware Routing Selection (EARS) protocols.

The uniqueness in EDRA compared with other conscious energy-based protocols is according to the following three aspects. Firstly, the scheme in the node selection algorithm, known as Energy Distance Factor Aware (EDFA), is based on the probability of candidate nodes (highest *rho*), that is, choosing a node that has a high value probability of the *rho* from energy-distance factor algorithm. Secondly, the scheme of Energy-Distance Forward Strategy (EDFS) algorithm is based on quadrant discovery of relay nodes within the network environment with an angle area adjustment of node discovery in the quadrant. Thirdly, the scheme of Energy-Aware Routing Selection (EARS) is based on the metric of maximum residual energy on cost path when the routes are established. With these three scheme algorithms proposed, the objective of this thesis can be achieved as interrelated functions of each other.

4.2 Related Model

Most of the mobile nodes in MANETs use power batteries where they have different capacities and capabilities in the early stages or after a long period of network operation. Power and capability nodes are usually referred to as size, model, property, and engineering capabilities since different battery manufacturers produce different capacities and decay rates [152, 153]. Each node has personal power for function and will accomplish lifetime function associated with the stage of power of nodes. Path finding would be more efficient if the node taking part in the path has efficient power to function within the transmitting range to the next-hop and handle the engaged number of packets [154].

4.2.1 Energy Consumption Model

One of the most important elements of powering radio devices in a mobile node is the energy consumption during the process of receiving and sending packets from neighbouring nodes [153, 155]. Any given node will be influenced by two factors, namely factor in the node itself and external factors. The internal factors are based on the efficiency of radio circuits to process packets received from and transmitted to neighbouring nodes. The transmission power and reception packet on the mobile node and a good energy model will determine the distance between transmitter and receiver, as shown by received signal strength indicator (RSSI). Meanwhile, external factors are the location and distance of source node to a neighbouring node or the next node. The signal strength received by any node has a relationship with signal attenuation with distance (such as $1/d^2$) where d is the relative distance that can be calculated among the two adjacent nodes. In the energy dissipation model [10, 156, 157], the transmitter and receiver have opposite functions. Functions and roles of each mobile node transmitting the packet are changed to a radio frequency signal. Then it is stimulated by the amplifier and transmitted through the antenna namely in the form of an electromagnetic wave (EM). Meanwhile, the receiver circuits will then convert the signal back into the form of an electric current in accordance with the characteristics of the same wavelength.

The power information contained in the physical layer on the nodes is read by the link layer while responding to the network layer [23, 153]. Based on the presumptions of individual power, energy consumption level of the network nodes can be extracted to for evaluation when the nodes transfer packets among each other.

Up to now, there have been many techniques for achieving energy efficiency used in MANET as described previously [17, 107, 115, 158]. A general energy efficient technique design was suggested by Rodoplu and Meng [153], and Li [159], with respect to the energy consumption between two nodes at range *d*, which is $u(d) = d^{\alpha} + c$ by continuous α and c with respect to the connection between the environment and the delivery of the device. Where α is the value of distance power gradient the path loss exponent reduction (attenuation) that usually fulfils a range ($2 \leq \alpha \leq 4$), the transmitting energy needed to achieve a node at range *d* is proportionate to *d* supposing that the continuous proportionality is 1 for notational convenience. They used the design with $u(d) = d^2 + 2 \times 10^8$, which is known as the RM-model in their tests.

The energy consumption design used in this thesis is known as the first order radio model [108, 112, 157, 160, 161]. Observe that the idea of energy design is not absolutely new. A identical idea known as energy model was first suggested by

Kuruvila et al. [162], where the energy consumption rate is between the nodes and the distance progress toward the destination. In this thesis, a supposition was made that allow resource and location nodes to be arbitrarily selected. An information packet can be produced at any node and can be sent to any other nodes, while the source-destination pair can regularly be modified over time. Each mobile node will consume energy for the transceiver process [163]. The radio model will consume E_{Tx} amount of energy to deliver a l –bits packet over distance d.

Let

$$E_{Tx-elec} = E_{Rx-elec} = E_{elec},$$

$$E_{Tx-amp} = \varepsilon_{mp}$$

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$= l * E_{elec} + l * \varepsilon_{mp} * d^2$$

$$E_{Tx}(l,d) = \begin{cases} l.E_{elec} + l.\varepsilon_{fs}.d^2, & if\ d < d_o \\ l.E_{elec} + l.\varepsilon_{mp}.d^4, & if\ d \geq d_o \end{cases} \tag{4.1}$$

where, on transmitter $E_{Tx\text{-}elec}$ is the transmission energy dissipation, while on the receiver part $E_{Rx\text{-}elec}$ is the receiver energy dissipation of the radio device, which explains the two parts of energy consumption by electronic circuits of E_{elec}, as well as by the radio amplifier $E_{Tx\text{-}amp}$. On the receiver part of the radio device, the amount of energy required to receive this message is E_{Rx}:

$$E_{Rx}(l) = E_{Rx-elec}(l) = l * E_{elec}$$

$$E_{Rx}(l) = l.E_{elec}, \tag{4.2}$$

4.2.1.1 Energy Behaviour of the Intermediate Node

An amount of energy is required for forwarding E_{Fx} with a packet of l data length to the distance d next hop, while the distance threshold d_o can be determine by square root of energy free space model ε_{fs} divided by the energy multi-path model ε_{mp}.

$$E_{Fx}\ (l,d) = \ E_{Tx}\ (l,d) + \ E_{Rx}(l)$$

$$E_{Fx}(l,d) = E_{Tx}(l,d) + E_{Rx}(l) = \begin{cases} 2l.E_{elec} + l.\varepsilon_{fs}.d^2\ , & if\ d < \ d_0 \\ 2l.E_{elec} + l.\varepsilon_{mp}.d^4, & if\ d\ \geq \ d_0 \end{cases} \quad (4.3)$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$

In the power dissipation design, each energy consumption part is situated within the radio transceiver on the mobile nodes. It is consistent with Equations 4.1 to 4.3 which describe strongly the two areas of energy consumption by electronic circuit (E_{elec}) as well as by the radio amplifier (ε_{amp}).

In order to normalise the energy per packet value in mobile nodes, divide both expressions by $l^* \varepsilon_{fs}$ in Equation 4.1 and 4.3 so that the radio consumes $T = E + D^2$ energy for transmission and $P = E$ energy for reception, where $E = E_{elec} / \varepsilon_{fs}$. Therefore, the power needed for forwarding (reception and retransmission) is $u(d) = 2E + d^2$.

4.2.2 Propagation Model

All radio transceivers in mobile nodes must use the radio propagation model to estimate the propagation of signal within an environment [164, 165]. It can be adjusted significantly depending on the terrain, frequency of operation, speed of mobile node interface sources, and other powerful factors. The following section talks about the depiction of the radio route through key factors and the importance of a mathematical model for forecasting the indication coverage and potential propagation of a signal within an environment.

A signal channel link between a transmitter *u* and recipient *v* is established if the energy of the radio signal obtained by node *v* reaches a certain limit of sensitivity threshold. The direct wireless link between *u* and *v* will occur if $E_{Rx} \geq \beta$, where E_{Rx} is the energy of received signal by *v* and β signifies the threshold level. In the wireless channel radio, propagation can be made as a power attenuation operating the distance between each node couple.

In this thesis, the propagation model was used in the simulator to estimate the obtained signal power on each node in packet transmission. The free-space area and multipath transmitting models were used to explain issues of the analysed short-distance and long-distance communication. The free-space area model represents the ideal propagation condition of clear line-of-sight path between the transmitter and recipient. If the distance is less than $d_{crossover}$, the transfer power is attenuated according to the free-space model. This is considered as a single line-of-sight direction and it is the most popular design of radio propagation in processing the obtained signal energy. The computation is as follows:

$$P_r\,(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L} \tag{4.4}$$

In mobile node communication, when the distance of adjacent nodes is less than the crossover distance ($d_{crossover}$), then the free-space model (d^2 attenuation) is the most appropriate model to use. However, when the communication distance exceeds crossover, then the multipath model (d^2 attenuation) is used. Here crossover distance is defined as:

$$d_{crossover} = \frac{4\pi\sqrt{L h_r h_t}}{\lambda} \tag{4.5}$$

Whereas, for the propagation of distance communication signals that exceed $d_{crossover}$, two-ray signal ground reflection is more appropriate. This model considers the addition of a single signal line-of-sight path, also taking into account the ground reflection path which gives a more clear-cut prediction at a long distance compared to the free-space propagation model. An attenuation of transmission power according to the two-ray ground propagation is shown as the following equation:

$$P_r\,(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \tag{4.6}$$

Table 4. 1.

Propagation Parameter Symbols

$P_r(d)$	The receiver power given a transmitter-receiver distance *d*,
P_t	The transmit power
G_t	The gain of the transmitting antenna
G_r	The gain of the receiving antenna
h_r	The height of receiving antenna above ground

h_t	The height of transmitting antenna above ground
λ	The wavelength of the carrier signal
d	The distance between transmitter and receiver
$L \geq 1$	The system loss factor not related to propagation

Furthermore, it is clear that Equation 4.6 does not hold for d = 0. Because of this, large-scale propagation models use a short distance as a known received energy reference point. The obtained energy, $P_r(d)$, at any distance $d > d_o$, may be related to $P_r$at d_o. The value $P_r(d_o)$ may be expected from Equation 4.6, and it may also describe the radio environment to be in a position of multi-points within the coverage of the transmitter area as the average value of the receiver power at the nodes. The distance for referrals must be selected such that it can be found in the far-field area, that is, $d_o \geq d_f$, and d_o is chosen to be smaller than any practical distance used in the mobile network.

4.2.3 Transmission Power Control Model

To sustain the lifetime of the node connection and to minimise disruptions in the network, the min-max power transmission adjustment is required. This is to reflect the real environment of MANET behaviour [161]. Therefore, there is a need to min-max each transmitting node energy value. While reducing transmitting energy at the link layer [7], a consideration is needed for the connection restriction and the signal to interference plus noise ratio (SINR) constraint. The network connection can then be preserved, if the transmitting energy from node i to node j (P_{ij}) is more than or equal to d_{ij}^{α}, increased by the transmitting quality parameter β for all $(i, j) \in L$. Also P_{ij} should be more than zero as far as the circulation f_{ij} is more than zero and less then or similar to P_{max}, the highest possible transmitting energy. To be able to fulfil the SINR constraint, the recipient energy at node j should be more than the interruption energy plus distance increased by the SINR needed parameter (γ_{ij}). The issue of reducing the transmitting energy of MANET is formulated as a linear line optimisation problem, as follows.

Let $P_{ij} \geq \beta . d_{ij}^{\alpha}$,

$$SINR_{ij} = \frac{P_{ij}/d_{ij}^{\alpha}}{\sum_{(k,j)\in L} P_{kj}/d_{kj}^{\alpha} + \sigma} \geq \gamma_{ij}, \tag{4.7}$$

$$P_{max} \geq P_{ij} \geq 0, \forall_i \in N, \forall(i,j) \in L. \tag{4.8}$$

4.2.4 Traffic Model

To optimise the lifetime connection of the nodes, it must be taken into consideration the traffic model, which is the only resource node that makes a l -packet and all the intermediate nodes forward this packet to the mobile location node. Therefore, the traffic model can be considered as an event-based design. The energy consumption for each of the mobile nodes is given as follows:

$$E = \{E_i, i \in \{1,\ldots,N\}\} \tag{4.9}$$

The optimum position of the intermediate node refers to individual distance d_i node as;

$\sum_{i=1}^{n} E_i$ is minimal.

In the communication process, the energy consumption is the energy used to process packet transmission without taking into account the energy consumption of electronic circuits. Therefore, the energy consumption on node of direct transmission *l*-bit packets at a distance *d* can be described as:

$$E_{dt} = l \,.\, \varepsilon_{amp} \,.\, d^{\alpha} \tag{4.10}$$

Here, ε_{amp} = $\varepsilon_{fs,}$ when α = 2, and $\varepsilon_{amp} = \varepsilon_{mp}$ when α = 4. Thus, if the distance *d* is equally divided into *n* pieces, the total energy on the node consumption for the multi-hop (next-hop) transmission with individual distances d_i= *d* / *n* will be:

$$E_{mh} = l \,.\, n \,.\, \varepsilon_{\,mp} \,.\, (\frac{d}{n})^{\alpha} = l \,.\, \varepsilon_{mp} \,.\, \frac{d^{\alpha}}{n^{\alpha-1}} \tag{4.11}$$

If the observed is larger, then *n* has more energy which can be reduced in the transmission process, where the direct transmission process can be converted into a multi-hop transmission method. However, the part of energy consumption by components circuit (radio transceiver) cannot be ignored. With short distance *d*, the aspect of power consumption by components circuit $l \,.\, E_{elec}$ is comparable to that consumed by the communication process $l. \varepsilon_{\,mp} \,.\, d^{\alpha}$. Thus, the energy consumption with too many short hops could be even larger than that through direct transmitting, which can also be seen from Equation 4.12.

To transmit a one bit message over the next-hop route will consume a total *E*(*n*) amount of energy, as follows:

$$E(n) = \left(E_{elec} + \varepsilon_{amp} \,.\, r_1^{\alpha}\right) + \sum_{i=2}^{n-1} \varepsilon_{amp} .\, r_i^{\alpha} + 2 \,.\, (n-1) \,.\, E_{elec} =$$

$$(2n-1).\, E_{elec} + \sum_{i=1}^{n} \varepsilon_{amp} \,.\, r_i^{\alpha} \tag{4.12}$$

Here, $\sum_{i=1}^{n} r_i = d$. The objective is to find the minimal value of $E(n)$ with optimal hop number n as well as the corresponding r_i under certain constrain conditions such as $\sum_{i=1}^{n} r_i = d$.

4.2.5 Modelling Hop Number

To get the energy-efficiency in route path, the optimal number of relay nodes is required in order to achieve the best connection. Thus the number of relay nodes must be taken in account in path calculation cost in the MANET network.

4.2.5.1 Determination of Hop Number

To achieve the optimum lifetime in route path, an aspect that must be considered is the number of relay nodes in the path in accordance with the consideration of other aspects in getting the maximum hop nodes as described before. In order to determine the hop number, the given resource focusing on the node has the range of $d(d = \sum_{i=1}^{n} r_i)$. Equation 4.12 $\sum_{i=1}^{n} r_i^{\alpha}$ has a minimal value when $r_1 = r_2 = \cdots = r_n = {}^{d}/_{n}$. Finally, the total energy consumption $E(n)$ is equal to:

$$E(n) = (2n-1).E_{elec} + \varepsilon_{amp}.n\,.({}^{d}/_{n})^{\alpha} \tag{4.13}$$

Equation 4.13 has the minimum when $E(n)$ = 0 or

$$2E_{elec} + \varepsilon_{amp}.(1-\alpha).({}^{d}/_{n})^{\alpha} = 0,$$

Finally, the optimal hop number can be achieved theoretically as:

$$n_{opt}^{*} = d\,.\left(\varepsilon_{amp}\,.{}^{(\alpha-1)}/_{2E_{elec}}\right)^{1/\alpha} \tag{4.14}$$

Meanwhile, the corresponding optimal individual adjacent-neighbour distance is:

$$r_i^* = {}^{d}/_{n_{opt}^*} = \left(2E_{elec}/(\alpha - 1).\varepsilon_{amp}\right)^{1/\alpha} \tag{4.15}$$

Referring to the characteristics and parameters of components in Table 4.1, the optimal power consumption $E\left(n_{opt}^*\right)$ can be acquired from Equation 4.13 and provide information for nodes within the range of distance *d*. Therefore, the free-space transmission model (d_2) can be used. For example, the minimum amount of energy consumption along the one particular multi-hop route path can be used when n_{opt}^* and the optimal intermediate distance is $r_i = d/n_{opt}^* = \sqrt{2\,.\,E_{elec}/\varepsilon_{fs}}$. Similarly, we can get $n = n_{opt}^* = \left(3\,.\,\varepsilon_{mp}/2\,.\,E_{elec}\right)^{1/4}.\,d$ for multi-path transmission model (d^4) where each individual distance $r_i = d/n_{opt}^* = \left(2\,.\,E_{elec}/3\,.\,\varepsilon_{mp}\right)^{1/4}$ can be obtained.

Whereas, the larger the *d* value gets, the more energy will be absorbed on average with the same hop number since the average individual distance is farther [166]. However, it can also be seen that more energy can be reduced through the multi-hop transmission as *d* increases. It can be observed that when the *d* gets larger, a fewer number of hops would be involved. This happens because the relay node distance is kept as a constant (as described in the previous paragraphs). In the same way, the smaller the distance *d* gets, the larger the hop number will be become and the intermediate distance r_i is kept as a constant.

In this thesis, the sub-optimal hop number is known as n_{opt} and with different hardware parameters of distance *d*, the maximum hop number and the corresponding r_i will be different. The value of these hardware parameters are identified based on several aspects such as electronic circuit, antenna, and receiver threshold [164].

The minimal energy consumption $E(n)$ is under free space and multi-path transmission models with different source to n-hop distance d by considering the constrained condition $r_i < d_o \ or \ r_i \geq d_o$. However, the optimal hop number can be taken as the nearest decimal value to meet the constrained condition.

4.2.5.2 Determination of the sub-optimal hop number

In determining the sub-optimal hop number, the theoretical optimal hop number and corresponding intermediate distance cannot be used directly for three reasons:

i. The constrained conditions such as $r_i < d_o$or $r_i \geq d_o$ can be considered.
ii. The optimal hop number should be an integer value rather than a decimal value under the practical mobile wireless network environment.
iii. It is very difficult (if not impossible) to discover such n_{opt}^{*} optimal intermediate nodes which equally divide the source to next-hop in line under practical mobile wireless network. Thus, the sub-optimal hop number n_{opt} as well as the corresponding intermediate nodes under actual mobile wireless network has to be discovered.

This part provides the choice requirements of the sub-optimal hop variety and intermediate distance for the research simulator and analysis in this study. However, this is not the maximum solution since there is no global information about the network topology. Furthermore, it only depends on regional information such as the comparative distance of adjacent nodes.

Table 4.2.

Selection Criterion of the Sub-optimal Hop Number

d	r_i	*Hop Number*
$(0, d_c)$	$r_i < d_c$	1
$[d_c, 2d_0)$	$r_1, r_2 < d_0$	2
⋮	⋮	⋮
$[(n\text{-}1)d_0, nd_0)]$	$r_1,\ldots, r_n < d_0$	n

The transmission method will be the key for the source node to determine the technique to forward the packet using n-hop, based on the distance d and hardware parameters as provided in Table 4.2. Due to the multi-hop transmission technique used, the free-space transmission model has been compared with multipath transmission model to reduce the overhead calculations.

The selection of the intermediate distance nodes is based on the following criteria:

i. Each of the intermediate distance nodes should be larger or equal to d/n_{opt} under real mobile wireless network conditions.

ii. The relay node should be as near as possible to the direct line that joins the (origin line) resource and target/destination. In this way, the average hop number might not increase.

In this case, a source node should select the next hop frontward nearest to the destination. This means that packet progress should be made toward the target under each quadrant. If there is no such nearby node under the scalable network, it will simply select its next door neighbour which is nearest to the target/destination as its *n*-hop node.

4.3 Transmission Manner

The short-hop strategy would be the most energy efficient strategy whenever the total power transmitted over the path is taken into consideration when the candidate nodes are communicating with minimum power in reaching the destination. This is caused by the signal attenuation which is proportional to the power function (Equations 4.1 to 4.6). However, the reception cost should not be neglected; there is the lowest range of source-destination distance for which direct interaction is a maximum substitute. This is due to the point that the preservation in the transmitting power by the multi-hop scheme does not compensate for causing extra energy cost generated in the electronic circuit. If the distance between the transmitter and recipient is increased, there is a limitation on the two-hop routing to be the better option. However, if the transmitting distance increases, the three-hop interaction will become more optimal. Therefore, in order to determine a better power effective routing method for a given topology, an evaluation between the energy consumption of a single-hop and two-hop transmitting is needed.

When the distance source (s) to the target (t) is $d < d_o$, it is easy to prove that $E(n)$ in Equation 4.10 is a directly increasing function hardware parameter, as shown in Table 4.1. Therefore, the single hop transmission ($n = 1$) is always more energy efficient than the multi-hop (*Mh*) transmission ($n \leq 2$).

If the distance $d \in (d_o, 2d_o)$, the usage can be either direct transmission or in a two-hop manner. Let

$$f(d) = E_{Dt} - E_{Mh}\,(2) \geq 0$$

So

$$f(d) = (E_{elec} + \varepsilon_{mp} . d^4) - \left(3E_{elec} + \varepsilon_{fs} . {d^2}/{2}\right)$$

$$f(d) = \varepsilon_{mp} . d^4 - \varepsilon_{fs} . {d^2}/{2} - 2E_{elec} \geq 0 \qquad (4.16)$$

Equation 4.16 will always hold true when

$$d \geq d_c = \sqrt{\frac{\frac{2\varepsilon_{fs}}{2} + \sqrt{\frac{\varepsilon_{fs}^2}{4} + 8\varepsilon_{mp}}}{2 . \varepsilon_{mp}}} \qquad (4.17)$$

When the distance condition $d_o < d \leq d_c$ holds true, the direct transmission with multi-path model can still be chosen. However, if $d > d_c$, the multi-hop transmission is chosen. Table 4.4 lists the determination of the transmission manner under different source (s) to target (t) with distance d. Detailed pseudo-code for the routing algorithm is depicted in Algorithm 1 and 2.

Table 4.3.

Transmission Manner Method

d	**Transmission Manner**
$d < d_o$	Direct
$d_o \leq d \leq d_c$	Direct
$d_c < d$	Multi-hop

Table 4.4.

Algorithm 1: Transmission Manner Algorithm

Input: A parameter radio device, remaining energy, transmission distance *d*, energy model, propagation model.

Output: Transmission manner (single hop or multi-hop)

(1) Assume the uniform transmission range of all nodes is *R*

(2) Each node *i*, with transmission distance d_i broadcasts a message with ID_i to all first-hop neighbours in its transmission range.

(3) **while** node *u* receives a packet with destination *t* **do**

(4) if $||t - u|| < d_o$, i.e., *t* is neighbour of *u* **then**

Node *u* forwards the data to *t* directly and returns.

or

(5) **if** $d_o \leq d \leq d_c$ **then**

(6) **else if** $E(n)$ with ||t – v|| + ||v – u|| > ||t – u|| **then**

Node *u* forwards the data to *t* direct and returns.

(7) **and if**

(8) **if** $d_c < d$

else if $E(n)$ with ||t – v|| + ||v – u|| < ||t – u|| **then**

Node *u* forwards the data to *t* through *v* and returns.

end if

else if *d* > transmission region, **then**

Node *u* simply drops the packet.

(9) **end if**

(10) **end while**

4.3.1 Direct Transmission

This analysis is based on two cases of research pertaining to the direct transmission as a single hop; 1) maximum distance of the first hop from relay nodes in multi-hop transmission; 2) maximum distance of the single hop [165]. Keeping in mind the maximum distance of the single hop differs to the first hop from intermediate nodes in the multi-hop transmission. Using the direct transmission, each mobile node sends its data directly to the target/destination. If the target/destination is far away from the source, the direct transmission requires a large transmitting power amount from each node (since d in Equation 4.1 is large). This will quickly drain the battery of the nodes and reduce the network connection lifetime. This indicates that direct transmission consumes less energy than the multi-hop transmission.

The first hop from the relay nodes in multi-hop transmission is not equal in energy consumption compared to single hop transmission, as shown in Equation 4.18 below.

$$\frac{E_{elec}}{\varepsilon_{amp}} > \frac{r^2 * n}{2} \tag{4.18}$$

Since $d = n * r$ when the power transmission beyond the first node distance, Equation 4.18 can be re-formulated as:

$$\frac{E_{elec}}{\varepsilon_{amp}} > \frac{r^2 * n}{2} = \frac{d^2}{2 * n} \tag{4.19}$$

So

$$n_e = \frac{\varepsilon_{amp} * d^2}{2 * E_{elec}} \tag{4.20}$$

4.3.2 Multi-hop Transmission

Even though the multi-hop transmission can cut down communication energy consumption, increasing the number of hops in the routing will proportionally increase the communication energy. Therefore, to obtain optimum energy efficiency, the nodes must use transmission power based on the distance between sender and receiver nodes. In order to proceed with the research, this researcher presupposes that there is a linear network model, as shown in previous studies [167, 168]; namely considering that n + 1 nodes are moving according to a random direction (RD) motion, assuming that $d_{i,i+1}(0) < R, 1 \leq i \leq n$, and considering that the path of n (bidirectional) links is connected to next node (n + 1) in the network.

If it involves the multi-hop delivery, the total energy consumed by the network is equated as sum of multi-hop energy $E_{m\text{-}hop}$ to be the result of the number of the sender at the source node E_{Tx} added to the amount of energy used at each receiver node E_{Rx}.

$$E_{m-hop} = nE_{Tx}(k) + (n-1)E_{Rx}(k) + nE_{Tx}(k,r)$$

$$= (2n-1)kE_{elec} + nE_{Tx}(k,r)$$

The conclusions are as follows.

When radius of the transmitter is equal to or higher than threshold distance $r \geq d_o$, it is observed that direct transmit energy is greater than 0 to the total energy transmission node,

$$E_{direct} - E_{m-hop} = n^4r^4kE_{Tx} - 2(n-1)kE_{elec} - nr^4kE_{Tx-\varepsilon fs} > 0$$

when $nr \leq d_{o,}$ so

$$E_{direct} - E_{m-hop} = n^2r^2kE_{Tx-\varepsilon fs} - 2(n-1)kE_{elec} - nr^2kE_{Tx-\varepsilon fs} < 0$$

When $r < d_o, nr \geq d_o$, this gives

$$E_{direct} - E_{m-hop} = n^4r^4kE_{Tx} - 2(n-1)kE_{elec} - nr^2kE_{Tx-\varepsilon fs}$$

Here, it was found that to an enhanced multi-hop transmitting point, it must/should take into consideration the relevant aspects of establishing the shortest path, highest possible remaining power, and minimisation of energy consumption from the aspects of hop number and network lifetime.

4.4 Assumptions and Definitions

The following assumptions were made for mobile node behaviour referring to this thesis for MANET environments.

Table 4.5.

Node Behaviour for MANET Environments

Mobility	All nodes have random mobility even though sometimes they act as relay or destination nodes.
Homogenous	All mobile nodes have similar energy processing and communication capabilities.
Unattended	All mobile nodes cannot be recharged during deployment.
Symmetric	In the communication link, if node *v* can get a packet from node *u*, node *u* can also get that packet from node *v*.
Localisation information algorithms [169, 170, 171, 172]	The nodes can determined the relative distance between their location and their adjacent-neighbour node as well as their destination node. Here, a GPS

	device is necessary for each mobile node. This approach allows the accurate value of distance of each other by position-based coordinates.
Obstacles	There are no big challenges between the resource, relay and destination nodes.
Bi-dimensional area	The network comprises homogeneous nodes moving over a bi-dimensional area; in particular, all nodes have a common radio range and the same mobility pattern.
Independently	Nodes move independently of each other.
Propagation model	A free-space and multipath propagation is considered, i.e., the received signals only depend on its distance from the transmitter.

Route discovery in a routing protocol is a process of identifying a path from a source to a destination before or after a request for transmission [170]. The implementation of the proposed Energy Distance Aware Protocol (EDRA) as a routing protocol is to improve the efficiency of routing connection for prolonging the network lifetime in MANET.

4.4.1 Modelling Assumptions

In general, a MAGNET can be depicted as an array of disks with the distribution of mobile nodes as $G = <V, E>$ where V represents a set of wireless mobile hosts (nodes) and E represents a set of bidirectional or unidirectional links supposing all hosts have the same transmitting range r [173, 174]. The supposition is that there are N nodes arbitrarily spread in two dimensions within the coverage area. Two nodes are assumed to be adjacent-neighbours if the distance between them is less than their highest transmitting radius. The purpose of routing is to discover a sequence of links from resource (S) to location (D) nodes under certain constraints such as energy-efficiency, brief latency, or great information constancy, and etc. The routing issues in MANET can be very complicated due to various aspects such as network characteristics topology [175, 176]], different traffic patterns, as well as different applications [115, 177].

In this thesis, the focus was on N nodes which are distributing on a two-dimensional plane using a homogenous distribution with node density. A link between two nodes exists if they are within the identified transmitting distance. However, the establishment of a link does not guarantee packet delivery to all directions. Two nodes are considered as adjacent-neighbour to each other if there is a direct link between them. Even in the case of no relationship, the chance that a packet may be missing due to the node failing (such as out of coverage) was taken into consideration. For simplicity's sake, this researcher believes that the network topology does not change during the route discovery process. This supposition is realistic because the mobility timescale is much smaller than that of a single route discovery. For the simulations in this research, a discrete event-driven simulator Ns edition 2.34 (Ns-2) was used. Table 4.6 summarises the details of the simulation parameters.

Table 4.6.

Simulation Environment and Parameters

Environment Factors	Defined Configuration
Simulation time	200s
Simulator Area	[1000 x 1000]m^2
Number of Nodes	[50, 100, 200]
Node Pause Time	0 – 3s
Routing Protocol	AODV

Initial Node Energy	1000J
Transmitted Power Drain	50 nJ/bit
Received Power Drain	10 pJ/bit/
Energy of free space model	10 pJ/bit/m^2
Energy of Multi-path model	0.0013 pJ/bit/m^4
Transmission range of each node (*d*)	(100 – 150)m
Data length (*l*)	2000 bits

4.5 The Proposed Energy-Distance Aware Protocol (EDRA)

The proposed protocol is designed as an extension to the well-known AODV protocol. In the proposed protocol, an individual energy parameter and distance of adjacent-neighbours nodes were used to select the best path. Thus, the following three variants of the suggested protocol as the AODV extensions are described in greater detail.

- EDFA implements the relay node selection technique in the discovery process based on energy-efficient routes while optimising the distance with reference to the value of *rho*. *Rho* value assessment is conducted while referring to the energy that is effective in the delivery of data packets based on the most optimum distance at each node. Relay nodes that have the greatest probability of the best *rho* value would be selected as the candidate, followed by relay nodes that have a lower *rho* value to become the relay nodes in establishing the path.
- EDFS performs the route discovery technique with the choice selection of relay nodes within the quadrant area based on the source and destination node locations within the network.

- EARS establishes the route path from source to destination nodes based on the projection of EDFA and EDFS. Path selection is based on the optimal energy path within the network environment.

4.5.1 Workflow of EDRA

The workflow of this proposed study routing algorithm scheme is shown in Figure 4.2. The algorithm scheme involves three parts; first is the EDFA as the node selection scheme, the second is the EDFS as route discovery quadrant scheme, and the third is the EARS scheme. All of these schemes are developed to substantiate the development of efficient routing protocols in order to prolong the connection lifetime of a mobile network. Figure 4.2 clearly illustrates the routing workflow of the EDRA in this thesis.

Once the source node wishes to send a packet to a destination using the energy efficient technique, it will first determine the transmission manner based on Table 4.4. It will then decide to transmit its data directly to the target or destination based on the position of next forward nodes. Otherwise, it will use the multi-hop transmission. The selection of the next hop is based on the criteria that enable it to select some of its neighbour nodes, which is shown in Figure 4.5 (i.e., candidate nodes for forwarding the packet). The purpose of this selection phase is to have only a subset of neighbour nodes to be evaluated in the actual forwarding node selection phase as described below.

EDFA technique is a scheme which makes a preliminary assessment on the nodes in network coverage to be selected as a relay node. The relay node is selected based on an assessment of the effective power in a node for transmitting data packets at a distance effective to next hop. The energy parameter on the node and the effective distance to the next node are assessed as *rho* values.

To ensure that the route discovery area is minimal, the EDFS technique of forward strategy is used by adjusting the quadrant area of route discovery. This technique implements the method of route discovery process within the quadrant coverage. This technique uses the source and destination node information as reference to perform the quadrant route discovery. The quadrant area size for route discovery may be wider if the capacity of nodes in the network is low, while the quadrant size could have a smaller angle when the number of nodes in the network is high. This will reduce the overhead and end-to-end packet transmission in the network. Finally, a stable route path will be formed from the energy-capable relay node. The EARS technique is implemented to select a path that more resilient in order to sustain the connection lifetime based on best metrics cost

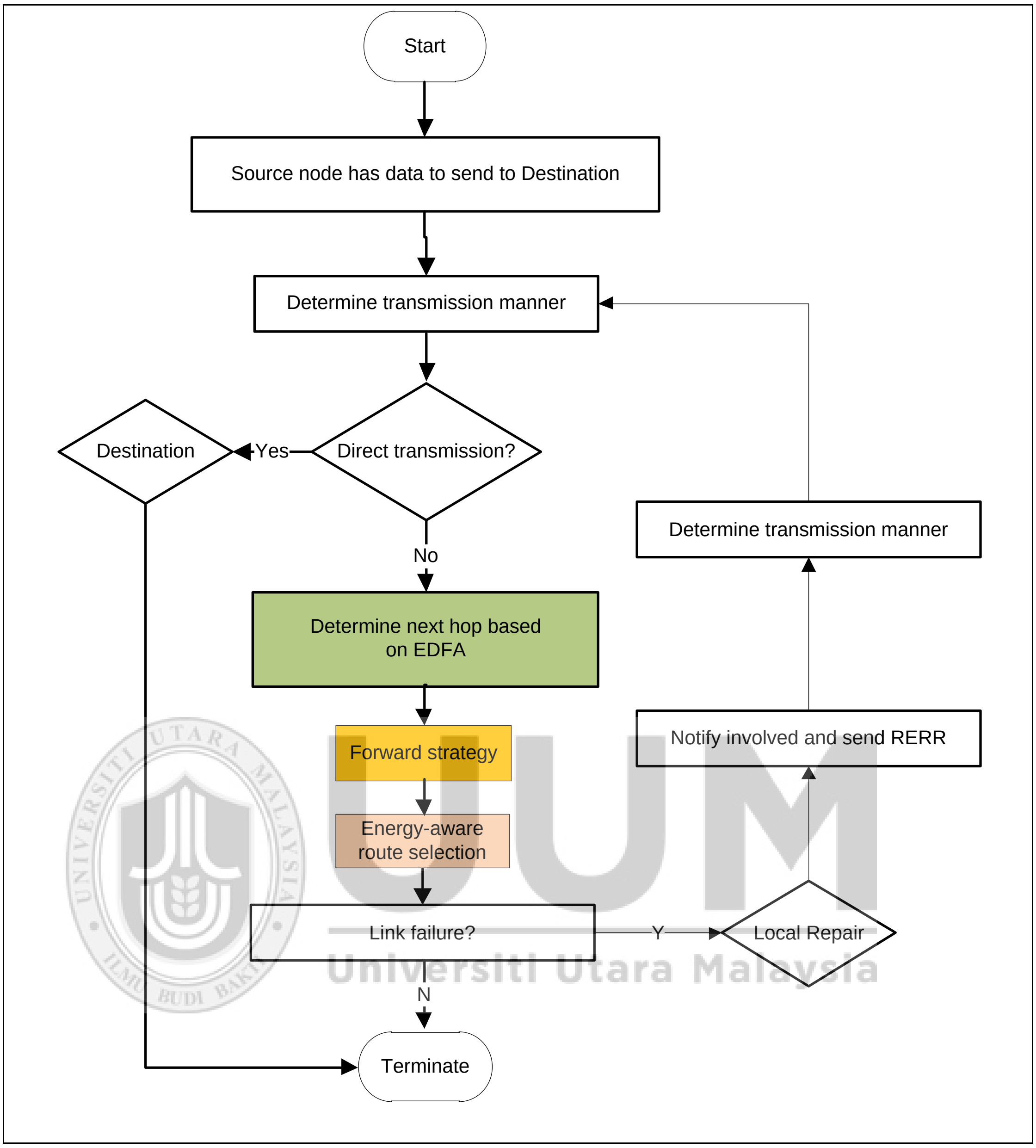

Figure 4.2. The proposed energy distance aware routing protocol.

4.5.1.1 Design of Energy Distance Factor Algorithm

This algorithm was developed for selecting nodes based on the energy-aware and effective distance to the next hop that would identify the potential candidate node within the formulated route. Energy Distance Factor Algorithm is a distributed and localised algorithm for practical mobile nodes within a MANET, which is hop-based in nature during the routing formation process in route discovery.

This indicates that the determination of the next-hop based on EDFA (green part in Figure 4.2) is the key issue during the routing process in MANETs.

In the multi-hop routing, the total energy consumed for the end-to-end communication will increase as communication process increases both the number of relay nodes and energy consumption in each individual hop, which are mainly determined by the remaining energy of the individual node (e_i) and transmission distance (d_i). The amount of energy consumption for end-to-end communications would increase as the number of relay nodes involved is high. This is due to the communication process that takes place at each relay node as a whole. Therefore, if the hop number is small, the energy consumption for a transmission is lower. The increasing number of relay nodes and the use of energy in each hop will affect the optimum energy balance of the individual nodes.

The assumption is that there are N nodes randomly scattered in a two-dimensional square field of mobile nodes. This shows the necessity of having a multi-hop transmission method in a situation whereby the communicating nodes are geographically distributed and the destination nodes are outside the transmission range of the source node. There are more relay node candidates needed between source and destination when forwarding packets to a destination that is far greater than the transmitting capability of the source node. This condition consumes unequal energy capacities among the nodes along the way, which would affect the overall connection whenever a set of packets are forwarded through multi-hops to the final destination. Every node with various energy capacities has different maximum radius coverage limited to the transmission power when forwarding packets [92][178].

4.5.1.2 Work Flow of EDFA

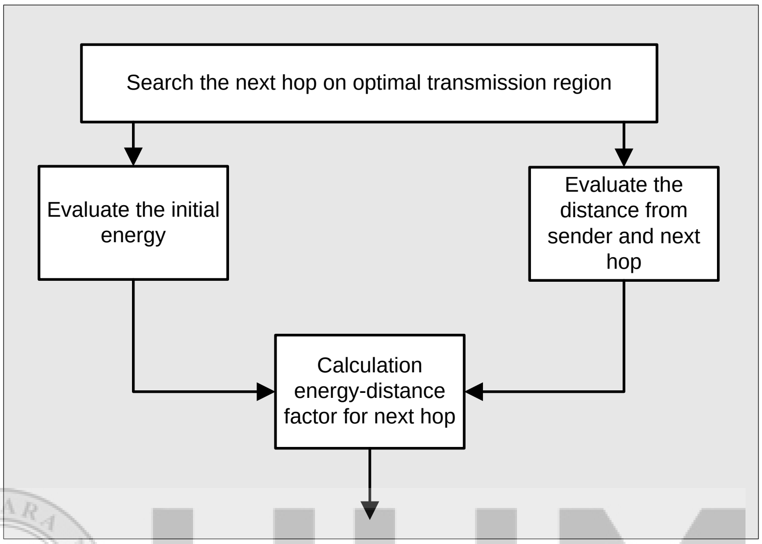

Figure 4.3. Detail workflow of the EDFA.

Inspired by the work in many research endeavours of the past [26, 107, 108, 132, 160, 179, 180, 181], the techniques used in this study to make the relay node selection was based on efficient energy capacity of the node and the optimum distance for the transmission of packets to the next node by taking into account the hardware parameters. Therefore, it is worth to emphasise that the selection criteria of the next-hop node is purely from the intermediate node point of view in the EDFA.

The workflow of the EDFA can be either real-time or otherwise, depending on the traffic pattern as well as traffic load. Under a low traffic load based on the traffic model, when each node takes its turn to send its data to the destination node, the data can be sent immediately after it is received. This is referred to as a real-time transmission. Under a heavy traffic load or event-based traffic model, when several nodes have data to send simultaneously, a node may have several traffic sessions to forward. Thus, it will store certain traffic flows in its buffer and forward them later on when the current traffic is finished. This is not considered as a real-time transmission. The energy from propagation models is considered in determining the energy-distance factor using proposed algorithm following Equations 4.23 to 4.26. If the energy on the nodes exceeds the given threshold, it will be selected based on the proposed algorithm to calculating the energy distance factor as a *rho* value. The *rho* value on each node will reflect whether that particular node type has achieved efficiency or otherwise.

The energy level and the distance of the node i are given by e_i and d_i respectively. The energy-distance factor (ρ_i) is computed as represented by the following mathematical model below.

e_i : energy level of node i

d_i: distance between the source node and node i

ρ_i: energy-distance factor of node i

m_i: energy-distance product of node i

If the energy level and the distance of the node i are given by e_i and d_i respectively, then

the energy-distance product of node $i(m_i)= e_i * d_i$ (4.23)

the energy-distance factor of node $i(\rho_i) = \frac{e_i d_i}{\sum_{i=1}^{n} e_i d_i}$ (4.24) where the number of nodes is in tier 1.

Properties of energy-distance factor

i. $\rho_i \epsilon$ [0, 1] for all i

Proof:

Consider the extreme case of no other nodes is in the vicinity of the source node. Then $e_i = 0$.

Thus $\rho_i = \ 0$

The other extreme case is when there is only one node in the vicinity of the source node with energy level e and at a distance d. So,

Energy-distance product $(m) = ed$

Energy-distance factor $(\rho) = \frac{ed}{\sum ed} = \frac{ed}{ed} = 1$

For all other cases when there are more than one node in the vicinity of the source. So,

Energy-distance product of node $i(m_i) = e_i d_i < \sum e_i d_i$

Hence, Energy-distance factor of node $i(\rho_i) = \frac{e_i d_i}{\sum e_i d_i} < 1$

Thus for all cases,

Energy-distance factor of node i is $0 \leq \rho_i \leq 1$

ii. $\sum \rho_i = 1$

Proof:

Consider that there are *n* nodes in tier 1 of the source node S.

Let $\sum_{i=1}^{n} e_i d_i = e_1 d_1 + e_2 d_2 + \ldots + e_n d_n = c$

$$\rho_i = \frac{e_i d_i}{\sum_{i=1}^{n} e_i d_i} \tag{4.25}$$

$$\sum \rho_i = \sum \frac{e_i d_i}{\sum_{i=1}^{n} e_i d_i}$$

$$\sum \rho_i = \frac{e_1 d_1}{c} + \frac{e_2 d_2}{c} + \ldots \ldots + \frac{e_n d_n}{c}$$

$$\sum \rho_i = \frac{e_1 d_1 + e_2 d_2 + \ldots \ldots \ldots + e_n d_n}{c}$$

$$\sum \rho_i = \frac{c}{c} \tag{4.26}$$

$$\sum \rho_i = 1$$

The probability that a node selected as the relay node is based on the value of *rho* as a reference from the algorithm on each node within the route discovery. Energy-distance factor values from the algorithm show the ability of transmission energy in forwarding the packet to the next hop. E_i on each node will be evaluated when it passes a predetermined threshold level, while a node that does not pass the threshold will not be evaluated by the algorithm. The efficient value E_i on each node will be evaluated for the effectiveness of a packet transmission over d_i on each node. The *Rho*(ρ) value output at each node indicates the optimum distance transmission of the node. *Rho*(ρ) value will be listed in the routing table and will be selected to establish the route according to the largest to lower ρ values.

Table 4.7.

Energy Distance Factor Algorithm

Algorithm 1 EDFA

Input: e_i - of the mobile node, d_i - of the adjacent-neighbour nodes.

Output: ρ_i – rho (ρ) is the highest energy-distance factor

(1) Each node i, with transmission distance d_i, broadcasts the hello packet to the n-hop neighbourhood to obtain the node *IDs* of their mutual distances and the directions of the systems coordinates.

(2) Each node i locally evaluates the initial energy e_i. If $e_i \geq e_t$, accepted it as a candidate node.

(3) Each node i locally evaluates the current distance d_i of the adjacent-neighbour. If $d_i < d_o$, accept it as a candidate node.

(4) When node i updates its initial energy e_i, update the current distance d_i, i checks for all neighbours.

(5) Calculate $E_{Tx}(l,d)$ /*equation 4.1

(9) Calculate $E_{Rx}(l)$ /*equation 4.2

(10) Calculate $E_{Fx}(l,d)$ /*equation 4.3

for node$_i$

(11) Calculate remaining energy

(12) **if** ($Ere \geq E_{Th}$) then

(13) Add node$_i$ to candidate_list

(14) **else if** ($E_{re} < E_{Th}$) then

(15) Add node$_i$ to unwanted_list

(16) Each node i locally computes the ρ of energy-distance factor of the node as $\rho_i^1, \ldots \rho_i^c, \ldots \rho_i^k$.

(17) Compute the position of the n-hop neighbours in its Local Coordinate System

(18) Compute the n-hop neighbourhood centre as:

$$c_x = \frac{\sum j_x}{m}$$

$$c_y = \frac{\sum j_y}{m}$$

(19) Compute the n-hop neighbourhood direction as the average of the Local Coordinate System direction of the nodes that belong to its n-hop

neighbourhood and for which it can obtain the positions.

(20) Each node i updates its neighbour list and updates the transmission range according to the new neighbours.

For a non-real-time transmission, the buffer size and delay are two important factors for consideration in the design. Each node has a queue for packets awaiting transmission by the network interface that holds up to 50 packets and is managed in a drop-tail fashion. If the buffer size is too large, it will cause long addressing time to search from buffer. If it is too small, it will cause a high packet drop-off rate during traffic congestion periods. For example, if the link rate is 1Mbps and the round trip time is 10ms, the final empirical buffer size is 10Kbps. The buffer delay is determined by various factors such as switching methods, buffer size, and packet length.

The process of determining the next-hop node based on the EDFA is shown in Figure 4.6. The evaluation of the nodes' initial energy e_i and distance d_i is performed.

The candidate relay nodes are evaluated by assessing the energy and distance of the nodes with an objective to prolong the network connection lifetime by the intermediate nodes. In EDFA, whenever possible, the nodes select the neighbours inside a restricted neighbourhood (defined by a density of $Rho(\rho_i)$) that has the optimum energy mileage (i.e., the distance traveled per unit energy consumed) as the next-hop node. This helps to achieve both energy efficiency by carefully selecting the forwarding neighbours and high scalability based on information obtained locally from each node to decide the routes. This will also able to reduce energy consumption during the multi-hop routing process in a MANET.

4.5.1.3 Characteristics of the Energy-Distance Factor Aware

The EDFA has the following characteristics:

- The relay nodes are selected based on determined residual threshold to evaluate energy-distance factor.
- The density of largest *rho* value (ρ_i) will be preferred compared to other nodes to be selected as the next hop to the destination.
- The EDFA is distributed algorithm and satisfies the variance evaluation in node power levels.

4.5.1.4 Functionality of EDFA

The first stage in the routing process in a wireless mobile network is how to determine the efficient and effective relay node in participating route path to sustain network connection lifetime. Therefore, in order to select the effective relay nodes in routing, EDFA was proposed, which is a triangulation evaluation on energy consumption the distance travelled per unit energy consumed to adjacent-neighbour nodes. This approach will determine the candidate relay nodes in the path having potential to sustain the connection.

4.5.1.5 Formulation Model

To give an illustration of the network, Figure 4.7 shows an arbitrary arrangement of nodes in a given situation. The placements of these nodes are arbitrary in the sense

4.5.2 Design Energy Distance Forward Strategy (EDFS)

The EDFS routing algorithm performs the route discovery procedure for minimising the discovery quadrant zone. The route discovery is the first stage of any wireless routing protocol function, which is the process of finding a route/set of potential routes between a source and an intended destination. The selected node is based on an energy-distance efficiency routing protocol that can prolong the lifetime of a network connection.

4.5.2.1 Work Flow of EDFS

The overview of the proposed discovery mechanism can be simply illustrated by the behaviour in an image, as shown in Figure 4.6. The process is initiated based on the findings of the destination node in an identified quadrant zone to reduce the number of broadcasts in the ad hoc network. The proposed algorithm uses the signal strength (as discussed in Chapter 2) to determine the feasible nodes that will forward the broadcast message and reach the optimum distance possible of adjacent-neighbour nodes within the ad hoc domain.

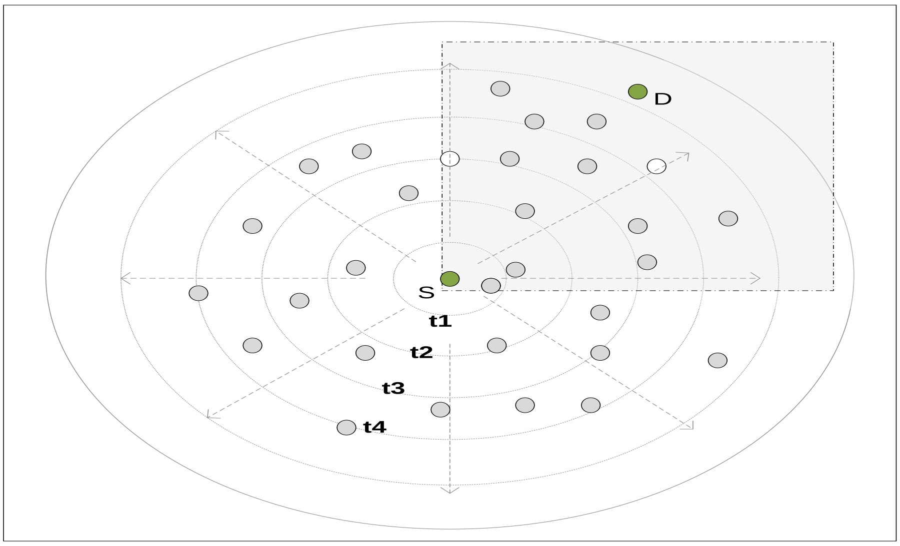

Figure 4.6. An ad hoc network with spreading nodes in two dimensions.

An assumption is made for this particular case by taking into consideration the two-dimension network topology as illustrated in Figure 4.7. The location of *D* node is at the upper right corner of the quadrant that contains a source node in the centre of nearest tier 1. In the proposed forwarding algorithm (EDFS) of this study, the candidate nodes will be selected from the highest range probability of $Rho(\rho)$ from EDFA. The best forwarding node is computed as the angular position for each neighbour based on the position of target/destination location on the four reference quadrants as described in the algorithm code in Table 4.2. The intermediate node which is closest to the origin line that connects the *S* to the destination *D* will be selected as the next forwarding nodes, as illustrated in Figure 4.8. The next nodes of the multi-hop transmission at individual hops are searched within angular communication ranges that point outward from the source node *S.* The origin line designates the bisectors of the angular slices at hops $i - 1$, i, and $i + 1$, respectively.

Node with the optimal transmission range within the maximum allowed range can minimise energy consumption.

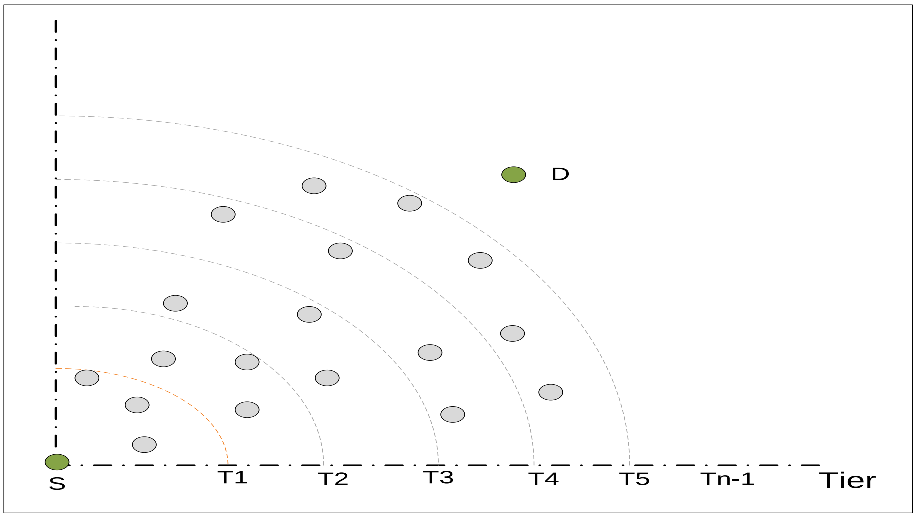

Figure 4.7 . Start of route discovery: The dashed lines orange coloured indicate that source node S transmits a RREQ which is received by nodes in the orange tier of radius r_o.

Before a packet can be sent, it is necessary to determine the position of its destination (*D*). This can be determined with the local algorithm on all nodes of the network [81]. In the proposed routing algorithm, the route discovery technique is referred to as discovery "Forward Strategy" (FS). With the FS algorithm method, only the node that is in the same forwarding quadrant will participate in the routing until the packet reaches its destination. Once the node has determined its coordinates, it will be used in the route discovery. The FS algorithm on the node will determine the quadrant where the node and destination are located compared to the source.

by nodes within the $r_o \leq r_c$ radius of these neighbours where the nodes straggle in tier 1.

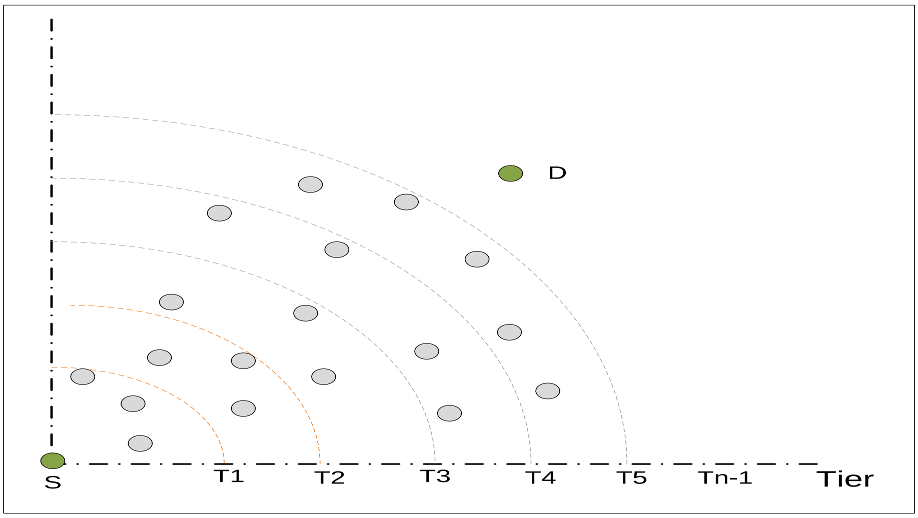

Figure 4.9. Neighbours of S – nodes in tier T1 – broadcast which is received by nodes in the tier T2 (i.e., the nodes within the T2 tier receive the RREQ from the transmitter node in tier T1).

In the next iteration, the nodes located in tier *T1* will broadcast RREQ, as shown in Figure 4.7, which will be heard in tier *T2*, as in Figure 4.9. Therefore, the expected forward degree of two-hop neighbours is computed by dividing the number of nodes in *T2* to the number of nodes in *T1*. For example, d_f [2] = 5/3. When the nodes in *T2* are broadcasted, they are heard in *T3* (Figure 4.16). Dividing the number of nodes in *T3* with the nodes in *T2* will give the expected forward degree of three-hop nodes. The broadcast storm continues to ripple across the network in the same manner (Figure 4.10).

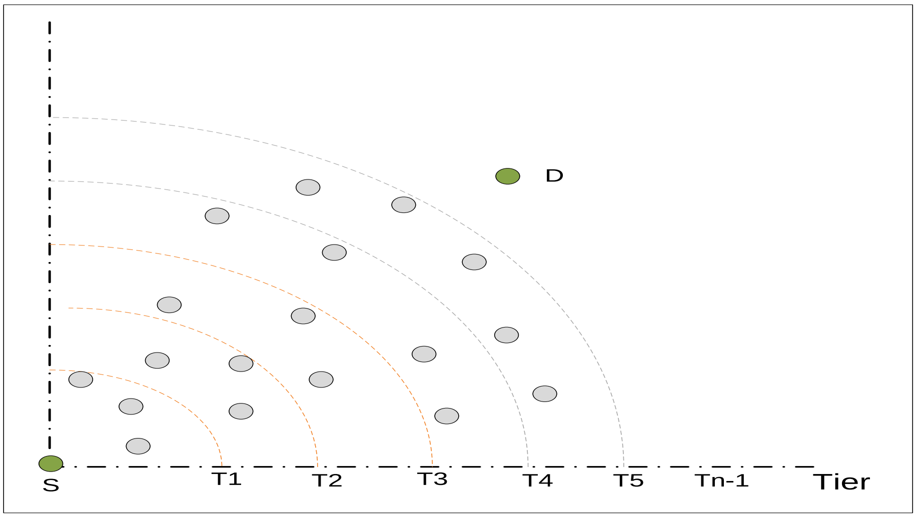

Figure 4.10. Nodes in T2 broadcast which is heard in T3. The inactive area is shown in T1.

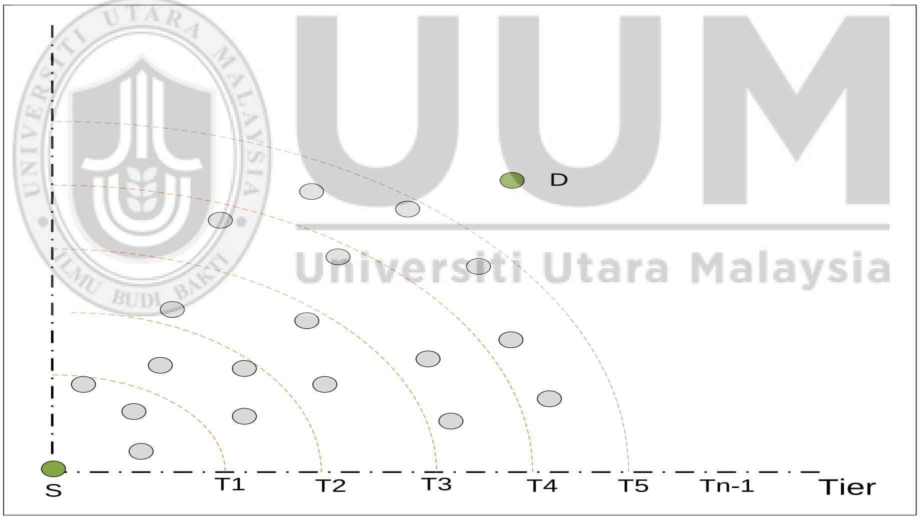

Figure 4.11. Nodes in T3 broadcast which is heard in T4. T2 and T1 are inactive.

Now, the expected forward degree of one-hop neighbour is given by

$$d_f\ [1]\ \simeq\ \frac{3\rho\pi r_0^2}{\rho\pi r_0^2 - 1} \tag{4.27}$$

$$d_f\ [j]\ \simeq\ \frac{2j+1}{2j-1} \quad \text{Where } 1 < j < h - 1 \tag{4.28}$$

The nodes located in the second last tier are excluded (Figure 4.11). For example, nodes at $h - 1$ hops as in Equation 4.28. The reason is that the inherent assumption in the derivation of Equation 4.28 in according to which the outer tier contains the maximum possible nodes. The following number, $\frac{1}{4}\rho\pi r_0^2$, represents the number of nodes in *T1*. *E* is simply the multiplied area of *T1*, i.e., $\frac{1}{4}\rho\pi r_0^2$ with the node density ρ which is possible only if the tier is full. Now just imagine the case in which *T1* has far less number of nodes than this, i.e., Nodes in tier T1 $<<\frac{1}{4}\rho\pi r_0^2$. Of course Equation 4.28 will not hold here.

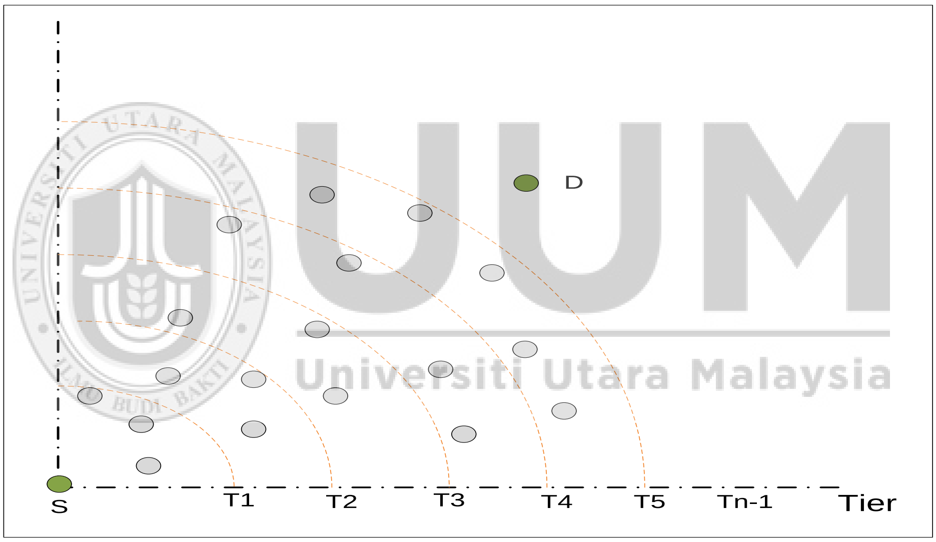

Figure 4.12. Nodes in T4 broadcast which is heard in T5. T3, T2 and T1 are inactive.

For the reasons mentioned above, the number of nodes in the last tier as well as the nodes at *h - 2* hops need to be calculated (Figure 4.12). For example, the second last tier shows that nodes at *h - 2* hops are $2(h - 2) + 1 = (2h - 3)$ x $\frac{\rho\pi r_0^2}{4}$. For calculating the number of nodes in the last tier, the total number of nodes distributed in the inner rings is subtracted from the network size which equals to $N-(h-1)^2 . \frac{\rho\pi r_0^2}{4}$ with $h>$ 1. Therefore, the forward degree of nodes at h - 1 hop is

$$d_f[\,h-1] \simeq \frac{N-(h-1)^2 . \frac{1}{4}\rho\pi r_0^2 .}{(2h-3) . \frac{1}{4}\rho\pi r_0^2} \tag{4.29}$$

By combining all the three cases (i.e., Equations 4.27, 4.28, and 4.29), the following expression is derived:

$$d_f[\mathrm{j}] \simeq \begin{cases} \frac{3\rho\pi r_0^2}{\rho\pi r_0^2-1} & if\ j=1 \\ \frac{N-(h-1)^2 . \frac{1}{4}\rho\pi r_0^2 .}{(2h-3) . \frac{1}{4}\rho\pi r_0^2} & if\ j=h-1\ where\ h>1 \\ \frac{2j+1}{2j-1}, & otherwise \end{cases} \tag{4.30}$$

Remember that h in Equation 4.30 represents the number of hops from the source node up to which the routing computation overhead can be calculated. Those protocols that flood the RREQs in the entire network are represented by AODV, h = $\frac{D}{2}$ where D is the diameter of the region measured in terms of hops. On the other hand, Equation 4.30 is more suitable for the restricted flooding protocol because the assumption is that the broadcast of nodes within an inner region (e.g., tier *T1* in Figure 4.7) is heard in the entire outer region (tier *T2*). For the stochastic broadcasting protocols, those nodes that do not forward the RREQ need to be factored out. By reducing the number of forwarding nodes, the number of the potential receivers is also reduced proportionally in the outer tier. Therefore, the expectation is that the forward degree will remain the same because it represents the ratio of nodes in the two tiers.

The forward relay node will increase with the number of nodes in the network (i.e., d_f [1] >d_f [2] >…). This trend is shown by plotting Equation 4.26 for a network of 200 nodes. This condition occurs because as the RREQ broadcast storm sweeps across a continuously increasing coverage area, the number of potential forwarding nodes will increase. The steady state phase indicates that each node in this particular condition can only effectively deliver a packet to a new node on average of one broadcast to a unicast transmission. Thus, if each node in a network is connected to approximately d_{avg} nodes, the broadcast coverage per node will decrease to approximately $\frac{1}{d_{avg}}$ nodes. The significantly smaller value leads to to the conclusion that unconditional broadcast in the surroundings of a source node is more effective when its performance deteriorates because the nodes will switch away from the source. Therefore, it is more appropriate to perform conditional broadcast in the region that can change the area size of broadcasting. This can be implemented in broadcast technique in the FS of route discovery.

Broadcasting processes that occur in this study were not similar as in real networks since a real-life situation would not follow perfectly the quadrant tier styles as illustrated in this study. Consequently, the routing overhead estimated by the proposed model may be slightly higher than the actual calculations. A similar argument holds for sparse networks (or the cases where ρ_i is significantly higher).

Table 4.8.

Discovery Forward Strategy Algorithm

Algorithm 2: EDFS
Q_i: the set of neighbouring nodes *i* in same quadrant; A_i: the set of neighbouring nodes *i* that satisfy the minimum angle to destination;

N_i: the number of nodes belonging to Q_i; n_i: the number of nodes belonging to A_i; (1) Each node i, identified quadrant based on d_f [1] $\simeq \frac{3\rho\pi r_0^2}{\rho\pi r_0^2 - 1}$, node i checks for all neighbours, and chooses j as new neighbour if: - j is inside the same quadrant, - j has the $\rho_i \geq$ min among all neighbours of i in the same quadrant (2) **for** $1 \leq j \leq N_i$ (3) **if** $d_{ij} \leq D_{th}$ (4) $\overrightarrow{F_{ij}}$ → is calculated by local algorithm (capacity of nodes). (5) **end if** (6) **if** $d_{ij} > D_{th}$ (7) Find the neighbours which belong to both A_i and Q_i. m is the number of nodes that satisfy $d_{jm} < R_c$ and belong to S_i; (8) **if** $m < 2$ (9) $F_{ij} = 0$ (10) **end if** (11) Compute the angle Θ formed by node i, j_c, and j_{ac} where $\overrightarrow{i\,j_c}$ is on the clockwise side of $\overrightarrow{i\,j}$, while $\overrightarrow{i\,j_{ac}}$ is on anti-clockwise side. Node j_c and j_{ac} belongs to A_i and Q_i. (12) **if** $\Theta > \pi/3$ and there are not any nodes located in quadrilateral ij, j_c, j_{ac} (13) $\overrightarrow{F_{ij}} = 0$ (14) **else** (15) $\overrightarrow{F_{ij}}$ → is calculated by local algorithm. (16) **end if** (17) **end if** (18) **end if** (19) **end for**

Therefore, every node that receives this packet will use the information to determine its quadrant compared to the source and destination as shown in the EDFS.

Table 4.9.

Algorithm used to Forward or Drop a RREQ Packet

Quadrant of compared to source? *1* Quadrant of destination compared to source? *1* If same, FORWARD

If not, DROP.

4.5.2.2 Characteristic of EDFS

The EDFS has the following characteristics.

- EDFS works on minimum angular degrees nodes to destination.
- The candidate relay nodes chosen will be the closest to the origin line that connects the *S* to *D* (in the angular slice at hops *i*-1, *i*+1 respectively)
- In EDFS, the angular quadrant of discovery zone will be adjusted to increase or decrease based on the scalability number of nodes.

4.5.2.3 Functionality of EDFS

In the original AODV route discovery, RREQ will be broadcasted to all neighbours and will create flooding of RREQ packets in the network. Therefore, in order to reduce flooding in network, EDFS is proposed, which is a modification of the AODV protocol. Distance and position angular information of nodes in route discovery where only nodes that are in same quadrant to the destination compared to the source will participate. The intermediate node which is closest to the origin line that connects the *S* to *D* will be selected as the next forwarding nodes. The forwarding of packets will be more directed toward the destination. This approach will reduce cost of updating each node's information in the network and reduce storage capacity if the number of nodes increases.

4.5.3 Energy-Aware Route Selection

For the purpose of increasing the system lifetime, an effective path selection measurement is needed. An Energy-Aware Route Selection (EDRS) is based on candidate relay nodes from the projection of two schemes was proposed. For convenience, a route is defined from source node s to destination d as a linear network model according to the following formula.

$$R = \{(i_0, i_1), \dots, (i_{h-1}, i_h)\}, \forall (i_k, i_{k+1}) \in L, \tag{4.31}$$

where $i_0, i_1, \dots, i_h$ are distinct nodes, $i_0 = s, i_h = d$, and h is the number of hops between source nodes and destination node d. Consider there is a number of m available routes between source node $s \in S^{(c)}$ and destination node $d \in D^{(c)}$. The residual energy of route r, with the intermediate nodes $i_1, \dots, i_h - 1$, source node $i_0 = s$, and destination node $i_h = d$, is defined as follows.

$$E_r = Min\left(E_{i_0}, E_{i_1}, \dots, E_{i_{h-1}}\right) \tag{4.32}$$

The best route r_{max} is the route with the maximum residual energy node. All routes r_{max} are selected from m available routes as,

$$r_{max} = Max(E_{r_1}, \dots, E_{r_m}) \tag{4.33}$$

The notation for the formulation is summarised in Table 4.10 for convenience.

Table 4.10.

Energy-aware Route Selection Algorithm Parameters

T	The network lifetime defined as the time it takes for the first node to die.
T_i	The time it takes for the battery of node i to drain out.

T_G	The time of the network G.
P_{ij}	The transmission power required by node i to transmit data to node j.
E_i	The initial energy for node $i \in N$.
E_r	The residual energy at node $i \in N$.
e_{ij}	The energy for transmitting one bit across the link $(i, j) \in L$.
$f_{ij}^{(c)}$	The rate at which bit of commodity c are transmitted across the link (i, j) per second, $\forall_c \in C$.
$f_{ij}'^{(c)}$	The total number of bits of commodity c for link (i, j) transmitted from node i to node j over T, $\forall_c \in C$.
$Q_i^{(c)}$	The throughput requirements, i.e., the number of bits that should be routed between source $s \in S^{(c)}$ and destination $d \in D^{(c)}$ nodes per second, $\forall_c \in C$.
$TQ_i^{(c)}$	The number of bits transmitted over T, at the source node $s \in S^{(c)}$ for $d \in D^{(c)}$, $\forall_c \in C$.
$SINR_{ij}$	The Signal to Interference with Noise Ratio requirement at the receiver node j from sender i.
$\alpha \geq 2$	The distance-power gradient.
$\beta \geq 1$	The transmission quality parameter.
d_{ij}	The Euclidean distance between the nodes i and j.
σ	The ambient noise power level.
$\gamma_{ij} \geq 1$	The SINR requirement for the transmission from node i to node j.

4.5.3.1 Characteristic of EARS

The EDRS has the following characteristics:

- Establish a path based on projection of EDFA and EDFS.
- Use the shortest-hop metric route path.
- Use the high reliability value of communication node from candidates in the path.

4.6 Maximising the Network Lifetime

In order to maximise the network lifetime, the minimum lifetime needs to be maximised for all nodes in that network. Furthermore, there is a need to consider the flow conservation separately, applied to each commodity [182].

Let the lifetime of node i be defined as the time it takes for the battery of node i to drain out. Let T_i(F) be the lifetime of node i under flow $F = \{f_{ij}\}$, where $(i, j) \in L$. T_i(F) is defined as the ratio between the initial energy at node i, E_i, and the total energy needed to transmit the flow from node i to its neighbours. The lifetime for node i is formally defined as follows.

$$T_i(F) = \frac{E_i}{\sum_{\forall j \in N, (i,j) \in L} \quad e_{ij} \sum_{c \in C} f_{ij}^{(c)}} \tag{4.34}$$

The lifetime of network G under flow F is defined as the minimum battery lifetime over all nodes,

$$T_G(F) = Min_{i \in N}\, T_i(F)$$

$$= \; Min_{i \in N} \frac{E_i}{\sum_{\forall j \in N, (i,j) \in L} \quad e_{ij} \sum_{c \in C} f_{ij}^{(c)}} \tag{4.35}$$

The maximum network lifetime problem for MANET is formulated as a non-linear optimisation problem as follows.

$$\text{Maximise}_{\boldsymbol{F}} \; T_G(\mathbf{F}) = Min_{i \in N} \frac{E_i}{\sum_{\forall j \in N, (i,j) \in L} \quad e_{ij} \sum_{c \in C} f_{ij}^{(c)}}$$

Subject to

$$\sum_{(i,j) \in L} f_{ij}^{(c)} - \sum_{(k,i) \in L} f_{ki}^{(c)} =$$

$$\begin{cases} Q_i^{(c)} \text{ if } i \in S^{(c)} \\ -Q_i^{(c)} \text{ if } i \in D^{(c)}, \forall c \in C, \\ 0 \text{ otherwise.} \end{cases} \tag{4.36}$$

$$f_{ij}^{(c)} \geq 0, \quad \forall i \in N, \forall c \in C.$$

Similar previous research [123], the above maximum network lifetime problem can be formulated as the following linear programming problem with some proper manipulation. Note that T is the network lifetime defined as the time it takes the first node to die. Denoted by f'_{ij}, the amount of bits transmitted from node i to node j in the network lifetime T would be $f'^{(c)}_{ij} = Tf^{(c)}_{ij}$.

Maximise T *while*

subject to

$$\sum_{(i,j)\in L} e_{ij} \quad \sum_{c\in C} f'^{(c)}_{ij} \leq E_{i,} \forall i,j \in N, \tag{4.37}$$

$$\sum_{(i,j)\in L} e_{ij} - \sum_{(i,j)\in L} f'^{(c)}_{ij} =$$

$$\begin{cases} TQ_i^{(c)} \quad if \ i \in S^{(c)} \\ TQ_i^{(c)} \ if \ i \in D^{(c)}, \forall c \in C \\ 0 \quad otherwise. \end{cases} \tag{4.38}$$

$$f'^{(c)}_{ij} \geq 0, \quad \forall (i,j) \in L, \forall c \in C$$

$$E_i > 0, \quad \forall i \in N.$$

The linear programming formulation given above can be viewed as a variation of the conventional maximum flow problem with node capacities (i.e., $\sum_{\forall(\mathrm{i,j})\in\mathrm{L}}\sum_{\mathrm{c}\in\mathrm{C}} \mathrm{f}_{\mathrm{i,j}}^{\prime(\mathrm{c})} \leq \mathrm{E_i}/\mathrm{e_i}$) [183], and without power control (i.e., the transmission power at each node is fixed, $e_{ij} = e_i$). With this linear formulation, the problem can be solved in an efficient way [184][185]. To maximise the network lifetime, it is also important to consider the power control problem. Transmitting at minimum power helps to prolong the lifetime of a node and thus the network lifetime [186][187]. In this Chapter, the power control is addressed with the maximum network lifetime problem as in the following subsection.

4.7 Preliminaries and Formulation

The proposed EDRA was tested by running a preliminary test on the proposed algorithm in a simulation environment using the Ns-2.34 simulator [188]. The experiment was setup with hardware parameter settings as energy dissipation (E_{elec}) = 50nJ/bit, free-space model (ε_{fs}) = 10pJ/bit/m^2, multipath model (ε_{mp}) = 0.0013pJ/bit/m^4, and data length (l) = 2000 bits. The network coverage area is assumed to be a circle with radius of 100 metres and node ranges 50 up to 200. Locating the nodes at different distances creates different energy-distance factors for the nodes though they possess the same level of energy. Figure 4.13 shows the energy consumption of the intermediate node during a unit size packet transmission. The energy consumption has been computed by subtracting the initial energy from the remainder energy using Equation 4.39.

Based on the energy-distance factors of the intermediate node, the highest probability *rho*(ρ) of the node, shows the lowest energy consumption. The lowest

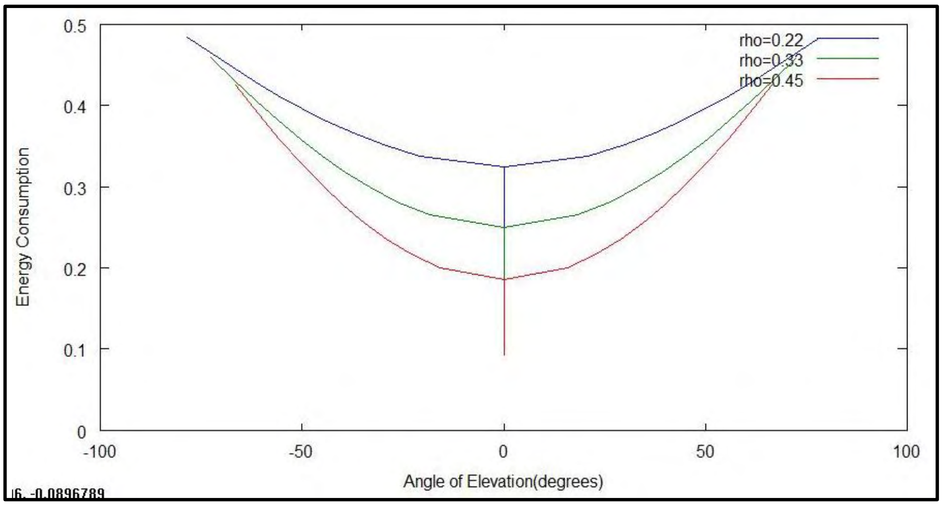

Figure 4.15. Energy consumption in the intermediate node in free space transmission.

The energy consumption by the intermediate node increases drastically with the rise of distance as they are related through higher orders of the distance as shown in Equation 4.39.

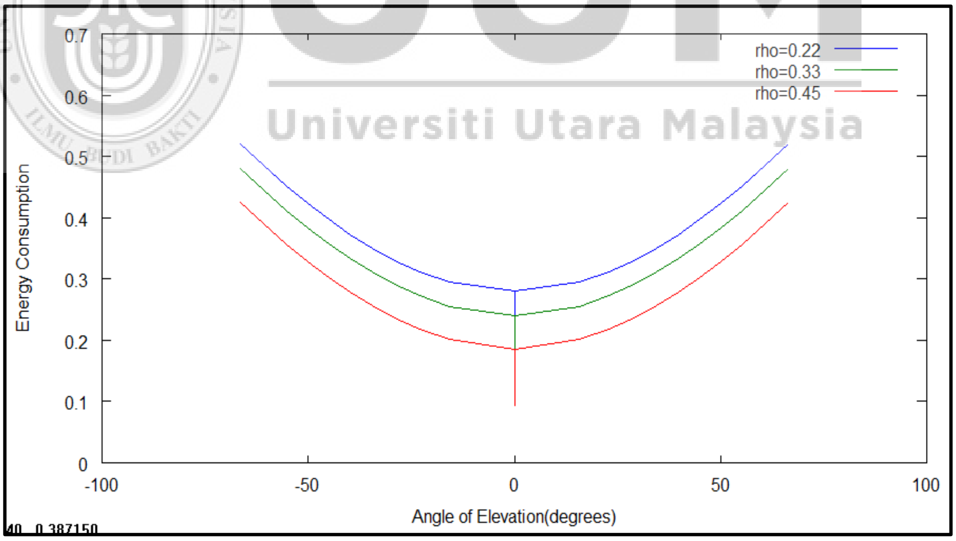

Figure 4.16. Energy consumption in the intermediate node in multi-path transmission.

Figure 4.15 shows the free-space model whereby the node with the highest energy-distance factor (ρ) has the lowest consumption energy. This indicates that the intermediate node has higher residual energy compared to the other intermediate nodes. Figure 4.16 presents the results of the experiment that was set up using the intermediate nodes with different initial energy levels, but located at the same distance. In both cases, the node with the largest ρ has the highest remaining energy. This indicates that it has more energy left after the transmission of a data packet [189]. This information is very important for selecting the intermediate node that could provide a stable route in terms of the node lifetime. If a node with low remaining energy was chosen for the transmission, it would not have sufficient energy left for future transmission, forcing the nodes to rearrange the routes through other nodes. Hence, it can be concluded that the node with the largest energy-distance factor (ρ) provides the best intermediate node for the transmission of data toward the destination. From the results, when the energy-distance factors are arranged in an ascending order, they provide the intermediate nodes with remaining energy from highest to lowest. This means that the energy-distance factors can be used to select the best node as well as the backup nodes with an order of preference in times of node failure due to other reasons, such as node mobility.

was subsequently required for the packet to reach its ultimate destination [99]. Specifically, the first-hop energy-distance efficiency is defined as the ratio of the average progress of a packet during its first transmission and the energy consumption of that transmission. The first-hop energy-distance efficiency should be consistent with the overall energy-distance efficiency of the entire route in a homogeneous environment. Note that the maximum distance of the single hop is different to the first hop from the intermediate nodes in the multi-hop transmission [64, 190]. It can be observed from both figures that the first-hop energy-distance efficiency improves initially for small r, and then decreases after r exceeds a certain value. Figure 4.19 shows the changes of the optimal transmission range (r^*) for different nodes (ρ). When the node (ρ) is 0.45, the optimal transmission range is around 360 and it reduces to 330 when node (ρ) reaches 0.22. In Figure 4.20, the optimal transmission range is around 170 on node (ρ) 0.45 and reduces to 120 when node (ρ) reaches 0.22. The explanation of this result is that the probability of finding relay nodes that are closer to the final destination is higher when there is a higher number of nodes (ρ) in the network. Thus, each hop makes more progress toward the final destination thereby improving overall energy-distance efficiency.

Usually when a wireless network consumes more energy, its life is shorter. However, it is not always true in this case. To investigate the performance of the proposed algorithm, both the EDFA and EDFS are simulated. After increasing the number of mobile nodes scalable varied to 200 (three scale scenarios), the result does not change significantly. Therefore, sometimes it is better to consume more energy especially when this is done to be more equivalent to the distance mileage in the network. This is exactly what happens with routing in multi-path transmission. Three measures of network longevity are considered: (1) lifetime to first node, (2) total energy consumption, and (3) time to network disconnection.

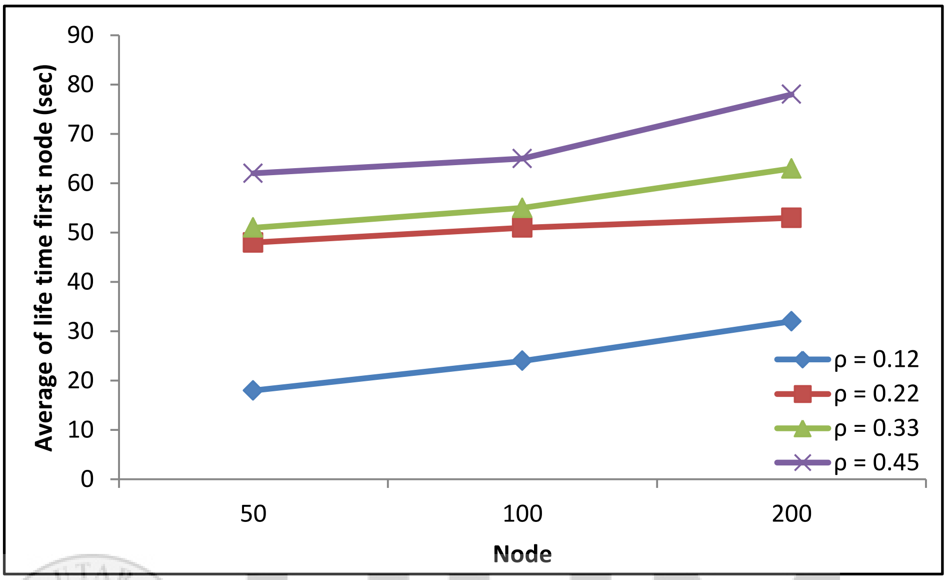

Figure 4.19. Average lifetime of the first node in free-space transmission.

In the first hop transmission, it was found that the nodes in the multipath transmission routing have used more energy consumption compared to the free-space transmission. This is shown in Figure 4.19 and Figure 4.20. The node lifetime is longer for different (ρ) in both routing transmissions. This shows that the packet route in the multipath transmission routing makes the network nodes consume more energy, up to more than one and a half of free-space transmission. The experiments in this study revealed that the use of routing in both transmission methods present excellent benefits from an energy-efficiency point of view.

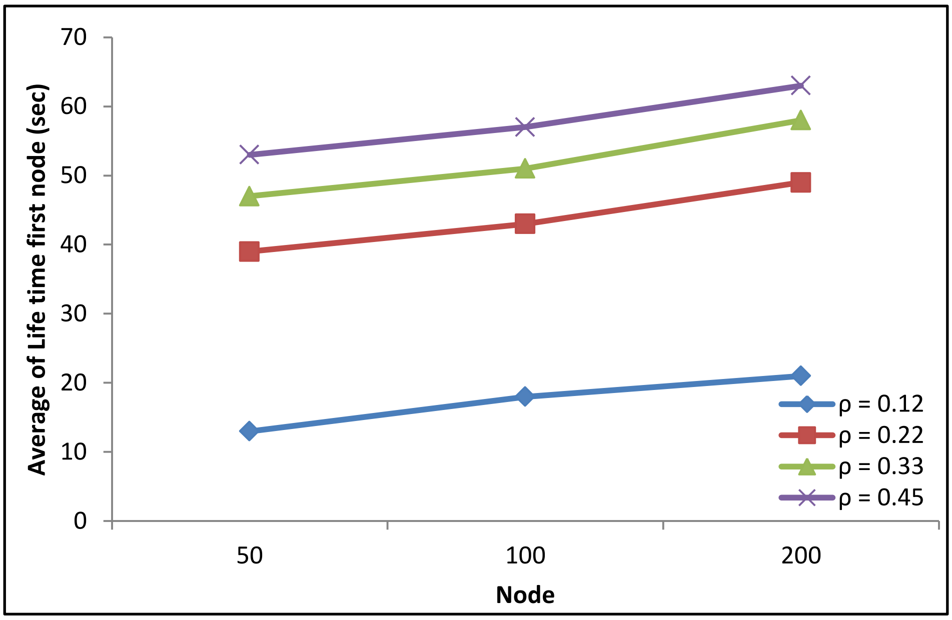

Figure 4.20. Average lifetime of first node in multipath transmission.

From the experiment results in Figures 4.19 and 4.20, the lifetime node will be prolonged in large density node scale situations compared to those of the distance-energy efficiency. In the large scale nodes, the proposed algorithm can identify more quality candidate relay nodes which can provide an efficient route to the end destination [101, 169, 191]. For all scenarios, it can be observed that the increases of nodes (*N*) in the network denote the increment in the number of relay nodes in the route path. Given that $e(n) = \sum_{i=0}^{n} e_i$, it is suggested that the energy consumption per bit for an individual node e_i decreases faster than the order of $\frac{1}{n}$, when n increases. The intuitive reason is that the distance between the adjacent-neighbour relay nodes decreases at the order of $\sqrt{1/n}$, when n increases. Since the results in the theorems are under the real world radio propagation condition of $\alpha \geq 2$, e_i would decrease at the order of $\left(\sqrt{1/n}\right)^{\alpha}$, which is faster than the order of $\frac{1}{n}$. It is also noted for the energy factor used by hardware circuit (radio transceiver), as analysed in detail in Chapter 5.

This shows that the relay nodes consist of nodes that have optimum energy-distance efficiency as illustrated in Figure 4.21 and Figure 4.22. Both transmission methods, in EDFS, have more effectiveness in energy-distance efficiency. The EDFS scheme can reduce energy consumption by 11%, as compared to the EDFA. It also can prolong the lifetime connection by 9%, compared to the EDFA in all scenarios.

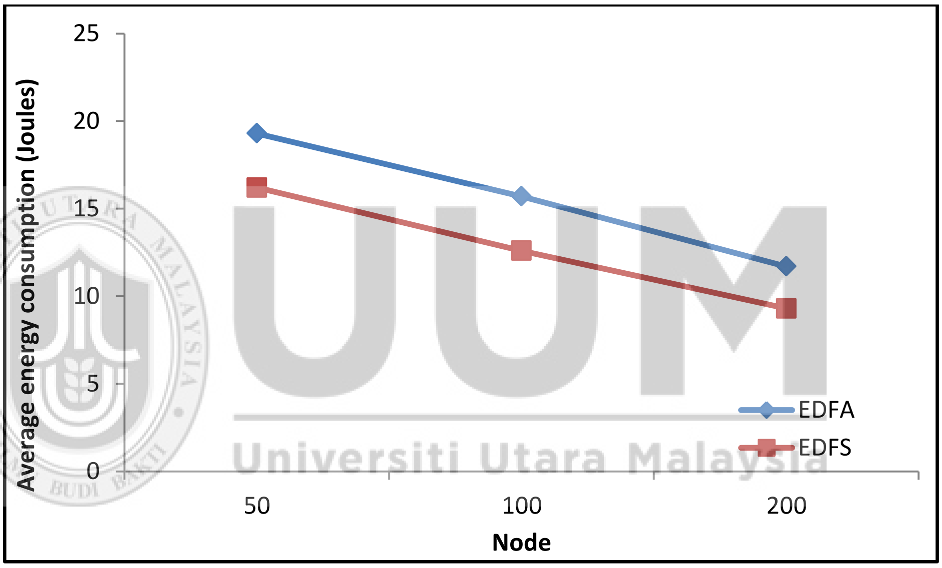

Figure 4.21. Energy consumption on the route path: Free-space transmission.

Based on the energy consumption per bit for an individual node e_i, it was found that the energy consumption on the path is equal to the average consumption for packet transmission in both transmission methods. The total average energy consumption is evaluated when the route is established. The total consumed energy is defined as the total energy consumption when the route passed each intermediate node. It was found that the EDFS algorithm in Figure 4.21 and Figure 4.22 surpasses both transmission methods with adopted strategy through limiting the area of discovering of a new route to a smaller zone [192]. Thus, the mobile node lifetime is increased. In addition, the result of the total energy consumption in the routing is a trade-off between decreasing discovering area with impact on the optimal energy-distance efficiency on nodes.

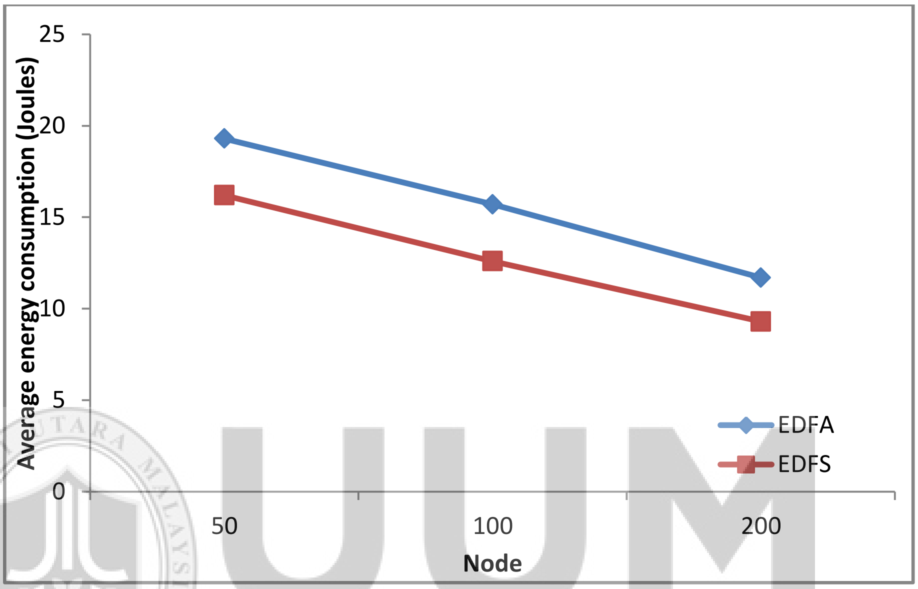

Figure 4.22 . Energy consumption on the route path in multi-path transmission.

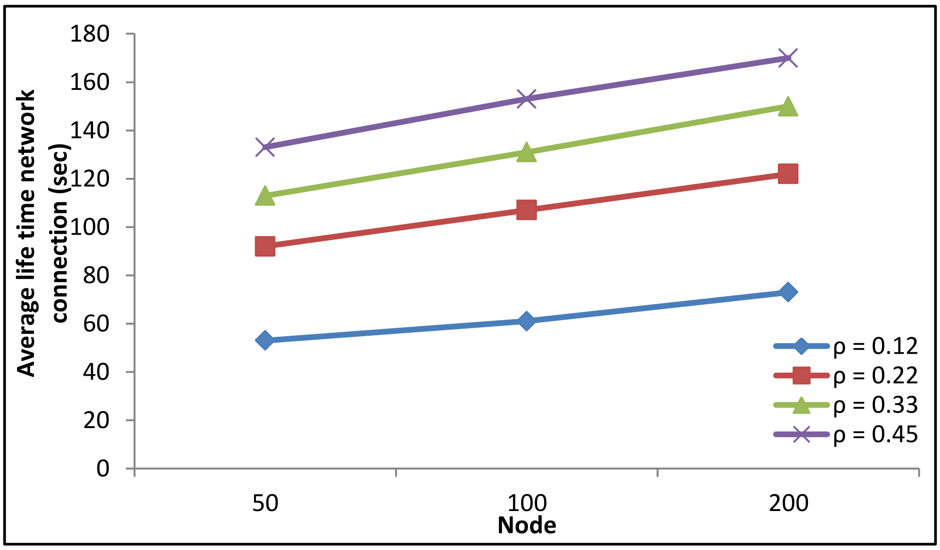

Figure 4.23. Network connection in free-space model.

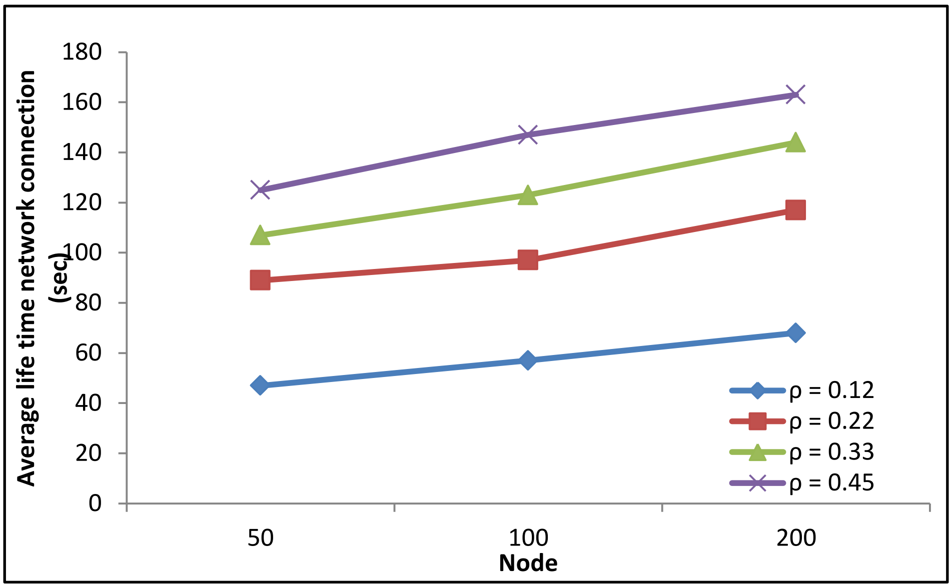

Figure 4.24. Network connection in multi-path transmission.

The results also indicated that on average, the network lifetime is 32% longer when using the free-space model routing compared to the multipath transmission routing. As a fact, the number of messages successfully delivered by the network until the very first node death is much larger with routing in the free-space transmission. Figure 4.23 and Figure 4.24 show that the results are based on the second definition of network lifetime. In this case, the dead node was taken into account because it is no longer efficient in delivering messages. Note that connectivity is one of the important features of network coverage. Also in this case, the free-space transmission routing overcomes the multipath transmission with 11% longer network life.

As portrayed in Table 4.11, the critical issue related to routing is that the energy constraint can influence the connection lifetime. However, the optimum energy-distance efficiency with energy consumption and hop number, link delay can sustain the lifetime for the whole network as achieved by the EDFA and EDFS.

Table 4.11.

Routes under Different Algorithms

	Energy cons.	Net. Lifetime	Hop number	Link delay
Direct Transmission	High	Short	1	Short
AODV	High	Short	8	High
Q-DIR	Medium	Long	5	Medium
DREAM	Medium	Long	6	Medium
EDFA	Medium	Long	5	Medium
EDFS	Medium	Long	3	Medium

In some applications when the link delay is critical, direct transmission routing is preferred [193]. In other applications when the network lifetime is critical, maximum residual energy and minimum energy consumption routing is preferred [194].

In this thesis, the selection criteria of the next-hop node are to optimise the energy-distance efficiency in the multi-hop routing process. The findings also indicated that the energy consumption is reduced, network lifetime is prolonged, and the node death phenomenon is alleviated more effectively.

4.8 Summary

In this Chapter, the main objective was to propose the scheme of Energy Distance Aware Protocol (EDRA) in order to prolong the network connection lifetime on the relay nodes. The solution had been proposed with EDFA and EDFS technique in route discovery. The energy and distance of the nodes are two significant variables for consideration as a factor to select the relay node. The initial energy and distance between neighbouring nodes will be the energy consumption as the distance travelled per unit energy consumed in order to sustain node life. By considering the energy-distance efficiency on nodes, the effectiveness to reduce the route discovery time and energy consumption in mobile nodes and in ad hoc network can be enhanced. The approach of EDFS in this scheme is interrelated to reduce the overhead, delay, and etc. By considering restricting the flooding routine with discovery quadrant, the energy-distance efficiency can be optimised in the scalability of networks. The results showed a large increase in the network lifetime with marginal increase of energy consumption per bit. Based on these factors, there is a probability of enhancing the effectiveness of the participating nodes in the route discovery.

CHAPTER FIVE

PERFORMANCE EVALUATION STUDY OF ALGORITHM

5.1 Analysis of Relevant Model

An analysis was conducted in finding the optimal network lifetime. The intermediate nodes will act as the potential paths to stabilise network connections. Therefore, the role of routing is not only to find a path, but also to find the optimal path that satisfies the performance requirements from a set of optional paths. Choosing an optimal path from a source to a destination can be done by optimising one or more routing metrics (e.g., number of hops, distance, energy consumption, and etc.).

5.1.1 Optimal Transmission Range

In order to achieve network connection stability with efficient packet delivery, the source node needs to send the data to the destination node using one or more relay nodes in order to reduce the power consumption rather than use direct transmission. Each relay node acts as a router that forwards the received packets from one neighbour to another. The relay node consumes three kinds of energies when forwarding the packet-energy to receive the data, energy to amplify the data signals, and energy to transmit the data [195]. These were expressed in the Equations 4.1, 4.2, and 4.3.

Note that for the purposes of packet forwarding, the transmission node should be strengthened by increasing transmitting power in accordance with the increase in distance between nodes. Thus, reducing energy consumption by introducing more relays will have a great effect to reduce the energy consumption in amplifying the signal, since the sum of the square distance of segments are much less that the square distance of the total distance. In other words, if $d = d_1 + d_2 + \ldots d_h$, then $d^2 \gg d_1^2 + d_2^2 + \cdots d_h^2$. However, at each relay, there is an extra energy needed to receive and retransmit the data. Thus, it is a trade-off to balance between these two types of reduction and increment in power consumption to achieve optimal total value.

For an end-to-end multi-hop transmission, the data packet is forwarded from the source to destination nodes, where the distance separating between them is L. Assume that the range of each hop is *r*, then the number of hops is derived as:

$$m = \frac{L}{r}\,. \tag{5.1}$$

Based on the energy consumption model mentioned in Chapter 2, the energy consumption of the end-to-end transmission with optimum transmission energy is as follows,

$$E_{Tx} = m \text{ x } \{[(E_{Tx-elec} + E_{Tx-amp} r^{\alpha})l] + (E_{Rx-amp} \,.\, l)\} \tag{5.2}$$

$$= \frac{L}{r}\, X\, \{(2E_{Tx-elec} + E_{Tx-amp} r^{\alpha})l\}.$$

To compute the minimum energy consumption, the first derivative of E_{Tx} with respect to the grid-length, *r*, and let $\frac{\partial E_{Tx}}{\partial_r} = 0$ is taken as

$$E'_{Tx} = L.\,l\left[(-1)E_{Tx-amp} r^{n-2} - 2E_{Tx-elec} r^{-2}\right] = 0. \tag{5.3}$$

Solving Equation 5.3 for *r* gives the optimal transmission range as,

$$r^n = \frac{2E_{Tx-elec}}{(n-1)E_{Tx-amp}} \tag{5.4}$$

$$r^* = \sqrt[n]{\frac{2E_{Tx-elec}}{(n-1)E_{Tx-amp}}}$$

With specific transceiver parameters, Equation 5.4 is accepted when the number of hops (*m*) is large, the transmission range of each hop (*r*) becomes smaller, and the fixed energy consumption for each hop (energy consumed for transceiver electronics) dominates the energy consumption. When the number of hops is small, the transmission range of each hop becomes larger, and the energy consumed in the transmitter amplifier of each hop increases rapidly and dominates energy consumption. When *n* is large, the energy consumed in the transmitter amplifier becomes relatively more important than the fixed energy consumption, and vice versa. In this case, the EDFS covers the small discovery area in the routing process. Therefore, it will have a small number of participating nodes in the path.

5.1.2 Different Distance Transmission Radius

The influence of the transmission radius *r* on energy consumption is also investigated since different routing algorithms will choose the next-hop node based on their *n*-hop selection criteria. Thus, the performance of the energy consumption changes a lot under different transmission radius sizes. The nodes are increased by setting d_c = 100 and $\Delta = 50$. Then, a communication link with specific *d* = 150m to study the total energy consumed along the link under different routing algorithms was chosen. Figure 5.1 portrays that direct transmission always consumes the largest amount of energy since it utilises the multi-path energy model with average long distance. There is no variation in the energy consumption value since the hop number as well as the distance is fixed in the direct transmission algorithm.

For the DREAM algorithm, the node chooses its next-hop node based on the remaining energy which is irrelevant to the distance distribution. As the transmission radius increases, there will be more candidates with perhaps larger residual energy. Thus, there is a trend that the energy will decrease as r increases. When r is large enough (like $r > 100$), there is no variation since each node can find its neighbour with the largest residual energy. Thus, energy consumption does not change as r keeps on increasing.

Additionally, in the DREAM routing algorithm, the hop number is larger when r is small, which causes more energy consumption. As r increases, it prefers to choose the next hop with distance $r_i \approx r$ to get closer to the destination. Thus, the energy consumption decreases as r increases. The best performance of energy consumption is when $r = 70$ because the individual distance is close to the critical distance d_c which ensures desirable energy consumption. As r continues to increase, the energy consumption for DREAM algorithm increases since a larger distance is chosen, causing more and unbalanced energy consumption.

For the proposed EDFA/EDFS algorithms, they consume the optimum energy since they evaluate the distance compared to the remaining optimum energy of individual nodes. Taking $r = 50$ as an example, it can find an average of a four-hop multi-path with $d_i \approx 40$. When $r \geq 90$, there is a guarantee that the proposed EDFA/EDFS can always find the average three-hop route with each individual distance $d_i \approx 50$, which is very energy efficient. Thus, there is no variation in the energy consumption value as r increases from ≈ 90 and above for the EDFA algorithm. In addition, the EDFS algorithm has more average hops compared to the EDFA in all scenarios.

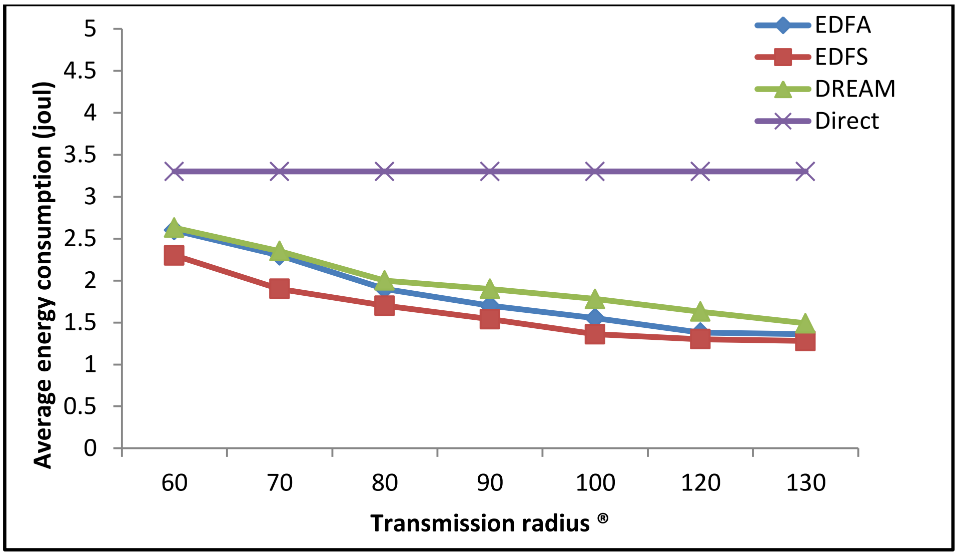

Figure 5.1. Energy consumption under different transmission radii.

It is worth noting that $r \in [< 60]$ can ensure desirable energy consumption performance for three routing algorithms, except direct transmission. If r is too large, it will cause other issues such as more interference, larger routing table, and more overhead control.

5.1.3 Different Neighbourhood Distance

In Figure 5.2, the energy consumption on one communication link with d = 160m is studied, followed by the same on different communication links. The simulation environment is the same as Figure 5.1 with R = 100.

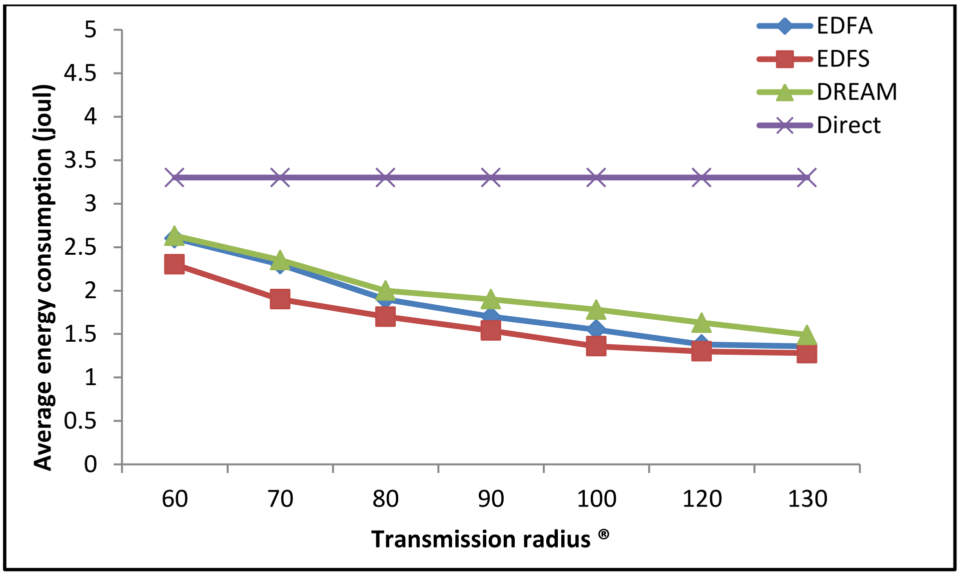

Figure 5.2. Energy consumption under different distances (*d*).

Figure 5.2 shows the energy consumption under different sources to a one-hop distance. When $d \leq R = 110$, direct transmission manner can be chosen by the three routing algorithms. The results showed that they have almost the same energy consumption levels, which is also very small. When $d > 110$, direct transmission is not suitable for the other routing algorithms because it consumes the largest amount of energy while transmitting from source to destination nodes. The performance of the DREAM algorithm is shown to be in the middle, while the proposed EDFA algorithm consumes the least energy. The reason is the same as in Figure 5.1.

5.1.4 Different Node Number

In Figure 5.3, the energy consumption is under different node numbers N in the four scenarios. Here, the node number changes from 50 to 200.

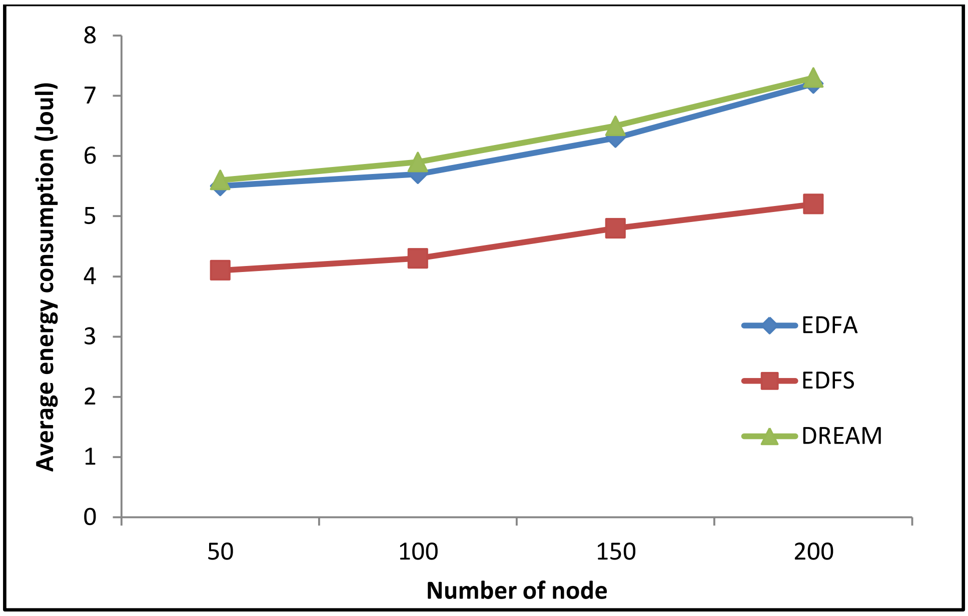

Figure 5.3. Energy consumption under different N.

Figure 5.3 shows a similar energy distribution for different routing algorithms as in Figure 5.2. In the direct transmission manner, more energy is used in transmission while the proposed EDFA / EDFS algorithms use the least energy on average. Moreover, it was found that the EDFS consumes more than the little average energy. The variant or fluctuation of the average energy consumption becomes smaller as *N* increases. This shows the essence of energy consumption for each routing algorithm. For the proposed EDFA algorithm, it can always find the suboptimal hop number and intermediate nodes as *N* increases.

5.1.5 Different Distances from the Origin Line

Figure 5.4 presents the findings of energy consumption under different distances from the origin line (*S* to *D*). The data length is 2000 bits and set as *R* = 100. Here, the origin line will change its position along the diagonal line from position *S* to *D* based on the location of the node *D* in a network.

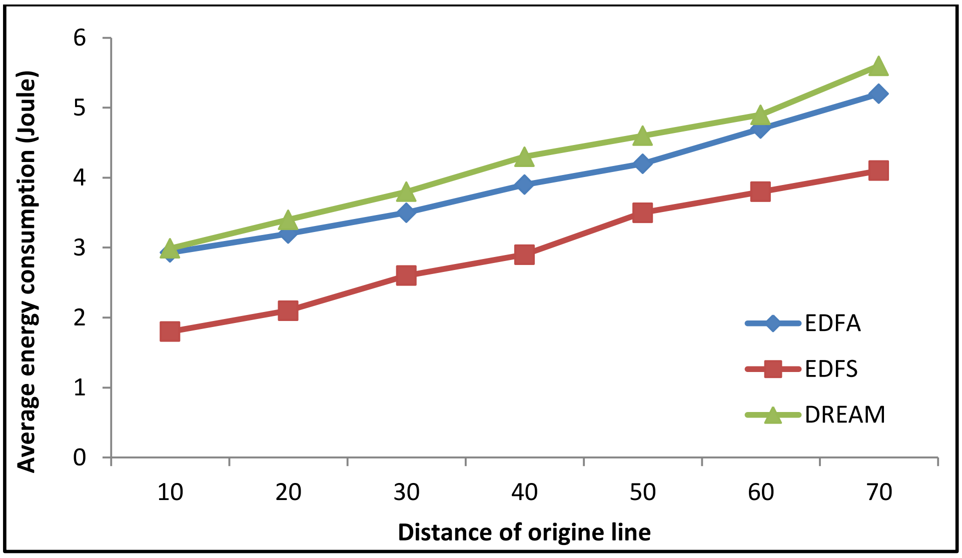

Figure 5.4. Energy consumption under different distances to the origin line.

From Figure 5.4, the energy consumption distribution for the algorithms is almost symmetric based on the origin line (0°). Minimal energy consumption can be achieved if the candidate nodes are located nearest to the origin 0°. It is easy to understand the symmetry property from the energy consumption model since there is average energy consumption. It was found that the EDFS has very less energy consumption compared to the two other. This strategy can achieve similar results to the greedy algorithm [188, 189].

The average energy consumption as a mathematic model $E_{avg} \propto \frac{1}{N}\sum_{i=1}^{N}(k.E_{elec} + k.d_{i.}^{\alpha})$ where $\sum_{i=1}^{N} d_{i.}^{\alpha}$ tends to get the minimum value when the relay node is located nearest to the origin line on the forward to destination.

In Figure 5.5, different energy consumption becomes larger as the packet length increases. It is worth noting that the EDFS algorithm consumes much less energy than the other two algorithms.

The EDFS has a factor about three to five times more energy reduction than the other routing algorithms.

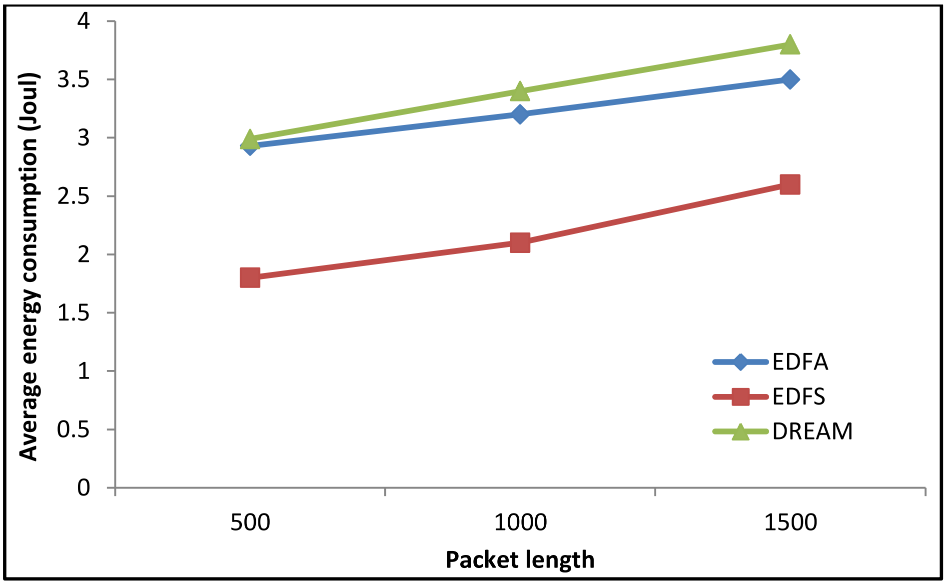

Figure 5.5. Average energy consumption under different packet lengths.

5.1.6 Different Network Scale

From the study of energy consumption in this section, the direct transmission algorithm consumes almost the largest amount of energy, especially when the network scale is large. Direct transmission also has the following advantages; (i) more energy efficient than the Minimum Energy Route (MRE) or other routing algorithms under small scale network; (ii) the hardware circuit or modules consume a large volume of energy (i.e., routing over many short hops may consume more energy than direct transmission); (iii) the direct transmission has better performance of route delay, packet delivery, and throughput. Thus, when there is QoS requirement on these factors, direct transmission is preferred. Moreover, direct transmission may be more energy efficient in some other wireless networks.

Therefore, it is a wise choice to combine the multi-hop method with direct transmissions during the routing process. The proposed EDFA/EDFS algorithms also adopt direct transmission when the relative distance is small. In large scale networks, the EDFS still surpasses in less energy consumption as seen in Figure 5.6. The algorithm can also perform in various scale networks.

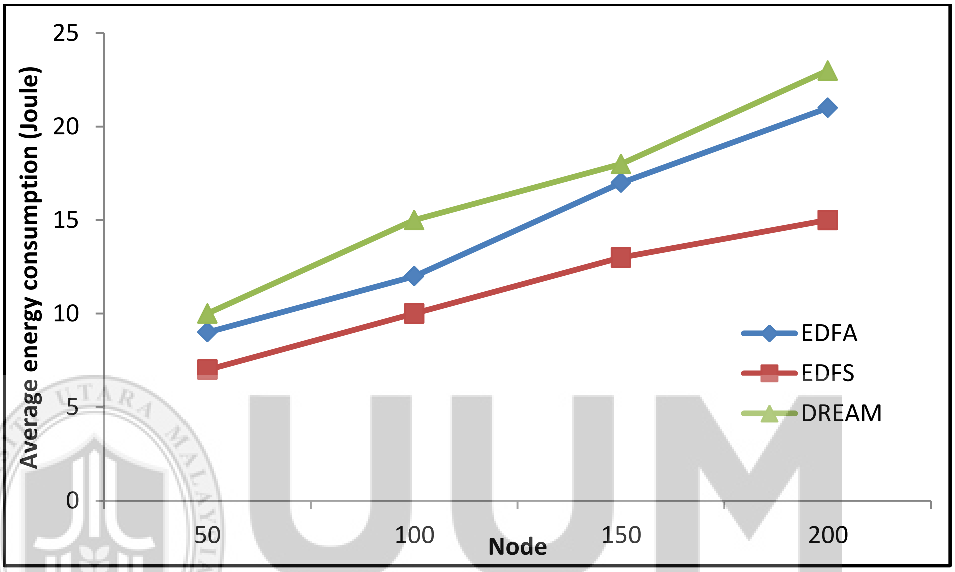

Figure 5.6. Total energy consumption under scaled networks.

The direct transmission in large scale networks is not economical especially when the distance factor is the main cause in determining the optimum node lifetime for routing purposes.

- The new transmission power calculation depends on the distance between the sender node and its first hop neighbour using a shadowing propagation model with a path loss exponent $\alpha = 3$ [184, 185].
- Simultaneous connections are considered to show the effect of multi-commodity flows.

This research had considered a typical MANET with 100 mobile nodes randomly located over a 1500 by 500 m^2 rectangular space [186, 187]. Identical loads and environmental conditions were used to compare AODV, DSDV, Q-DIR, and DREAM with the proposed routing protocol variations. Each simulated run accepted the following scenario files as input.

- Nodes randomly deployed in a 1500 by 500 m^2 area, and initial transmission range is uniformly distributed between 200 and 250m.
- Packet sequence originated by each node: the traffic source is constant bit rate (CBR) with a sending rate of four packets per second. The network contains 2, 4, 8, 16, 32, and 64 CBR connections with a packet size of 512 bytes. The connections are started at times uniformly distributed between 0 to 300 seconds.

This scenario is repeated 20 times using different random values, and the average result was presented with a 95 per cent confidence interval.

5.3 Algorithm Comparison

A simple comparison between the proposed EDFA, EDFS, EARS, AODV, DSDV, Q-DIR, and DREAM routing algorithms was made in terms of the average consumption energy, end-to-end delay, overhead, and average network lifetime. Having done this, it was observed that more energy could be saved on the node after event because both transmission distance and energy consumption of the process are largely reduced.

5.4 Simulation Results

For the simulation, the scalability and transmission radius parameters were considered in testing the impact of the network connection lifetime. The proposed Energy-Distance Routing Aware (EDRA) protocol with three schemes as Energy-Distance Factor Aware (EDFA), Energy-Distance Forward Strategy (EDFS), and Energy-Distance Route Selection (EDRS) performed better at scenarios in the simulated MANET environment compared to other protocols.

5.4.1 Number of Connections

In Figures 5.7 to 5.12, the different performance comparison of the variations of the proposed scheme on EDRA protocol (i.e., EARS) with the AODV, DSDV, Q-DIR, and DREAM routing protocols can be observed. These figures represents the simulation results in which the number of CBR connections changes. For these scenarios there is one connection at a time. From Figures 5.7 to 5.12, the proposed schemes under EDRA have better performance than others. Figure 5.7 shows the energy consumption rate. The proposed EDFS with adjustable power transmission decreased the total energy consumption rate by 20 to 30 per cent compared to the DREAM, Q-DIR, and other (i.e., no power control) protocols. As the number of connections increased, the proposed EDRS decreases the average physical node degree, as showed in Figure 5.8, which results in lower node interference. The proposed EARS preserved the throughput in 2, 4, 8, and 16 connections and increased it at 32 and 64 connections. This was due to less interference and low drop ratio. The drop ratio is shown in Figure 5.10. The end-to-end delay was decreased by the proposed protocol as shown in Figure 5.11. EDRS had lowered delay, which is clearly observed at 32 connections. Lower interference leads to decreased energy consumption and maximised network lifetime while preserving throughput and packet drop ratio. The network lifetime is shown in Figure 5.12. The proposed protocol showed better performance with 32 and 64 connections, which indicated good performance with higher load.

5.4.2 Impact of the Number of Connections

For this scenario there is one connection established at a time. From Figures 5.7 to 5.12, the proposed EDRS had better performance than others. The proposed EDRS with power transmission decreased the total energy consumption rate by 20 to 30 per cent compared to the DREAM algorithm. As the number of connections increased, the proposed EDRS decreased the average physical node degree as shown in Figure 5.8, which results in lower node interference. Figure 5.9 shows the network throughput. The proposed EDFA and EDFS preserved the throughput in 2, 4, 8, and 16 connections, and increase it at 32 and 64 connections. This was due to less interference and low drop ratio (Figure 5.10). The end-to-end delay was decreased by the proposed protocol, as shown in Figure 5.11. EDFS had lowered delay, and EDFA and DREAM had minimum delay compared to AODV and DSDV, which is clear at the 32 connections. Lower interference leads to decreased energy consumption and maximised network lifetime while preserving throughput and packet drop ratio. The network lifetime is shown in Figure 5.12. The proposed algorithm protocols showed better performance with 32 and 64 connections, which indicates good performance at higher network loads.

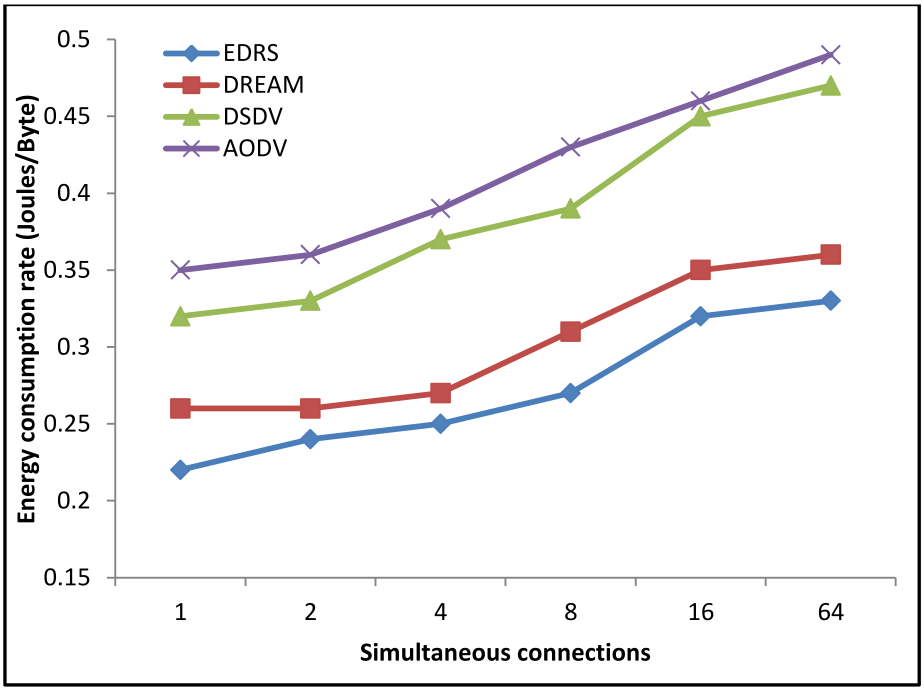

Figure 5.7. Energy consumption rate with various numbers of connections.

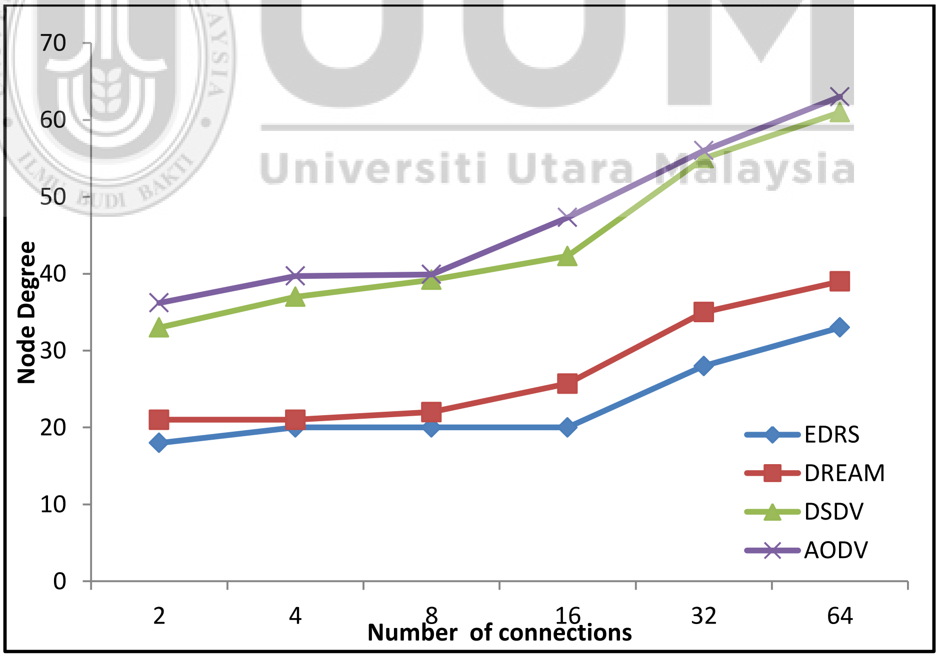

Figure 5.8. Node degree with various numbers of connections.

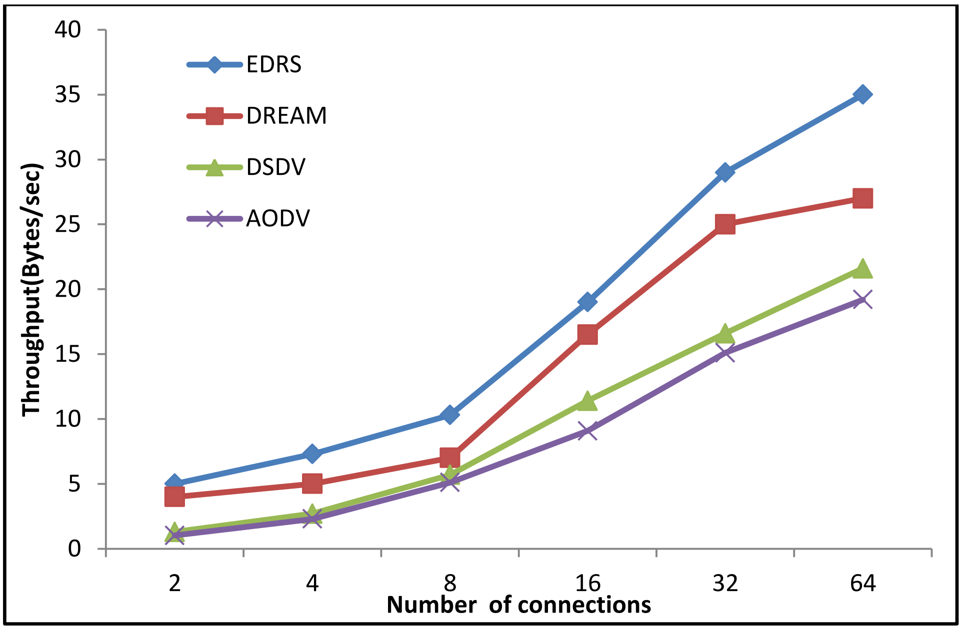

Figure 5.9. Network throughput with various numbers of connections.

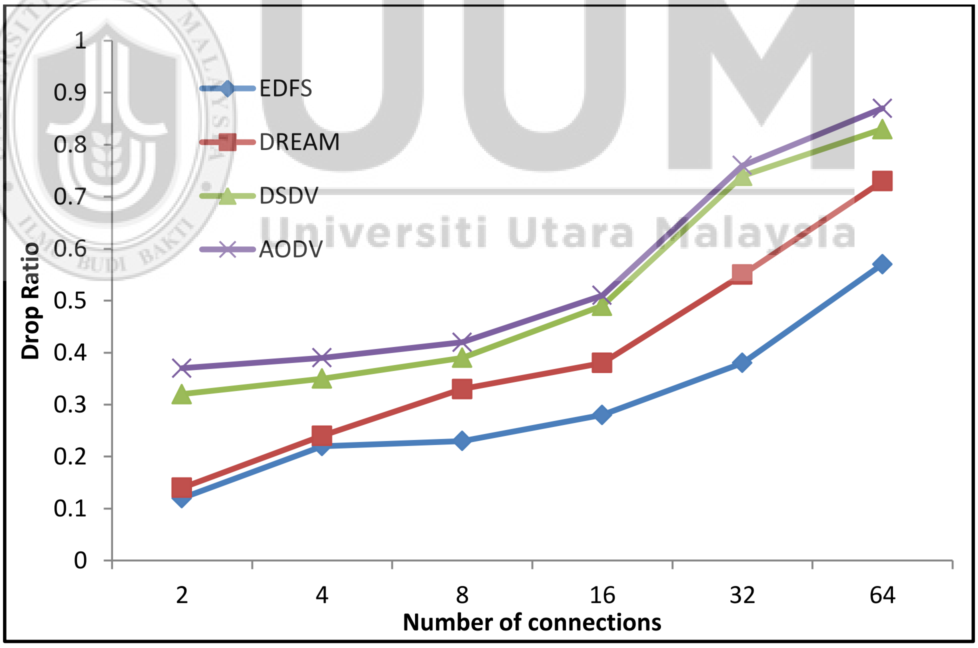

Figure 5.10. Packet drop ratio with various number of connections.

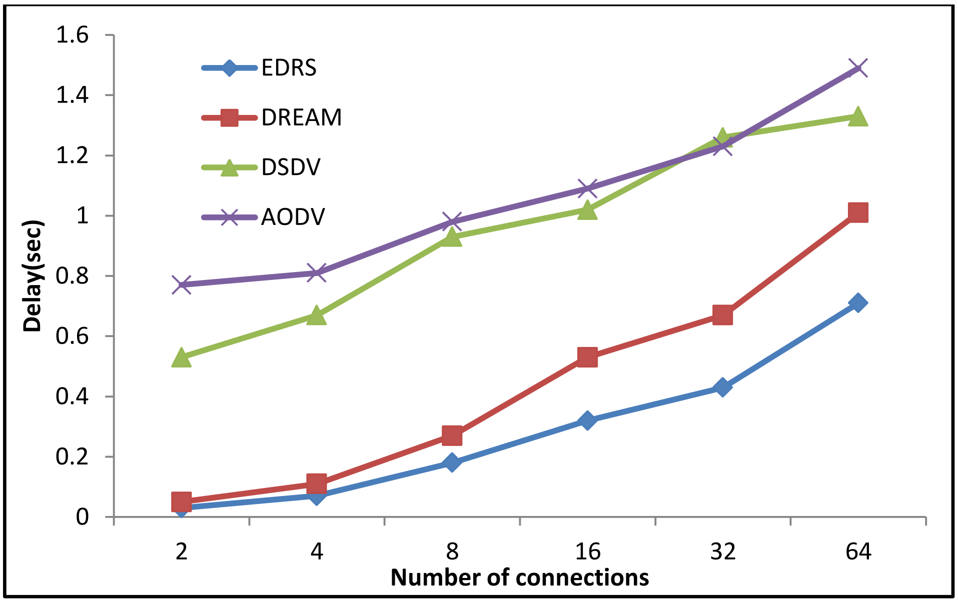

Figure 5.11. End-to-end delay with various numbers of connections.

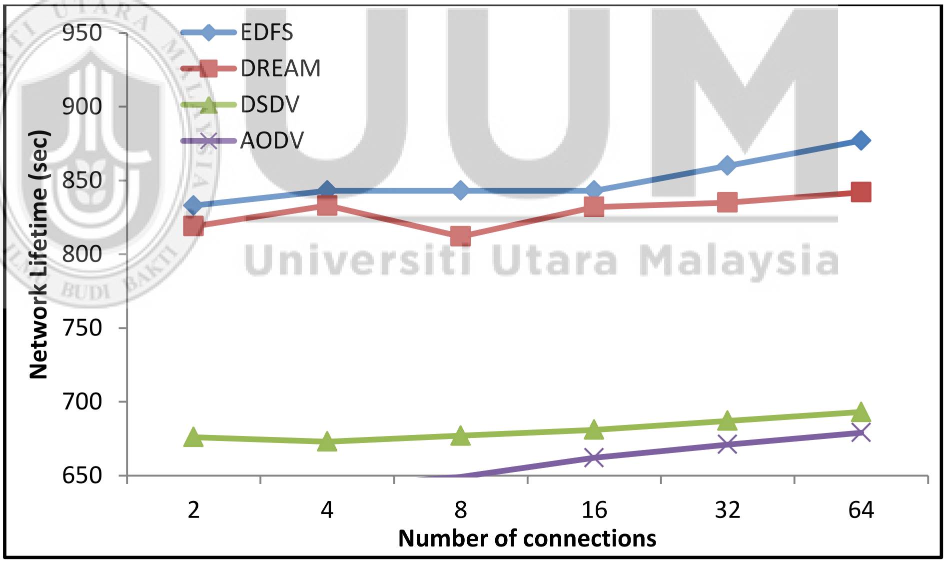

Figure 5.12. Network lifetime with various numbers of connections.

The simulation results showed that EDFS and EDFA resulted in the average overall performance from DREAM, and other results showed that transmission adjustment control has more effect on the performance than the route metric change.

5.5 Observations and Findings

The networks scalability and transmission radius distance are important factors in evaluating algorithms based on the multi-hop and energy-distance efficiency. As far as the conducted experiments on the chosen topologies are concerned, the following conclusions have been derived.

i. Performance of the proposed algorithm has shown advantages over other algorithms in all the evaluated metrics. This shows that the EDRA with algorithm schemes can be adapted to the protocol by addressing the issue of energy constraints on nodes.

ii. Based on the EDFS strategy, the increased scale of network does not significantly impact the route discovery process of the node degree, energy consumption, throughput, and end-to-end delay.

iii. The increased transmission radius distance on nodes is significant to the number of hops on the route. In fact, minimising the transmission range/energy of the nodes will considerably increase the hop and eventually increases the communication overhead and reduces the overall performance.

iv. The simulation results showed that the proposed EDFS algorithm can reduce network interference as it reduces the physical node degree (in case of scalability networks) regardless of node density. The proposed quadrant discovery zone strategy had reduced the routing overhead and latency of packet transmission.

v. The EDRS scheme showed effectiveness of efficient routing path of connection lifetime, despite an increase in node capacity.

5.6 Discussion

The performance of MANET in the practical simulation and real environments are not 100% similar. Therefore, an assumption was made that all network setup parameters and topology scenarios follow the standard characteristics, such as the hardware parameters and distance *d* of the nodes given. The optimal and sub-optimal hop numbers as well as the corresponding intermediate distance can be determined based on the theoretical and experimental analysis in this thesis.

The performance of the routing protocols under different levels of transmission range/energy of the nodes has been successfully evaluated. Obviously the change in the transmission range/power has a significant impact on the performance of the routing protocols. The multi-hop routing protocols deliver acceptably good performance only at a particular level of transmission range/power. Even though the use of high transmission range/power will reduce a lot of overheads and give excellent performance, any arbitrarily high level of transmission power cannot be used in most of the ad hoc network applications. In fact, minimising the transmission range/power of the nodes will considerably increase the hop that will considerably increase the communication overhead and reduce overall performance.

These results signified that any so-called “good” power aware and energy efficient routing protocol should use different transmission ranges, considerably very low *Tx* range performance (below the range of 250m in this case), in order to get the optimum level of performance. In a general sense, the “minimum” range refers to the very lower transmission range (i.e., below half of the length of the whole topology).

Then only would it give an optimum performance in terms of energy consumption as well as performance.

The power aware routing protocols should also be aware of the topology size and scalability under which it is functioning. Furthermore, it should use the “topology length or breadth” information while making decisions in reducing or changing the transmission power of any individual nodes in the network. Hence, future work may address the manner in estimating ways of setting the transmission range/energy of the nodes in a dynamic environment with respect to several dynamic parameters of the network. In addition, the dynamic scale size of the network topology and size of node play very important roles in deciding the maximum transmission range/energy during the dynamic MANET communication scenario.

CHAPTER SIX

CONCLUSION AND FUTURE RESEARCH WORK

6.1 Conclusion of the Research

This chapter presents a conclusion of the research work as explored and described in the thesis. The research contributions are supported by experimental results which have been highlighted previously. The applicability of the proposed algorithm in conjunction with the assumptions of the real world is also presented, followed by a discussion of the research limitations. Eventually, several possible future research directions to realise and extend the work are also identified and recommended.

The proposed schemes of EDFA, EDFS, and EDRS algorithms not only provide an efficient node selection and connection lifetime but also can enhance the overall performance of the network and establish effective route formation. The results indicated that the energy distance efficiency of EDRA for the overall experiment results showed more efficiency than compared to others. Thus, for the nodes located far away from the source node, their average energy consumption can be greatly reduced via the multi-hop routing process. Even for those nodes that are situated nearby the destination, only a few of them will be chosen to be placed along the multi-hop route from the source to destination with optimum distances. By that, the energy constraint on the nodes can be overcome in the routing process as performed by the EDFS algorithm scheme in prolonging the network lifetime.

It is worth to emphasise that the objective is to optimise the total energy consumption along the multi-hop route. To further prolong the network lifetime, each individual node distance and energy can be optimised so that each node consumes the optimum amount of energy under different transmission distances. Usually, when more energy is consumed effectively, mobile nodes can save their energy at the cost of more energy consumption compared to the nodes that are far away from the destination.

Considering all the facts identified during this experiments, one can design a more efficient, power aware or energy efficient routing protocol for MANET. Future work could perhaps address these issues and propose a new energy efficient routing protocol.

6.2 Significance of the Contribution

In this dissertation, this author has described the contribution of the proposed scheme for routing protocols in MANET, in terms of creating an efficient energy-aware routing to sustain longer network connection lifetime in MANET environment. The contribution is significant in promoting the use of green and sustainable next generation network technology.

i. Energy-Distance Factor Aware (EDFA)

In this dissertation, this author has proposed a new algorithm that decides on which relay nodes should be energy-distance efficient as a candidate for route path. The energy model and propagation model were used to evaluate the effective energy on each node and effective optimal distance of the node to an energy-distance factor (*rho*) in considering the selecting of nodes. Namely, the EDFA algorithm based on node evaluation in terms of optimum energy consumption on the node and optimum hop number to become an energy-aware route selection of the path. Then the results of the models were combined together to form the mechanism used as reference to the importance of route discovery to prolong network connection lifetime.

ii. Energy Distance Forward Strategy (EDFS)

The EDFS scheme is an extension of the EDFA in enhancing the connection lifetime of the network with two factors in the route discovery, which are as follows. The main two key advantages of this proposed new Forward Strategy (FS) are; firstly, the quadrant discovery zone is considered as the essential function in discovery technique for data forwarding, and secondly is the node forward with position angular degree from origin *S* to *D* as candidate nodes in routing path, i.e., when the EDFA calculates the potential nodes candidates.

iii. Energy-Aware Route Selection (EARS)

Energy-aware path selection is an extension of the selected nodes in EDFA and EDFS consisting of the maximum residual energy (r_{max}) node in the path, which are candidate nodes with the most energy efficiency on the packet are brought forward. This has affected the lifetime of nodes in the network connection.

This had become the motivation for studying the protocols which aim at achieving routing stability for network connection lifetime.

6.3 Future Work

The work reported in this research has opened up several avenues for exploration. From the previous in depth discussion and detailed analysis, this research could be further improved and extended in several aspects. The potential improvement areas in this thesis is summarised as follows.

There are plans to extend this protocol (EDRA) to cover and include the routing discovery and forwarding strategies with bio-inspired routing algorithms. Bio-inspired routing discovery is responsible for finding the best probability of node selection from among many route discovery algorithms with minimum response time. In this proposed algorithm, a simple calculation selection strategy was used, which depends on the RM model. Indeed, there are many criteria that should be considered in node selection strategies, since it plays a vital role in selecting the best algorithm selection.

The second strategy that could be included in this algorithm is route discovery maintenance strategy. Due to the dynamic nature of mobile nodes, candidate relay nodes in routing discovery algorithm currently may not be the best technique to fetch the discovery. Therefore, there a need to re-evaluate other parameters in a real network environment that also affects the resource constraints of mobile nodes in the wireless network.

Appendix A

Detailed Simulation Parameters

In this simulation, the Ns-2 network simulator [146] was used for performance evaluation. In this Appendix, all the defined parameters in the simulation is clearly stated, however for consistency's sake, its default has been defined according to previously published work.

Signal frequency	914e+6Hz
Receive power threshold	3.652e-10 watt
Receive power	0.2818 watt
Carrier sense threshold	1.559e11 watt
Default Transmission power[2]	0.2818 watt
Sensing range	550.0 metre
Propagation model	Two-ray ground model used in Chapter 4 and 5 Shadowing model used in Chapter x
Shadowing path loss exponent	3.0
Shadowing model reference distance	30.0 metre
Shadowing model deviation	4 decibels
Antenna	Omnidirectional antenna
Antenna height	1.5 metre
Antenna transmit gain	1.0
Antenna receive gain	1.0
Interface queue length	150
Mac Protocol	IEEE 802.11
Bandwidth	2 Mbps
Traffic	Constant Bit Rate (CBR)
Packet size	512 Byte
Packet rate	4 packet/sec

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