
**Faculty of Computer Science and Information Technology**

# Node Participation Evaluation Scheme Based on Link Quality for Energy Efficient Routing in Ad-hoc Networks

**Tie Tai Hieng**

**Master of Science**
**2016**

# Node Participation Evaluation Scheme Based on Link Quality for Energy Efficient Routing in Ad-hoc Networks

Tie Tai Hieng

A thesis submitted

in fulfillment of the requirements for the degree of Master of Science

(Information Technology)

Faculty of Computer Science and Information Technology

UNIVERSITI MALAYSIA SARAWAK

2016

## Declaration

This thesis is presentation of my original work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussion.

This work was done under guidance of Associate Professor Dr Tan Chong Eng, at the University Malaysia Sarawak.

_____

(TIE TAI HIENG)

DATE: 05 MAY 2016

**Acknowledgements**

First at all, I would like to take an opportunity to express my sincere thanks to my supervisor, Associate Processor Dr Tan Chong Eng for his guidance and support during my research period. Mr. Lau Sei Ping helps me in understanding the problem domain.

Not forgetting my friends, among them is Mr Voon Buang Hong, Ms Tan Ee Keng and Ms Lim Boon Hui who have put up with my questions. Thanks for all for your patience and tolerance. Appreciation is also towards University Malaysia Sarawak for their financial support.

Last but not least, I would like to thanks my parent for their continual support and valuable advices, and those peoples who are directly or indirectly helping me throughout my research.

## Abstract

Energy conservation in ad hoc network is a very important design issue and has been attracting a lot of attention in recent years.The limited energy capacity of mobile computing devices has brought energy conservation to the forefront of concerns for enabling mobile communications. This is a particular concern for ad hoc networks where devices are expected to be deployed for long periods of time with limited potential for recharging batteries. Such expectations demand the conservation of energy in all components of the mobile device to support improvements in device lifetime. The typical Ad Hoc Networks routing protocols of the Internet Engineering Task Force (IETF) are mainly the shortest path routing protocols and do not consider the energy issue. This thesis describes improvement of the conventional routing protocol by utilizing higher energy path and backup route. The aim of this paper is to design and evaluate the performance of energy aware routing protocols, called MEL-AODV (Maximum Energy Level Ad Hoc on Demand Distance Vector) and ALMEL-AODV (Alternate Link Maximum Energy Level Ad Hoc on Demand Distance Vector). Our proposed algorithms adapt the existing AODV routing protocol to select the optimal route based on the basis of the maximum energy of each route. The purpose of using energy metric as route select method is to improve the lifespan of Ad Hoc communication network and its corresponding impact on overall network performance. ALMEL-AODV routing protocol employs delaying method of RREQ flooding by considering the node's energy state. This ensures highest energy nodes are selected during path establishment. Between, intermediate nodes with energy level below predefined threshold were not chosen as forwarding node in order to prevent early route breakage and retransmission. Computer simulations using NS-2 simulator are performed with comparison to the conventional methods and the effectiveness of the proposed methods is quantitatively validated. The performance metrics used for

evaluation are first dead lifetime, expiration time of connection and percentage of depleted node. From the analysis, proposed schemes provide better performance than conventional schemes especially in dense network.

***Skim Penilaian Nodus Penyertaan berdasarkan Kualiti Penghubung untuk Penyaluran Cekap Tenaga dalam Rangkaian Ad Hoc***


***Abstrak***

*Pemuliharaan tenaga dalam rangkaian ad hoc adalah isu reka bentuk yang sangat penting dan telah menarik banyak perhatian sejak kebelakangan ini. Kapasiti tenaga yang terhad peranti pengkomputeran mudahalih telah membawa penjimatan tenaga kebarisan hadapan kebimbangan untuk membolehkan komunikasi mudah alih.Ini adalah satu kebimbangan tertentu untuk rangkaian ad hoc di mana peranti dijangkaakan digunakan untuk jangka masa yang lama dengan potensiter had untuk mengecas semula bateri. Jangkaan itu menuntut pemuliharaan tenaga dalam semua komponen peranti mudah alih untuk menyokong penambahbaikan dalam peranti seumur hidup. Ad Hoc biasa Networks laluan protokol daripada Pasukan Petugas Kejuruteraan Internet (IETF) terutamanya laluan terpendek laluan protokol dan tidak menganggap isu tenaga. Tesis ini menggambarkan peningkatan protokol routing konvensional dengan menggunakan jalan tenaga yang lebih tinggi dan laluan sandaran.Tujuan kertas ini adalah untuk mereka bentuk dan menilai prestasi protokol tenaga penghalaan sedar, yang dipanggil MEL-AODV (Tenaga maksimum Tahap Ad Hoc atas Permintaan Jarak Vector) dan ALMEL-AODV (Ganti Link maksimum Tenaga Tahap Ad Hoc pada Vector Permintaan Jarak). Algoritma cadangan kami menyesuaikan diri protokol routing AODV yang sedia ada untuk memilih laluan yang optimum berdasarkan asas tenaga maksimum setiap laluan. Tujuan menggunakan tenaga metrik sebagai laluan pilih kaedah adalah untuk meningkatkan jangka hayat Ad Hoc rangkaian komunikasi dan kesan yang sama ke atas prestasi rangkaian secara keseluruhan. ALMEL-AODV protokol routing menggunakan kaedah melambatkan daripada RREQ banjir dengan mempertimbangkan tenaga negeri nod. Ini memastikan nod tenaga paling tinggi dipilih semasa penubuh anjalan.*

*Antara, nod perantaraan dengan tahap tenaga di bawah tahap yang telah ditetapkan tidak dipilih sebagai penghantar nod untuk mengelakkan pecahnya laluan awal dan penghantaran semula. Simulasi komputer menggunakan NS-2 simulator yang dilakukan dengan berbanding dengan kaedah konvensional dan keberkesanan kaedah yang dicadangkan itu secara kuantitatif disahkan. Metrik prestasi yang digunakan untuk penilaian adalah seumur hidup mati pertama, masa tamat tempoh sambungan dan peratusan nod habis. Daripada analisis, skim dicadangkan memberikan prestasi yang lebih baik daripada skim konvensional terutamanya dalam rangkaian padat.*

## Table of Contents

Declaration……....i

Acknowledgements……..ii

Abstract……iii

Abstrak……v

Table of Contents……..…vii

List of Tables……x

List of Figures……..xi

CHAPTER 1: INTRODUCTION ……..1

1.1. Overview ..... 1

1.2. Problem Statement..... 4

1.3. Objective..... 6

1.4. Scope ..... 7

1.5. Thesis Outline..... 7

CHAPTER 2: LITERATURE REVIEW…….....9

2.1. Introduction ..... 9

2.2. Motivation ..... 10

2.3. Ad Hoc Network..... 11

2.4. Ad Hoc Network Characteristics..... 13

2.4.1. Topology ..... 13

2.4.2. Energy Constrained Operation ..... 14

2.4.3. Bandwidth Constraint..... 14

2.4.4. Limited Physical Security ..... 15

2.5. Routing Protocols in Ad Hoc Network..... 15

2.5.1. Flat Routing..... 17

2.5.2. Other Routing Protocols..... 34

2.6. Comparison on Wireless Ad hoc Routing Protocol..... 35

2.7. Energy Efficiency Issue..... 38

2.7.1. Type of routing protocol Affect Energy Efficiency..... 38

2.7.2. Type of Energy Efficiency Routing Protocol ..... 40
2.7.3. The Energy Efficiency Alternatives ..... 40
2.8. Computer Network Simulator Tools ..... 46
2.8.1. Network Simulator Tool (Ns-2) ..... 46
2.8.2. Glomosim Simulator Tool ..... 48
2.8.3. Omnet++ Simulator Tools ..... 49
2.9. The Reason to Choose NS-2 ..... 50
2.10. Simulation Model ..... 51
2.10.1. Scripts In Ns-2 Simulation ..... 51
2.11. Network Animator ..... 52
2.12. Summary ..... 54
CHAPTER 3: THE PROPOSED MEL-AODV AND ALMEL-AODV SCHEMES ..... 55
3.1. Introduction ..... 55
3.2. Link Quality AODV ..... 55
3.2.1. MEL-AODV ..... 56
3.2.2. ALMEL-AODV ..... 60
3.3. Estimation of Energies ..... 67
3.4. Conclusion ..... 68
CHAPTER 4: SIMULATION MODELING AND RESULTS ANALYSIS ..... 69
4.1. Introduction ..... 69
4.2. Network Performance Evaluation ..... 70
4.3. NS-2 Simulation Concept ..... 70
4.4. The Simulation Assumptions ..... 75
4.5. Performance Metrics ..... 75
4.5.1. First Dead Lifetime ..... 75
4.6. Simulation Result Analysis ..... 76
4.6.1. First Dead Lifetime ..... 77
4.6.2. Expiration Time of Connections ..... 81
4.6.3. Percentage of Depleted Node ..... 85
4.7. Summary ..... 90

CHAPTER 5: CONCLUSION & FUTURE WORK ……...92

REFERENCES ……..…….94

## List of Tables

Table 2.1 Overall Comparisons of On-Demand versus Table-Driven Routing Protocols……36

Table 2.2 Comparison between Ad-Hoc Routing Protocols……..37

Table 4.1 The Protocols Being Shipped With The Current Library…….49

Table 4.2 Simulation Parameters of Network Simulation 2…….74

Table 4.3 First Dead Lifetime (S) Vs Number Of Nodes……....78

Table 4.4 Expiration Time of Connections Vs Number of Nodes……81

Table 4.5 Percentage of Depleted Node Vs Number of Nodes……....85

## List of Figures

Figure 1.1 Route establishment through intermediate node ……..…5

Figure 2.1 Example of Simple Ad Hoc Network with Three Participating Node ……...12

Figure 2.2 DSDV use sequence number to prevent stale route……....19

Figure 2.3 Reverse Path Setup in AODV…….27

Figure 2.4 Forward Path Setup in AODV……....27

Figure 2.5 Building Record Route during Route Discovery……....29

Figure 2.6 Propagation of Route Reply with the Route Record ……..29

Figure 2.7 Radius 1 Hop with Node E Is Border Node……... 34

Figure 2.8 Comparisons of Four Ad Hoc Routing Protocols with Different Energy Models..39

Figure 2.9 Separate Data Path and Control Path Implementation……...47

Figure 2.10 Simplified User's View of NS-2 ……..48

Figure 2.11 Functional Diagram of NS-2 ……51

Figure 2.12 Node Broadcasting RREQ ……....52

Figure 2.13 Different Color of Show Node Remaining Energy ……..53

Figure 3.1 Route establishment ……57

Figure 3.2 Flow of MEL- AODV Process ……...…59

Figure 3.3 Energy Accumulation Process…… 60

Figure 3.4 Estimation of Threshold Value……....62

Figure 3.5 Forwarding Path Formations……...64

Figure 3.6 Flow of ALMEL- AODV Process……..66

Figure 4.1 Overview of Simulation Model……...72

Figure 4.2 Comparison Between DSR, AODV On First Dead Lifetime ……79

Figure 4.3 Comparisons between Existing Protocols and Proposed Schemes On First Dead Lifetime ……81

Figure 4.4 Comparison Between DSR And AODV On Expiration Time Of Connection…. .83

Figure 4.5 Comparisons between Existing Protocols and Proposed Schemes on Expiration Time of Connection……. 85

Figure 4.6 Comparison between DSR And AODV on Percentage Of Depleted Node……...87

Figure 4.7 Comparisons between Existing Protocols and Proposed Schemes on Percentage of Depleted Node ……89

# CHAPTER 1

# INTRODUCTION

## 1.1. Overview

Wireless networks are computer networks that are not connected by cables of any kind. The use of a wireless network enables enterprises to avoid the costly process of introducing cables into buildings or as a connection between different equipment locations. The bases of wireless systems are radio waves, an implementation that takes place at the physical level of network structure.

Wireless networks use radio waves to connect devices such as laptops to the Internet, the business network and applications. Wireless networks typically work in one of two configurations: ad-hoc or infrastructure. The topology or mode you choose depends on whether you want your PCs to communicate directly or with an access point.

Most wireless networks function in infrastructure mode. Devices on the network all communicate through a single access point, which is generally the wireless router. For example, let's say you have two laptops sitting next to each other, each connected to the same wireless network. Even when sitting right next to each other, they're not communicating directly. Instead, they're communicating indirectly through the wireless access point. They send packets to the access point and it sends the packets back to the other laptop. Thus, infrastructure mode requires a central access point to establish connection.

However, infrastructure networks cut the data transfer rate about in half, because of the time it takes to send the signal to and from the access point rather than directly to its destination, as

in an ad-hoc network. Infrastructure networks are more expensive than ad-hoc networks because you have to purchase an access point. Ad-hoc mode can be easier to set up if you just want to connect two devices to each other without requiring a centralized access point.

A wireless ad hoc network (Zhonglin & Yuhua, 2010) is a decentralized type of wireless network. The network is ad hoc because it does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Ad hoc network is a collection of devices that uses wireless networking interfaces to form a temporary communication infrastructure. A communication link is set up between two devices if they lie in the transmission range of each other. In addition to being a host, a device can act as an intermediate node for forwarding messages to other devices.

In order for devices to forward message, devices within the network need to work cooperatively to route the data to the destination. These nodes also work cooperatively to maintain network connectivity between nodes. Between, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity

This is in contrast compared to wired network technologies in which some designated nodes, usually with custom hardware and widely known as routers, switches, hubs, and firewalls, perform the task of forwarding the data. It is also in contrast to managed wireless networks, in which a special node known as an access point manages communication among other nodes.

The decentralized nature of the wireless ad hoc networks makes them suitable for monitoring some physical phenomenon in the environment where wired infrastructure is difficult to be deployed. Typical sensed phenomena include temperature, humidity, position, speed, motion, and others, used in applications ranging from health care and logistics, through agriculture, forestry, civil and construction engineering, military applications, mine site operations, urgent business meetings and robot data acquisition (Jubin & Tornow, 1987) (Perkins, 2001).

The development of WANET is mainly focused on general-purpose use for legacy TCP/IP based applications and emerging context-aware and location-based services. Several other specialized extensions of multi-hop ad hoc networking such as Wireless Mesh Network (WMN), Vehicular Ad hoc Network (VANET) and Wireless Sensor Network (WSN) are nowadays promising towards industrial and general purpose popularity.

A wireless mesh network often has a more planned configuration, and may be deployed to provide dynamic and cost effective connectivity over a certain geographic area. Although mesh routers are pre-deployed nodes, the wireless mesh network are self-configurable, self-healing and easy to deploy. VANET is another important extension of WANET which temporary ad hoc network for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. VANET is extensively used in Intelligent Transportation Systems (ITS) such as traffic management navigation, passenger information, safety emergency, electronic toll, on demand Internet-based applications and services etc.

Standards commonly used in WSN communications include ZigBee, Bluetooth and IEEE 802.11. Each node in a sensor network is typically equipped with a radio transceiver or other

wireless communications device, a small microcontroller, and an energy source, usually a battery. Limited power source in sensor devices is the primary challenge to provide consistent network management. WSN is now mainly used in hazardous environment monitoring, industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control.

The dynamic topology of WANET tends to unpredictable network topology. Since, wireless links are bandwidth-constrained, traffic congestion is common in ad hoc network topology. Moreover, power conservation is crucial in mobile wireless systems since ad hoc network rely on batteries for their energy. Due to wireless connectivity, mobile wireless networks are generally more prone to physical security threats such as eavesdropping and jamming attacks. Wireless is typically less secure because it uses radio waves for transmission. In other words, you have your data "floating" in airspace which makes it more susceptible to being compromised. With a wired connection someone cannot "steal" your data frames unless they physically connect to the network cabling.

However, ad hoc wireless networks are power constrained since nodes operate with limited battery energy. The failure of a single node in the network could possibly cause network partition and topology change. Network lifetime is therefore dependent on the lifetime of individual nodes. This necessitates energy efficient design on every layer of the protocol stack.

### 1.2. Problem Statement

The highly dynamic nature of WANETs results in frequent and unpredictable changes in the network topology, which add to the difficulty and complexity to the routing scheme among

the mobile nodes within the network. Thus, establishing communication among mobile nodes is a great challenge in itself. The applications associated with the field of WANETs, make them an important part of the next generation wireless networks.

Since the ad hoc networks do not possess the functionality of a fixed infrastructure, individual nodes may have to rely on portable, limited power sources. In this research work, focus has been put on the strategy to address the energy issue within WANETs since nodes are generally more vulnerable to insufficient energy than fixed-wired networks. Ad hoc network require mobile node to act as forwarding node in order to maintain survivability network. For example, source node A require intermediate node B to forwarding data packet to destination node C where it is not located within transmission range of node A. However, the network between node A and node C will be disconnected if nodes B do not have sufficient energy.

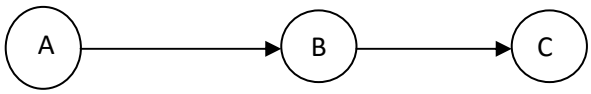


Figure 1.1 Route establishments through intermediate node

The shortest path is the most common criteria adopted by the conventional routing protocols in the WANET Working Group. The first forwarding path received by source node is shortest path. The problem is that nodes along shortest paths may be used more often and exhaust their batteries faster which create disparity in their residual energy. Eventually when nodes in the network become disconnected, the path is disconnected. Therefore, the shortest path may not be the most suitable metric to be adopted for a routing decision.

Furthermore, a lot of emphasis has been given to the routing mechanism but the network lifetime issues have not been address. Over the last few years, many routing protocols for Wireless Ad-hoc Networks have been proposed and enhanced to improve energy efficiency in a network. It is not clear how different protocols behave in different environments. A protocol may be the best one to be used in one network topology and mobility scenario, but might perform poorly in other network setting. Thus, the issue to design and develop an efficient routing protocol is still remaining wide open.

### 1.3. Objective

Ad hoc wireless networks are power constrained since nodes operate with limited power source. Current energy efficiency routing such as Energy Dependent Participation (EDP) (Pearlman & Deng, 2002)where node participation in the network is evaluated based on the residual energy in its battery. If a node's battery has low power, transmit signal along longer path or, interference, it will have poor link quality compared to other nodes. Thus, node participation based on link quality can be used as a potential measurement for improving nodes participation. Besides improving energy efficiency, quality of signal transmission will not be affected because node with poor link quality will not be selected for participation.

Therefore, the objectives of this thesis are as follow:

1) To design a more efficient node participation scheme to prolong the network sustainability.
2) To prolong network lifetime in ad hoc routing
3) To improve energy efficiency and minimize energy wastage due to frequent retransmission.

4) To benchmark against conventional with NS2.

### 1.4. Scope

This research evaluates node participation in existing routing protocols and proposes a new protocol which can prolong network lifetime. A comparison between the conventional protocols and newly proposed scheme is carried out in term of network lifetime and percentage of depleted node. The assumption is made for the mobility node to move in predefined directions with predefined velocities. Initially, the locations of nodes are randomly located in the network. In addition, each node has randomly predefined battery capacity. All nodes have same transmission range of 250m within size of 1000x1000 m. Protocol are designed for moderately sized topologies of 10 to 100 nodes.

### 1.5. Thesis Outline

The thesis consists of five chapters. Each chapter elaborates different stage development of this research until the end. First chapter of this thesis describes the background of the research, problem statements, objectives and the scope of the research.

Chapter 2 explains about the literature reviews and reviews the relevant background, current development and trend of the research. Most of the literature reviews are taken from IEEE and the journals that have been made by the researcher in the wireless ad hoc networks areas. The famous basic reactive routing protocol for ad hoc routing such as AODV and DSR explained deeply in order to show these protocol acts as a main role to realize this research. Besides, energy efficient routing protocols are described in this chapter.

Chapter 3 explains the methodology used of this research. This chapter elaborates the simulation tools used on the simulation and techniques used for network performance evaluation.

Chapter 4 describes the design and implementation where elaborates energy path accumulation process in details. It also describes the network model use in the research. The effectiveness between AODV and Link Quality AODV has been compared in this chapter. This chapter also presents the simulation results and analyze of these result which are related to thesis objectives with simple explanation.

Chapter 5 presents the conclusion together with thesis contribution and identifies some areas for future work.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. Introduction

Mobile computing (Basagni, Conti, Giordano, & Stojmenovic, 2004) is proliferating as devices are becoming smaller, cheaper and more powerful. By combining mobile devices with wireless communication abilities, the devices can be connected anytime, anywhere, anyhow. New applications begin from mobile entities interacting and collaborating towards a common goal. With cellular phones being widely employed (Xie, Kumar, Agrawa, & Srinivasan, 2006) and the mobile Internet emerging into the market place, concepts of dynamic wireless networks that do not depend on expensive infrastructure draws new attention to the area of ad hoc networks.

Mobile devices construct and form a mobile ad hoc network when they directly and wirelessly communicate with other devices nearby without any fixed infrastructure. By definition the nodes in ad hoc networks move from one location to another in either a random or predetermined pattern. Thus the network topology in ad hoc network is changing dynamically and frequently. The nonexistence of any hierarchy, established infrastructure, or centralized administration, forces the nodes to control the network on their own.

This chapter examines the current Ad Hoc Network paradigm as described by the Internet Engineering Task Force (IETF) MANET working group (Corson & Macker, 1999). Furthermore, different categories of routing protocols which are designed based on different

characteristic of ad hoc network are explained in details. Moreover, details of existing ad hoc routing protocols and their comparison are further explained in this chapter.

## 2.2. Motivation

Ad hoc network usually consists of battery-operated computing devices which cooperate with each other to transmit packet from a source node to a destination node. The availability of each node is important for the enforcement of such cooperation. Ad hoc networks do not have a central point of failure, which is good for providing redundancy, but it may overload some nodes in the topology due to unfair load distribution. These nodes are the ones that, due to their location, relay an increased number of packets in the network and consequently, are viewed as critical spots in the network. The failure of a single node can greatly affect the overall network performance. Since mobile nodes are usually battery-operated, one of the major reasons of node failure is battery exhaustion. In order to maximize the life-time of a mobile node, it is important to reduce the energy consumption of a node.

The existing conventional protocols such as Ad Hoc On Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) pose a significant technical challenge where the conventional protocols always select the shortest path and may cause batteries on group of nodes along the often used path to be depleted earlier than other nodes. Therefore, the shortest path approach may not always be the most suitable metric to be adopted as a routing decision especially in battery constrained ad hoc network. Hence, the proposed schemes aim to enhance the battery energy efficiency and network lifespan of the wireless ad hoc network.

There are some protocols that use different approaches to achieve energy efficiency or battery consumption balancing. However most of the protocols were trying to find some network layer mechanisms to avoid network flooding and reduce unnecessary packet forwarding but one major drawback of most of these ad hoc routing protocols is that they do not have provisions for conveying the load status and or quality of a path during the route setup.

Furthermore, some existing energy efficient protocols only use transmission power control to reduce energy usage during route setup and packet transmission. However, they do not significantly increase network lifetime. There is a high probability that some nodes turn into critical nodes just because they happen to have a strategic position in the network topology and several routes use them, consequently they consume more battery power which leads to node failure. Although some of the routing protocols consider minimum battery cost during route establishment, they do not consider link breakage problem. Node movement, interference or depleted nodes are possible causes to link breakage, which lead to frequent retransmission.

### 2.3. Ad Hoc Network

Ad hoc networks (Corson & Macker, 1999)are dynamically created and maintained by the individual nodes comprising the network. They do not require a pre-existing architecture or any type of wired infrastructure for communication purposes. Simple wireless networks require the existence of static base stations (BS), which are responsible for routing messages to and from mobile nodes (MNs) within the specified transmission range.

Instead of relying on a wired BS to coordinate the flow of messages to each MN, the individual MNs in Ad hoc networks form their own network and forward packets to and from each other. Each wireless node serves as a router and forwards packets for other nodes in the network. Figure 2.1 shows a simple ad hoc network with middle node acts as a router to transmit and receive packets with each other's instead of relying on base station.

Minimal configuration and quick deployment make ad hoc networks suitable for emergency situations like natural disasters or military conflicts. The decentralized nature of most wireless ad hoc networks makes them suitable for a variety of applications where central nodes cannot be relied on. In addition, wireless ad hoc network improve the scalability of common networks compared to wireless managed networks.

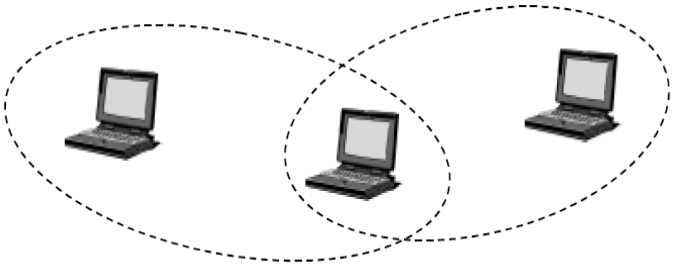

Figure 2.1 Example of Simple Ad Hoc Network with Three Participating Node

## 2.4. Ad Hoc Network Characteristics

Ad Hoc Network's are a collection of mobile devices equipped with a transceiver and connected in the absence of fixed infrastructure. Following are the characteristics of ad hoc network (Basagni, Conti, Giordano, & Stojmenovic, 2004) (Corson & Macker, 1999):

### 2.4.1. Topology

Nodes are free to move randomly with different speeds. Thus the network topology may change randomly and have no restriction on their distance from other nodes. As a result of this random movement, the whole topology is changing in a random manner which may consist of both bidirectional and unidirectional links. List of topologies in ad hoc network as below:

**A. Mobile ad hoc networks (MANETs)**

A mobile ad hoc network (MANET) is a continuously self-configuring, infrastructure-less network of mobile devices connected without wires.

**B. Vehicular ad hoc networks (VANETs).**

VANETs are used for communication between vehicles and roadside equipment. Intelligent vehicular ad hoc networks (InVANETs) are a kind of artificial intelligence that helps vehicles to behave in intelligent manners during vehicle-to-vehicle collisions, accidents.

**C. Smartphone ad hoc networks (SPANs).**

SPANs leverage the existing hardware (primarily Bluetooth and Wi-Fi) in commercially available smartphones to create peer-to-peer networks without relying on cellular carrier networks, wireless access points, or traditional network infrastructure.

**D. Internet-based mobile ad hoc networks (iMANETs).**

iMANETs are ad hoc networks that link mobile nodes and fixed Internet-gateway nodes. One implementation of this is Persistent System's CloudRelay.

**E. Military / Tactical MANETs.**

Military/Tactical MANETs are used by military units with emphasis on security, range, and integration with existing systems.

### 2.4.2. Energy Constrained Operation

Approximately all of the nodes in an ad hoc network may rely on batteries or other exhaustible means for their energy (Cano & Manzoni, 2002). For these nodes, the most important optimization criteria in system design may be energy conservation. This is because sufficient residual energy will make sure network survive for longer lifetime.

### 2.4.3. Bandwidth Constraint

Wireless links have lower bandwidth capacity (Couto, Li, Blake, Lee, & Morris, 2001) than infrastructures networks. The effect of the multiple access, fading, noise, interference conditions reduce the throughput of wireless communication. On top of that interference,

noise leads to signal fading and thus degrades the throughput. As a result, congestion becomes a bottleneck in bandwidth utilization.

### 2.4.4. Limited Physical Security

Physical security threats such as spoofing, eavesdropping, masquerading (Goyal, Shyam, & Gupta, 2006), and denial-of-service type attacks have higher possibility occurrence in ad hoc routing compared to wireless or wired networks. This is because the ad hoc network is a distributed system and all the security threats relevant to such a system are likely to happen.

## 2.5. Routing Protocols in Ad Hoc Network

Proper design of routing protocol is required due to energy constrained in ad hoc network. A routing protocol (Ramanathan & Streenstrup, 1996) is the method by which user traffic is directed and transported through the network from the source node to the destination node. The objectives of routing protocol include maximizing network performance in term of the application requirement such as hop count, delay, throughput, loss rate, stability and jitter. Beside application point of view, proper design of routing protocol is also essential in minimizing the cost of network itself in accordance with its capacity as well as energy usage. Routing protocol is one of the important protocols being research in mobile ad hoc network and the four basic functions of routing protocols are:

- Path generation: Node generates paths according to the distributed network and user traffic state information of the network and application. For example, in reactive routing protocols such as Ad Hoc On Demand Distance Vector (AODV), a node initiates route discovery process within the network when it requires a route to the

destination. A path is generated when source node receives route reply from destination or intermediate node if it knows of a route to the destination.

- Path selection: Appropriate paths are selected based on network and application state information. For example, path with lower battery cost will be given priority by source node during constructing and maintaining network connection with destination node.

- Data forwarding: Intermediate node forwards user traffic along the selected route. For example, intermediate node B receives data packet from source node A and forward it to destination node C which is not located within source node's transmission range.

- Path maintenance: When a node detects that a route to a neighbor no longer is valid, it will remove the routing entry and send a link failure message, a triggered route reply message to the neighbors that are actively using the route, informing them that this route no longer is valid. For this purpose, AODV uses a active neighbor list to keep track of the neighbors that are using a particular route. The nodes that receive this message will repeat this procedure. The message will eventually be received by the affected sources that can chose to either stop sending data or requesting a new route by sending out a new RREQ.

Routing protocols for ad hoc networks must deal with limitations such as limited power source, low bandwidth, high error rates and frequently changed topology. Due to its limitations, features such as fast route establishment, multiple routes selection, energy efficiency and fast adaptability to link changes are a must for ad hoc routing protocol.

Generally, routing protocols for ad hoc networks can be categorized as Flat routing, Hierarchical routing and Location aware routing (Perkins, 2001) (Abolhasan, Wysocki, & Dutkiewicz, 2004) (Kuosmanen, 2011) (Johansson, Larsson, Hedman, Mielczarek, & Degermark, 1999).

### 2.5.1. Flat Routing

In flat routing, there are two kind of routing schemes, namely, table-driven (or proactive) routing protocols and on-demand (or reactive) routing protocols (Castaneda & Das, 1999) (Ogier, Templin, & Lewis, 2004).

#### I. Table-Driven Routing (Global/Proactive protocols)

In table-driven routing protocols, each node attempts to maintain consistent, up-to-date routing information to every other node in the network. With this routing information, the route is known and immediately available when a packet needs to be sent. Each node has to maintain one or more tables to store routing information, and response to the changes in network topology by broadcasting and propagating updates throughout the network in order to maintain a consistent network view. The various proactive routing protocols differ in the way in which they update the routing information in the tables. Some of the existing pro-active ad hoc routing protocols are: DSDV (Destination Sequenced Distance-Vector, 1994), WRP (Wireless Routing Protocol, 1996), CGSR (Clusterhead Gateway Switch Routing, 1997).

#### A) Destination-Sequenced Distance-Vector Routing (DSDV)

Destination-Sequenced Distance-Vector Routing (DSDV) (Perkins & Bhagwat, Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers,

1994)is a table-driven routing scheme based on the Bellman-Ford algorithm. It was developed by C. Perkins and P.Bhagwat in 1994. It is also a hop-by-hop distance vector routing protocol which each node has a routing table that for all reachable destinations by storing the next-hop and number of hops for the destinations.

Traditional distance vector protocols have common problem of routing loops. Generally, a loop between node *A* and node *B* exists in the condition that the next hop of node *A* for a destination node *D* points to node *B*, and at the same time the next hop of node *B* for the same destination node *D* points to node *A*. The primary cause for formation of routing loops is nodes choose their next hops in a completely distributed fashion based on information which can possibly be stale, therefore incorrect routing information.

In order to achieve loop-freedom, DSDV uses a sequence numbers to tag each route. Each entry in the routing table contains a sequence number, the sequence numbers are generally even if a link is present; else, an odd number is used. Figure 2.2 show X receives information from Y about a route to Z. Let destination sequence number for Z at X is S(X), S(Y) is sent from Y. If S(X) > S(Y), then X ignores the routing information received from Y. If S(X) = S(Y), and cost of going through Y is smaller than the route known to X, then X sets Y as the next hop to Z. If S(X) < S(Y), then X sets Y as the next hop to Z, and S(X) is updated to equal S(Y).

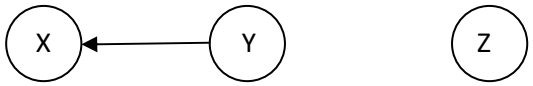


Figure 2.2 DSDV use sequence number to prevent stale route

In addition, the sequence number shows the freshness of a route and routes with higher sequence numbers are favorable. When a node detects a route to a destination has broken, its sequence number is increased. So the next time source node will advertise the route to destination again with an infinite hop-count and sequence number that is larger than before.

DSDV basically is distance vector with small adjustments that consists of triggered updates that will take care of topology changes in the time between broadcasts. To reduce the amount of information in these packets, there are two types of update messages defined: full and incremental dump. The full dump carries all available routing information and the incremental dump that only carries the information that has changed since the last dump. Full dump will be used if incremental dump exceeds one Network protocol data unit (NPDU).

DSDV needs a regular update of its routing tables, which uses up more battery power, overhead and a small amount of bandwidth even when the network is idle. As a result, it needs some time to converge before a route can be used and considered negligible in a static wired network where the topology is not changing so frequently. However, the topology in an Ad-hoc network is expected to be very dynamic, this converge time will mean a lot of dropped packets before a valid route is detected. (Khattak, Iqba, & Khiyal, 2008) Therefore,

the protocol will not scale in large network since a large portion of the network bandwidth is used in the updating procedures.

**B) Wireless Routing Protocol (WRP)**

The WRP protocol (Bharghavan, Demers, Shenker, & Zhang, 1994)also guarantees loops freedom and it avoids temporary routing loops by using the predecessor information. Similarity to DSDV, WRP maintains an up-to-date view of the network and every node has a readily available route to every destination node in the network. It differs from DSDV in term of table maintenance and in the update procedures. While DSDV maintains only one topology table, WRP uses a set of tables to maintain more accurate information. The tables that are maintained by a node are: distance table (DT), routing table (RT), link cost table (LCT), and a message retransmission list (MRL). The DT contains the network view of the neighbors of a node. The RT contains the up-to-date view of the network for all known destinations. It keeps the shortest distance, the predecessor node, the successor node (the next node to reach the destination), and a flag indicating the status of the path. The LCT contains the cost of relaying messages through each link. For example, number of hops to reach the destination node. The MRL contains an entry for every update message that is to be retransmitted and maintains a counter for each entry.

However, WRP has some disadvantages. The complexity of maintenance of multiple tables demands a larger memory and greater processing power from nodes in the ad hoc wireless network. At high mobility, the control overhead involved in updating table entries is almost the same as that of DSDV. So it is not suitable for highly dynamic and large topology network.

Due to a lot tables, WRP requires large memory storage and resources. These WRP is not suitable for large mobile ad hoc networks as it suffers from limited scalability.

**C) Clusterhead Gateway Switch Routing Protocol (CGSR)**

Clusterhead Gateway Switch Routing (CGSR) uses DSDV Routing algorithm as basic routing and further enhance it by introducing clustering technique (Anupama & Sathyanarayana, 2011). By using clustering technique, the mobile nodes are aggregated into clusters and a cluster-head is elected. All nodes that are within the communication range of the cluster-head belong to its cluster. In addition, a gateway node is a node that is in the communication range of two or more cluster-heads.

In highly mobility network, cluster head scheme can cause performance degradation due to frequent cluster-head elections. Thus, CGSR uses a Least Cluster Change (LCC) algorithm to solve dynamic network problem. With this algorithm, cluster-head change occurs only if a change in network causes two cluster-heads to come into one cluster or one of the nodes moves out of the range of all the cluster-heads.

The general algorithm works in the following manner. The source node transmits data packet to its cluster-head. From this cluster-head, the packet is sent to the gateway node which is connecting this cluster-head and the next cluster-head along the route to the destination. The gateway sends it to that cluster-head and so on till the destination cluster-head is reached in this way. When the destination cluster-head receive the packet then it transmits the packet to the destination that is within its communication range.

Thus, CGSR achieves a structure among clusters for code separation, channel access, routing and bandwidth by having a cluster head controlling a group of ad hoc nodes. It is very scalable to large ad hoc network because it uses the clustering approach that confines the number of packets that need to be sent. However, clustering in general have some drawbacks. Since the clusterhead and also the gateway nodes have to do the routing and managing work, they can easily become a bottleneck. The communication load will definitely be higher for a clusterhead or a gateway node than for an ordinary node, thus consuming more energy which can lead to an early outage of these nodes due to exhausted batteries. The frequent changes of cluster head can adversely affect routing protocol performance since nodes are busy in cluster head selection rather than packet relaying. Furthermore, routes that are created between nodes in different clusters are tend to be longer paths.

**II. On-Demand Routing (Reactive Protocols)**

In contrast to pro-active routing protocols which maintain all up-to-date at every node, routes are created only when desired by the source node in re-active protocols. Thus, reactive protocols are able to reduce overhead problem which are mostly happened in proactive protocols by maintaining information for active routes only.

Route discovery and route maintenance are two main procedures in reactive protocols. When a source requires a route to a destination, it has to establish the route by route discovery procedure. When the route-request message reaches an intermediate node that has a sufficiently up-to-date route, it stops forwarding the route request message and sends a route-reply message back to the source which containing forwarding path to the destination. Once the route is established, the validity of the route is maintained by maintenance procedure

where the route in the each node's internal data structure called a route table is no longer desired or it becomes inaccessible, and finally tears down it by route deletion procedure. Some of the existing re-active routing protocols are: DSR (Dynamic Source Routing, 1996), AODV (Ad hoc On-Demand Distance Vector Routing, 1999) and etc.

Reactive protocol can be further classified into two main categories which are source routing and hop by hop routing. DSR is an example of source routing and AODV protocol use hop by hop routing. In Source routed on-demand protocols, each data packets accumulate the address of each device between the source and destination during route discovery. Nodes will cache the accumulated path information when processing the route discovery packets. The information kept in the header of each packet will be used by each intermediate node during packet forwarding process. Therefore, the intermediate nodes do not need to maintain up-to-date routing information for each active route in order to forward the packet towards the destination. Besides, nodes do not need to maintain neighbors' connectivity through periodic beaconing messages. The major weakness of source routing protocols is that they do not perform well in large networks (Johnson & David, 2005-03-18).

In hop-by-hop routing (also known as point-to-point routing), the source is not expected to know all the information from the source to destination. It is sufficient for the source carries destination address and next hop address on each data packet. Therefore, each intermediate node uses its routing table information to find next hop in order to forward each data packet towards the correct destination. The advantage of this routing scheme is that routes are able to quickly adapt to mobility network environment. When the node receives fresher topology information, node can update its routing table and forward the data packets over fresher and

better routes. However, each intermediate node needs to maintain up to date routing information for each active route.

**A) Ad hoc On Demand Distance Vector (AODV)**

The Ad hoc On Demand Distance Vector (AODV) routing algorithm (Perkins & Royer, 2001) (Perkins, 2001) (Perkins & Royer, 1999) is a routing protocol designed for ad hoc mobile networks which enable multi-hop routing between distance vector algorithms. AODV is capable of both unicast and multicast routing. The difference between AODV compared to proactive protocol is AODV only requests a route when needed and does not require nodes to maintain routes to destination that is no actively used in communication. As long as the endpoints of a communication connection have valid routes to each other, AODV does not play a role. Features of this protocol include loop freedom and link breakages cause immediate notifications to be sent to the affected set of nodes. In addition, AODV supports multicast routing and avoids the Bellman Ford "counting to infinity" problem. The use of destination sequence numbers ensures a route is fresh and valid.

The algorithm uses different type of control messages to discover and maintain links. Whenever a node wants to try and find a route to another node, it broadcasts a Route Request (RREQ) to all its neighbors. The RREQ propagates through the network until it reaches the destination or a node with a fresh enough route to the destination. When a destination unicast a RREP back to the source, the route will be available and data packet in the queue will be forwarded.

The algorithm uses hello messages (a special RREP) that are broadcasted periodically to the immediate neighbors. The purpose of hello messages is to make sure continuous presence of the node and neighbors. If hello messages stop coming from a particular node, the neighbor can assume that the node has moved away and mark the link to the node as broken and notify the affected set of nodes by sending a link failure notification (RRER) to that set of nodes.

As a reactive protocol, the AODV has an latency weakness. The route discovery process can take some time and this delay can be a crucial factor in a network. Moreover, the scalability is another problem of AODV protocol. When the network grows and average path length increases, the probability that a link become invalid will also increase. Therefore the AODV is suited only for small and medium size networks which the scalability limit is about 1000 nodes.

**i) Route discovery**

A node will broadcasts a RREQ control packet when it needs a route to a destination and there are not route found in the cache. This can happen if the route to the destination is unknown, or if a previously valid route is expired. After broadcasting a RREQ, the source node waits for a RREP. If the reply is not received within a certain time, source node will rebroadcast the RREQ by expanding ring search or diameter network search.

Forwarding of RREQs is done when the intermediate node does not have a route to the destination. It then rebroadcast the RREQ. The node also creates a temporary reverse route to the source node. Meanwhile, the node also creates next hop in its route table which is equal to the IP address field of the neighboring node that send the broadcast RREQ. This is done to

create reverse route for destination node by unicast RREP back to the requesting node. If intermediate node have route towards destination, a RREP is also generated and unicasted back to the source node. Figure 2.3 shows source node A broadcast route request to find route to the destination D. After finding the route, it also successful creates a reverse route (G, E, B, A) back to the source node. While RREP is forwarded, a forward route is created to the destination. When RREP reaches the source node, there exists a route from the source to the destination. The forwarding path is graphically shown on Figure 2.4.

**ii) Route maintenance**

When a node detects that a route to a neighbor is no longer valid, it will remove the routing entry and a link failure message is send to the neighbors. Link failure message is a triggered route reply message used to inform the neighbors that are actively using the no longer valid route. For this purpose AODV uses an active neighbor list to keep track of the neighbors that are using a particular route. The nodes that receive link failure message can chose to either stop sending data or requesting a new route by sending out a new RREQ.

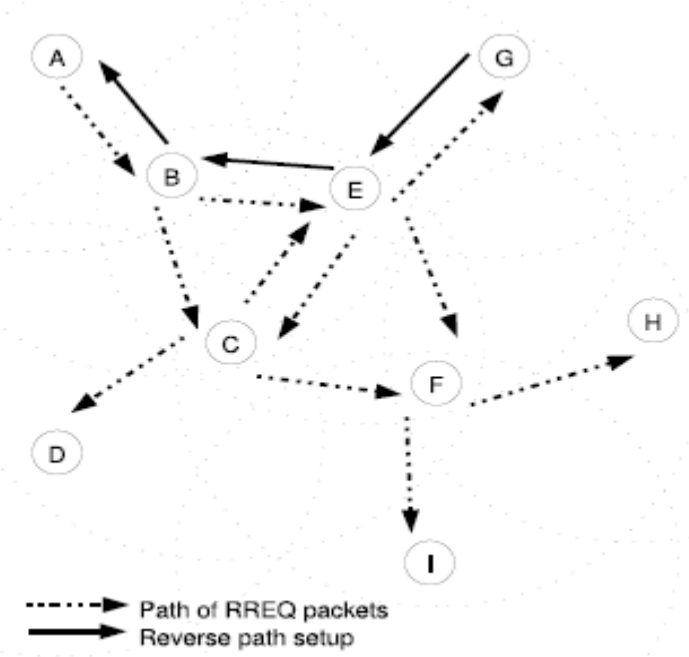


Figure 2.3 Reverse Path Setup in AODV

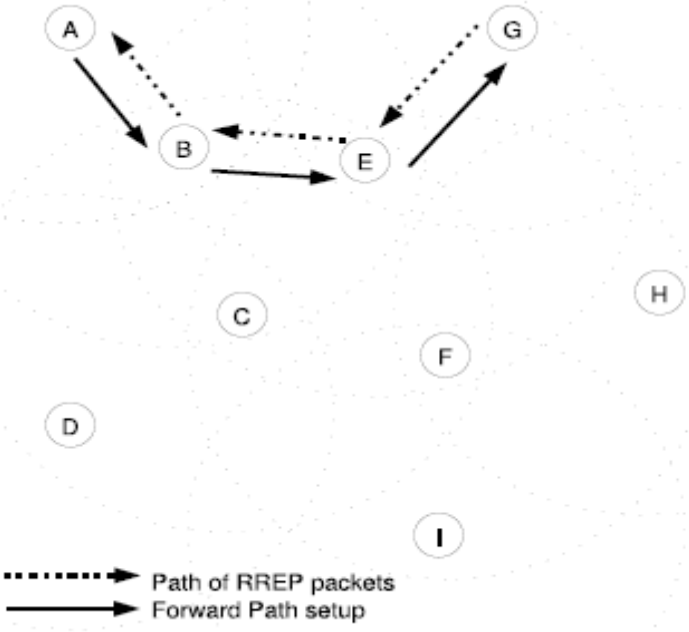


Figure 2.4 Forward Path Setup in AODV

**B) Dynamic Source Routing (DSR)**

Dynamic Source Routing (DSR) (Johnson & Maltz, Dynamic Source Routing, 1996) (Johnson, Maltz, & Broch, DSR: The Dynamic Source Routing Protocol for Multihop Wireless Ad Hoc Networks, 2001) (Traganitis, 2007) (Johnson, Maltz, & Broch, DSR: The Dynamic Source Routing Protocol for Multihop Wireless Ad Hoc Networks, 2001) allows nodes to dynamically discover a route across multiple network hops to any destination. It is similar to AODV but it uses source routing where each packet carries the complete ordered list of nodes in its header which the packet must pass through. DSR uses no periodic routing messages, thereby reducing network bandwidth overhead, conserving battery and avoiding large routing updates throughout the ad hoc network. DSR relies on MAC layer to inform the routing protocol about link failures.

**i) Route discovery**

Route discovery is the mechanism where source node requests a route by broadcasting a Route Request (RREQ) packet. Every node that receives this RREQ searches through its route cache for a route to the requested destination. Every node stores all known routes in its route cache. It will forwards the RREQ further and adds its own address to the recorded hop sequence if there are no route is found. Figure 2.5 shows the process of receiving node append its own address to the packet before broadcasting to its neighbor nodes. This request propagates through the network until either the destination or a node with a route to the destination is reached. If there are route found, a Route Reply (RREP) is unicasted back to the source node. In Figure 2.5, it is clearly shows that destination node unicasts RREP packet to the source node A based on the entire route (A, B, E) in RREQ.

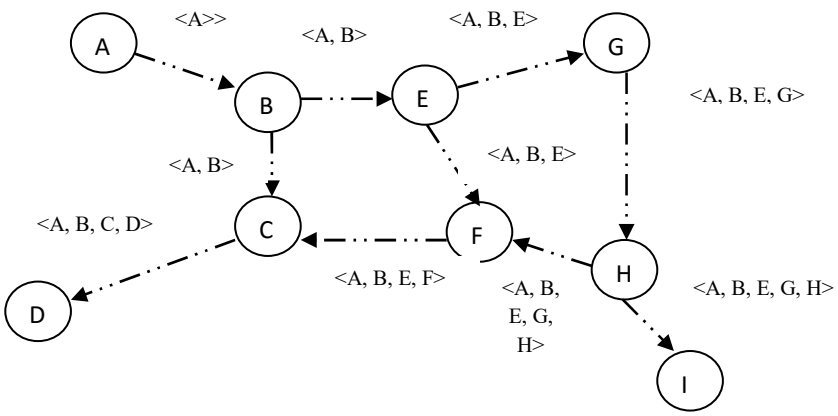


Figure 2.5 Building Record Route during Route Discovery

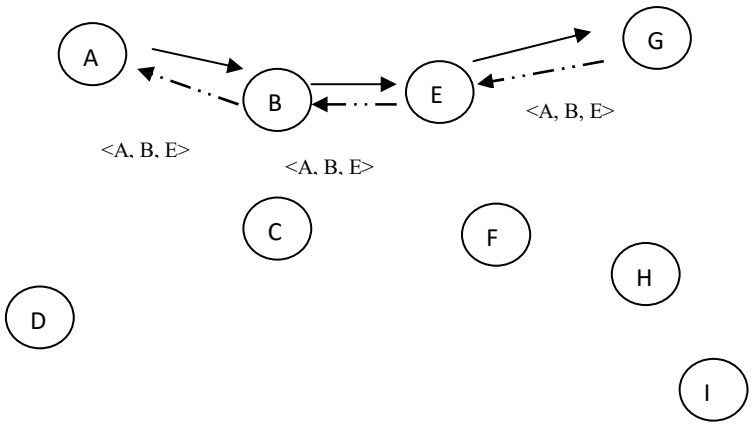


Figure 2.6 Propagation of Route Reply with the Route Record

Requesting node sends a RREQ with the maximum propagation limit (hop limit) set to zero to prohibit its neighbors from rebroadcasting it. At the cost of a single broadcast packet, this mechanism allows a node to query the route caches of all its neighbors.

In addition, nodes can operate their network interface in promiscuous mode, disabling the interface address filtering and causing the network protocol to receive all packets that the

interface overhears. These packets are scanned for useful source routes or route error messages and then discarded.

The simplest way to retrieved route back to the source node is to reverse the hop record in the packet by assuming symmetrical links is exist between source and destination nodes. Owning to that, DSR checks the route cache of the replying node. If a route is found, it is used instead. Another way is to piggyback the reply on a RREQ targeted at the source node. This means that DSR can compute correct routes in the presence of asymmetric (unidirectional) links. Once a route is found, it is stored in the cache with a time stamp and the route maintenance phase begins.

The disadvantage of this protocol is that the route maintenance protocol does not locally repair a broken link. So, the broken link is only communicated to the source node. Stale route cache information could also result in inconsistencies during the route reconstruction phase. Furthermore, there is always a small time delay at the beginning of a new connection because the source node must first find the route to the target. Although DSR performs well in static and low-mobility environments, the performance degrades rapidly with increasing mobility. Moreover, considerable routing overhead is involved because packet header size grows with route length due to the source-routing mechanism employed in DSR.

**ii) Route maintenance**

Route maintenance is the mechanism by which a node detects if the network topology has changed so that it can no longer use its route to the destination node. This might happen when a host in the source routing list moves away from wireless transmission range or turned off

causing the route unusable. Beside that a failed link can be detected by either actively monitoring acknowledgements or passively by running in promiscuous mode.

A route error packet is sent back to the source node when route maintenance detects a problem with a route in use. When this error packet is received, the hop in error is removed from this hosts route cache, and all routes that contain this hop are truncated at this point.

**C) Temporally-Ordered Routing Algorithm (TORA)**

Temporally-Ordered Routing Algorithm (TORA) is developed by Vincent Parks and M. Scott Corson. The first appearance of this protocol is in IEEE INFCOM'97.

TORA is a source initiated on-demand routing protocol which uses link reversal algorithm and provides loop-free multipath routes to a destination node. As being on-demand routing protocol, routes are discovered only when there are not route in its route table. In addition, reactions to topological changes are localized to minimize communication overhead.

During the route creation and maintenance phases, TORA uses a arbitrary 'height' parameter to determine the direction of a link between any two nodes. As a consequence, multiple routes are often present for a given destination. However, none of them are the shortest route to a given destination. A node broadcasts a RREQ to its neighbors in order to initiate a route. If it is not destination node, RREQ is rebroadcast through the network until it reaches the destination, or a node that has a route to the destination.

This node replies with an update message that contains its height with respect to the

destination to the sender. When each node receives the update, it will set its own height to one greater than the sending neighbor. This forms a series of directed links from the sender to the destination in order of decreasing height. When a node discovers link failure, it sets its own height higher than that of its neighbors, and issues an update by reversing the direction of the link between them. If it finds that it has no downstream neighbors the destination is presumed lost, and it originates a clear message to erase the invalid links from the rest of the network.

TORA is layered on top of Internet MANET Encapsulation Protocol (IMEP) for reliable delivery of all routing control messages, and link state notifications. IMEP is implemented to support TORA. It attempts to aggregate TORA and IMEP control messages (objects) into a single packet (object block) to reduce overhead.

One of limitation of TORA is that it relies on synchronized clocks among nodes in the ad hoc network. This protocol depends on intermediate lower layers for certain functionality. It assumes that the link status sensing, neighbor discovery, in order packet delivery and address resolution are all readily available. The solution is to run the Internet MANET Encapsulation Protocol at the layer immediately below TORA. This will make the overhead for this protocol difficult to separate from that imposed by the lower layer. (Aaron & Weng, 2010)

**III. Hybrid Protocols**

Hybrid routing protocols such as ZRP (Zone Routing Protocol, 1999) combine the good properties of both pro-active and re-active protocols were proposed. Each group has a number of different routing strategies, which employ a flat or a hierarchical routing structure. These protocols are designed to increase scalability by allowing nearest nodes to work together to

form some sort of a backbone to reduce the route discovery overheads. Hybrid protocol mostly use proactive routing method to maintain routes on neighbor nodes and determining routes to far away nodes using a reactive protocol strategy. Most hybrid protocols proposed to date are zone-based, which its network is divided into different zones. Each node may be within multiple overlapping zones, and each zone may with a different size.

**A) Zone Routing Protocol (ZRP)**

ZRP (Haas & Pearlman, 1998) is created based on two sub-protocols. Intra-zone Routing Protocol (IARP) is an intra-zone proactive routing protocol whereas Inter-zone Routing Protocol (IERP) is handled by reactive protocol. In ZRP, the nodes have a routing zone, which defines a range (in hops) that each node is required to maintain network connectivity proactively. Therefore, a route to destination within the routing zone can be immediately established by IARP proactively. Thus the packet can be delivered immediately if the source and destination is in the same zone. For nodes that lie beyond the routing zone, routes are determined reactively. Source node can use any on-demand routing protocol to determine a route to the required destination.

This hybrid routing protocol reduces control overhead compared to Route Request flooding mechanism employed in proactive and reactive approaches. This is because when a node needs to determine a route to a node outside the routing zone, the routing only has to travel to a node, which lies on the boundaries of the routing zone of the required destination. Since the boundary node would proactively and reactively maintain routes to the destination (i.e. the boundary nodes can complete the route from the source to the destination by sending a reply back to the source with the required routing address).

In the absence of query control, ZRP tends to produce higher control overhead than the proactive and reactive approaches. This can happen due to large overlapping of node's routing zones.

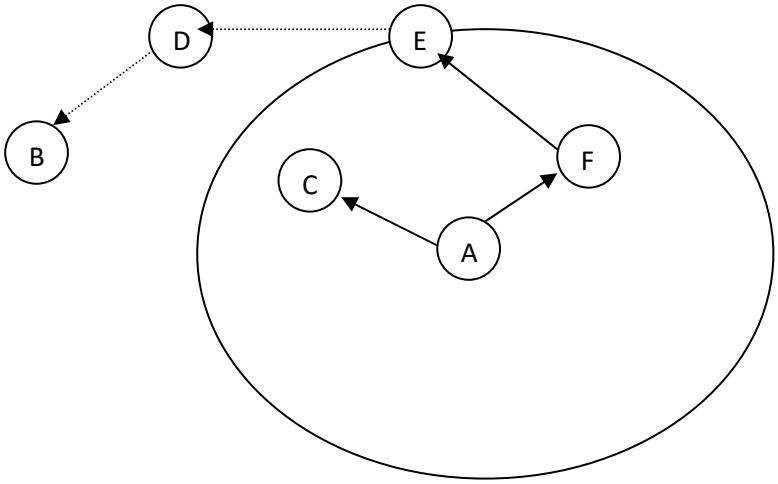


Figure 2.7 Radius1 Hop with Node E Is Border Node

### 2.5.2. Other Routing Protocols

The Hierarchical routing protocols (Murthy & Manoj, 2005) often group routers together by function into a hierarchy. These kind of protocols are famously used when the network size increases and the flat routing becomes in feasible due to increase in processing overhead. In this approach, the ad hoc routing is divided into different groups. After the formation of different groups, the nodes are assigned different functions within and outside the group in order to make sure successful of data transmission. Some of the routing protocols are Cluster Based Routing Protocol (CBRP), Core Extraction Distributed Ad hoc Routing (CEDAR) (P.

Sinha & Bharghavan, 1999)Fisheye State Routing protocol (FSR) and Global State Routing protocol (GSR).

The Geographical routing protocols (Sundrani, Awasthi, & Govil, 2005)mean that the nodes which involve in the routing process should be aware of their geographic positions. Currently, some of these routing protocols are Adaptive Location Aided Routing – Mines (ALARM), Distance Routing Effect Algorithm for Mobility (DREAM), GPS Ant-Like Routing Algorithm (GPSAL) etc (Ko & Vaidya, 1998).

### 2.6. Comparison on Wireless Ad hoc Routing Protocol

In pro-active routing protocols, large portion of the bandwidth is used to keep routing information up-to-date. Routes are always available regardless of need will lead to consumption of signaling traffic and power. Pro-active have the advantage that when a route is needed, the delay before actual packets can be sent is very small. On the other side proactive schemes needs time to converge to a steady state. This can cause problems if the topology is changing frequently. On the other hand, being more efficient at signaling and power consumption, re-active protocols suffer longer delay while route discovery if the information is not available in caches. However, re-active protocol do not consumed large portion of bandwidth. Table 2.1 lists some of the basic differences between the two classes of algorithms.

Table 2.1 Overall Comparisons of On-Demand versus Table-Driven Routing Protocols

| Parameters | **On-demand** | **Table-driven** |
|---|---|---|
| Availability of routing | Available when needed | Always available regardless of information |
| Routing philosophy | Flat | Mostly flat, except for CGSR |
| Periodic route updates | Not required | Required |
| Coping with mobility | Use localized route discovery as in ABR and SSR | Inform other nodes to achieve a consistent routing table |
| Signaling traffic generated | Grows with increasing mobility of active routes (as in ABR) | Greater than on-demand routing |
| Quality of service support | Few can support QoS, although most support | Mainly shortest path as the shortest path QoS metric |

Table 2.2 summarizes and compares the result from these theoretical/qualitative analyses and shows properties of wireless ad hoc routing protocols, include the Destination Sequenced Distance Vector (DSDV), Ad-Hoc on Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Zone Routing Protocol (ZRP), Temporally-Ordered Routing Algorithm (TORA), Internet Magnet Encapsulation Protocol (IMEP), Cluster Based Routing Protocol (CBPR). From the analysis, none of the protocols support power conservation or Quality of

Service. In addition, all protocols are distributed and easily reconfigure in the event of topology changes.

Table 2.2 Comparison between Ad-Hoc Routing Protocols.

| Characteristics | DSDV | AODV | DSR | ZRP | TORA/IMEP | CBRP |
|---|---|---|---|---|---|---|
| Loop-free | Yes | Yes | Yes | Yes | No, short lived loops | Yes |
| Multiple routes | Yes | No | Yes | No | Yes | Yes |
| Distributed | Yes | Yes | Yes | Yes | Yes | Yes |
| Reactive | No | Yes | Yes | Partially | Yes | Yes |
| Unidirectional link support | No | No | Yes | No | No | Yes |
| QoS Support | No | No | No | No | No | No |
| Multicast | No | Yes | No | No | No | No |
| Security | No | No | No | No | No | No |
| Power Conservation | No | No | No | No | No | No |
| Periodic broadcasts | Yes | Yes | No | Yes | Yes (IMEP) | Yes |
| Requires reliable or sequenced data | No | No | No | No | Yes | No |

## 2.7. Energy Efficiency Issue

In wireless ad hoc network, each device plays the role of a router and has limited battery energy. In addition, the network topology can constantly change. Thus, it is widely accepted that conventional routing protocols are not appropriate for mobile ad hoc networks, and, consequently, the design of routing protocols for such networks is a challenging issue if taking power factor into consideration.

Although a lot of approaches to develop better batteries and hardware with lower power consumption, from the networking point of view, most existing solutions for saving energy in ad hoc networks revolve around the reduction of power used by the radio transceiver (the device's network interface), which is often the single largest consumer of power (Chakrabarti & Mishra, 2001).

To reduce the energy consumption in mobile devices, there have been efforts in physical and data link layers as well as in the network layer related to the routing protocol. The physical layer can save energy by adapting transmission power according to the distance between nodes. At the data link layer, energy conservation can be achieved by sleep mode operation.

### 2.7.1. Type of routing protocol Affect Energy Efficiency

Ad hoc routing protocols can be broadly classified as table driven routing protocols and source initiated on demand routing protocols. The first approach uses a routing table which is maintained via periodic updates from all the other nodes in the network irrespective of the fact that the network may not be active in terms of data traffic. As a result, energy use is dominated by routing protocol overhead as a result of overhearing in table driven routing

protocols. Packet is broadcast in table driven routing protocols, it consumed energy when the packet is no used and discarded.

In contrast to table routing protocol, on-demand routing protocol sends out requests for routes to the destination only if the source node has data-packets which are to be sent to the destination. Thus**,** On Demand routing protocols consume less energy (on-demand) than table driven routing protocols.

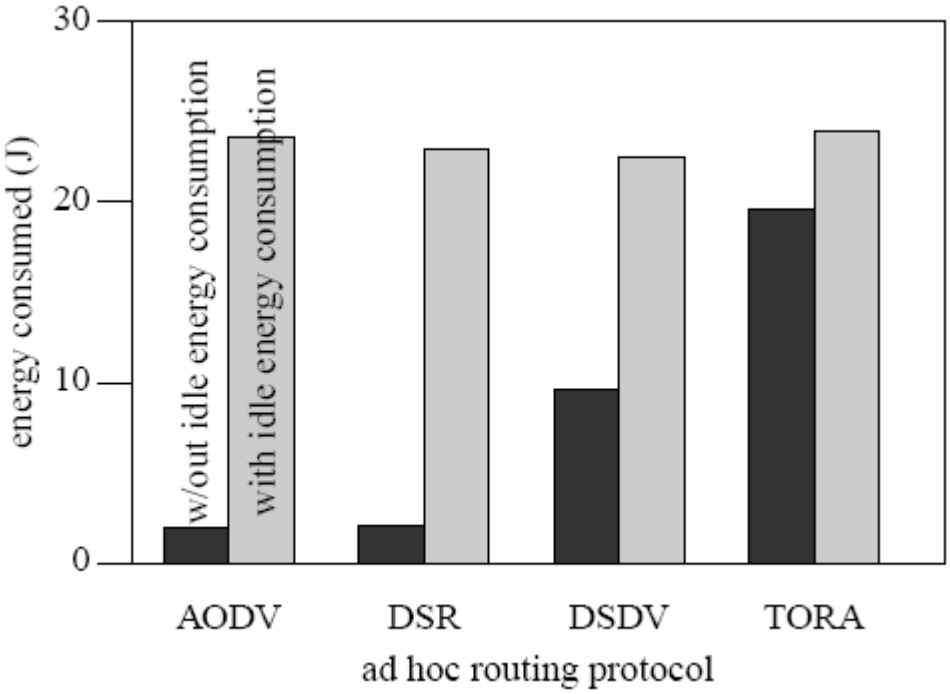


Figure 2.8 Comparisons of Four Ad Hoc Routing Protocols with Different Energy Models (The left black bars are the one without idle energy consumption; the right gray bars are the one with only idle energy consumption). The simulation has 50 nodes in a 1500m×300m area.

Nodes move according to random way point model. The energy model is based on Stemm and Katz. (M.Stemm & Katz, 1997)

### 2.7.2. Type of Energy Efficiency Routing Protocol

The basic energy efficient scheme would be adjusting the transmission power according to the distance between the sender and the receiver instead of using the constant maximum transmission power. This is called power control scheme. However, this is not optimal solution in terms of end-to-end energy consumption. To achieve the optimal solution, many energy efficient routing protocols have been proposed.

These protocols can be generally classified into two categories: Minimum Energy routing protocols and Maximizing Network Lifetime routing protocols. Minimum Energy routing protocols try to find the most energy efficient path to transmit the data packets from the source to the destination, while Maximizing Network Lifetime routing protocols try to balance the remaining battery power at each node.

### 2.7.3. The Energy Efficiency Alternatives

Prior studies have been aimed at designing minimum energy routing protocols. Dynamic power-conscious routing scheme (MPR) incorporates physical layer and link layer statistics to preserve power, while compensating for the channel conditions and interference environment at the intended receiver. This can be accomplished by altering the transmitter power to use just enough amount needed to maintain an acceptable signal-to-noise ratio (SNR) at the receiver. (Subbarao, 1999) However, this scheme does not consider battery capacity of individual node to extend network lifetime.

In addition, energy reserve of node that are responsible for routing packets on the path that are computed based on minimizing hop count or delay will get depleted resulting at node failure. Power-Aware Routing conserved power and carefully sharing the cost of routing packets will ensure that sustainable node and network lifetime**.** (Singh, Woo, & Raghavendra, 1998)They also suggest MAC layer modifications by power down the nodes when inactive to obtain energy savings. Although one of power aware metric such as minimizes energy consumed per packets that do result in energy efficient routing, some nodes may still facing early death due to widely varying energy consumption profiles.

The scheme suggested by Ramanathan (Ramanathan & Rosales-Hain, 2002) brings power savings by using transmit power adjustment to control the topology of a multi-hop wireless network. Node transmit powers is adjusted in response to topological changes and attempt to maintain a connected topology using minimum power. If the selected routes are via specific host, the battery of this host will be exhausted quickly due to only transmit power adjustment.

Volkan Rodoplu and Teresa H. Meng develop a distributed position based network protocol that uses location information to compute a multi-hop route which minimizes the energy to deliver the packet (Rodoplu & Meng, 1999)**.** The Minimum Energy Wireless Network requires an enclosure period during nodes rediscover their neighbors and re-compute the optimal paths to their peers. Re-enclosure may significantly reduce the effectiveness of throughput available for data communications because of the time required for each re-enclosure.

An online approximate power aware routing algorithm (Li, Aslam, & Rus, 2001) to maximize the lifetime of the ad hoc network, which involves choosing between the minimal power consumption path and the path that maximizes the minimum residual power in the network. In its basic version, max-min z$P_{min}$ needs to know all the locations and the energy levels of the nodes in the network.

Span (Chen, Jamieson, Balakrishnan, & Morris, 2001) is a distributed coordination technique for a multi-hop ad hoc wireless network that reduces energy consumption without significantly reducing the capacity and connectivity of the network. Each node makes decision on whether to sleep or stay awake as a coordinator and participate in the forwarding backbone topology. This technique can preserve capacity by one node become coordinator if two neighbors cannot communicate. Coordinator is kept low by rotating this role among the nodes. Energy savings are achieved by keeping certain chosen coordinator nodes active while the other nodes in the network are in a power save mode. However, SPAN basically only saves the power by minimizing the power wasted by nodes when they are not involved in the packet transmission

Energy Efficient Integrated Routing Protocol (E2IRP) (Kathiravan, Divya, & Selvi, 2009) for Mobile Ad Hoc networks used in remote surveillance systems proposed by Dr. K. Kathiravan, V. Divya and Dr. S. ThamaraiSelvi. E2IRP use integration of MAC and routing layers to reduce the amount of control information being exchanged for discovery and maintenance of the route in the network. This effectively reduces the amount of energy and time consumed for the processing of network packets. In E2IRP, the source sends the unique random identifier along with the route request. So, the nodes receiving the request can update their

ARP table without the need of ARP request and reply. This in turn reduces the battery power required for the construction and processing of these packets. However, nodes receiving the same random identifier create unwanted time to notify the source node, to resend the message with a new random identifier.

A new routing protocol, called Energy Efficient DSR (E2DSR) (Talook, Marques, Rodriguez, Água, Blanco, & Campos, 2010) is proposed to balance the energy consumption amongst the nodes in the network. E2DSR uses some mechanisms of Dynamic Source Routing (DSR) by defining a new structure for control packets, changes the routing behavior in nodes, implements a new "Energy Table" and creates a whole new algorithm for route cache and selection. Due to extra information on energy table, it creates additional overhead especially when network scalability is large.

Geographic adaptive fidelity (GAF) (Xu, Heidemann, & Estrin, 2001)is a cross-layer design that required geographic position devices to provide location information. The GAF protocol conserves energy by identifying unnecessary nodes based on location information and turns them off without sacrificing routing fidelity. Based on known node locations with GPS, the network may be partitioned so as to distribute routing duties to entire groups of nodes instead of one node having full responsibility and energy burden for the task. Nodes in the same grid will determine who will sleep and the duration of sleep time. Then nodes will periodically wake up and trade places to accomplish load balancing during establishing network. If a node does not hear any discovery messages for a given period of time, it will automatically become a master. If more than one node can become a master, the one with the longest expected lifetime becomes the master and responsible for that routing on that grid square. However,

this protocol may introduce significant delay as each sleeping node spent time to wake up and start processing received packets.

Network coding method to improve energy efficiency broadcasting in ad hoc network is recently proposed and its benefits are shown in (Widmer, Fragouli, & Boudec, 2005). The low efficiency of flooding for simple protocols has lead to the introduction of network coding method. Complexity of coding and packet overhead that network coding insert to the system are important parameters in a wireless ad hoc network. (Mansouri, Pakravan, & M.R. Sharif Univ. of Technol, 2008) All coding operations have been done on a unit size finite field which reduces the overhead size and complexity of operations.

M. Tamilarasi and T.G. Palanivelu (Tamilarasi & Palanivelu, March 2008) proposed improvement of on-demand routing protocol by introducing load balancing approach and transmission power control approach to maximize the life-span of ad hoc network. For load balancing approach, on-demand protocols select a route based on the minimum energy availability of the routes and the energy consumption per packet of the route at that time. Moreover, transmission power control approach reduces the power consumption per node by controlling transmission power on a link by link basis. The price paid for the improvement in these performance parameters is the 5% increase in average end-to end delay due to the inclusion of extra information in the packet header.

A new adaptive quorum based power saving protocol (Memarzadeh, Dehghan, & Jabbehdari, 2010) is proposed called consecutive quorum-based power saving (CQPS). Besides providing more efficient in energy consumption, CQPS also improves quality of service (QOS) for

network traffic. In order to achieve these goals, wireless nodes arrange consecutive wake intervals to exchange data with each other and at the same time it tries to reduce the number of control messages transmission as much as possible. Although CQPS has better performance than 802.11 PS in high traffic loads, but it still have slightly delay during route establishment.

Energy-efficient topology control problem in cooperative ad-hoc networks is introduced and propose two topology control algorithms to build cooperative energy spanners where in the energy efficiency of individual path is guaranteed paper (Zhu, Huang, Chen, & Wang, 2012). They suggested algorithms to carry out the performance in distributed and localized fashion by maintaining the globally efficient path. In paper (Karadge & Dr Sankpal, 2013), author proposes a routing algorithm, the maximum energy level maximum ad-hoc distance vector based on alternate maximum energy remaining routes in each node so as to increase the lifespan of the network.

In paper Yean-Fu Wen and Wanjiu Liao proposed a Lagrangian Relaxation approach which constructed the minimum energy broadcast tree by using a path-based mathematical formulation that differed from the previous link-based and node-based approaches (Yean-Fu & Wanjiun, 2011). It could obtain lower and upper bounds for the optimal solution. The narrow gap between the bounds demonstrated in the experimental results indicated that the proposed heuristic algorithm could achieve near optimality.

In order to increase node's lifetime, Suresh *Singh*, *Mike Woo*, and C. S. Raghavendra proposed the *Min-Max Battery Cost Routing* (MMBCR), which considers the residual battery

power capacity of nodes as routing metric (Singh, Mike Woo, & Raghavendra, 1998). MMBCR allows nodes with higher residual capacity to participate in the routing process more often than nodes with lower residual power so that the battery of each host will be used more fairly. In every possible path, there exists a weakest node which has the minimum residual battery capacity. Hence, MMBCR tries to choose a path whose weakest node has the maximum remaining power among the weakest nodes in all possible routes to the same destination. However, MMBCR does not guarantee that the total transmission power is minimized over a chosen route, which actually reduces the lifetime of all nodes.

## 2.8. Computer Network Simulator Tools

There are many simulators available in the market mainly used for evaluating network performance such as Network Simulator 2 (NS-2), OPNET Modeler, GloMoSim, OMNeT++ and etc. The general description about these network simulators are as follow:

### 2.8.1. Network Simulator Tool (Ns-2)

Network simulator 2 (CMU Monarch Group, Nov 5, 2000) (Fall & Varadhan, 2003) is the result of an on-going effort of research and development that is administrated by researchers at Berkeley. It is an object-oriented, discrete event driven network simulator targeted at networking research and provides substantial support for simulation of TCP, routing, and multicast protocols. It implements many network protocols such as Transmission Control Protocol and User Datagram Protocol, traffic source behavior such as File Transfer Protocol, Telnet, Web, Constant Bit Rate and Variable Bit Rate, queue management mechanism, routing algorithms and more

The simulator is written in C++ and a script language called OTcl. Ns use an OTcl interpreter as a front end language to the user. User has to writean OTcl script that defines the network (number of nodes, links), the traffic in the network (sources, destination, type of traffic) node interface and which type of protocols it will use. OTcl runs much slower but can be changed very quickly, is mainly used for simulation configuration. One of the advantages of this split-language programming approach is that it allows for fast generation of large scenarios. On the other hand, one disadvantage is that modifying and extending the simulator requires programming and debugging in both languages simultaneously. The result of simulations is output trace files that can be used to do data processing such as calculate delay, throughput, remaining energy etc) and to visualize the simulation with a program called Network Simulator (NAM). NAM is a very good visualization tool that visualizes the packets as they propagate through the network.

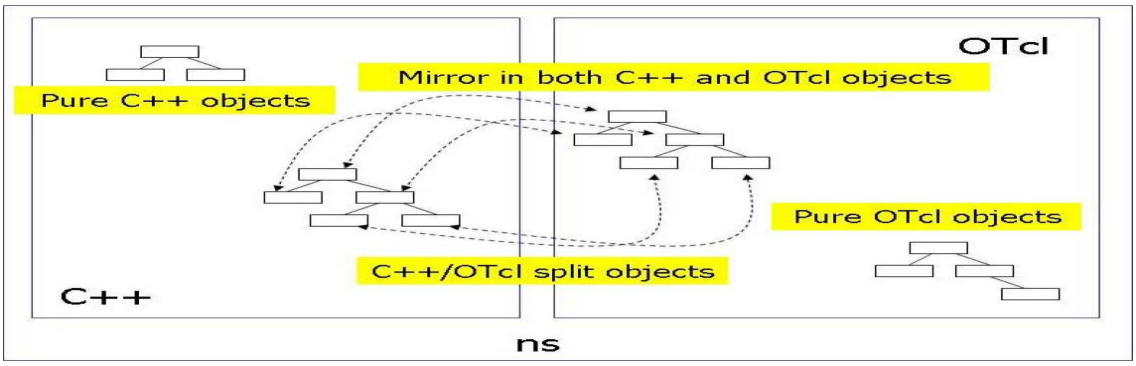


Figure 2.9 Separate Data Path and Control Path Implementation (Chung & Claypool)

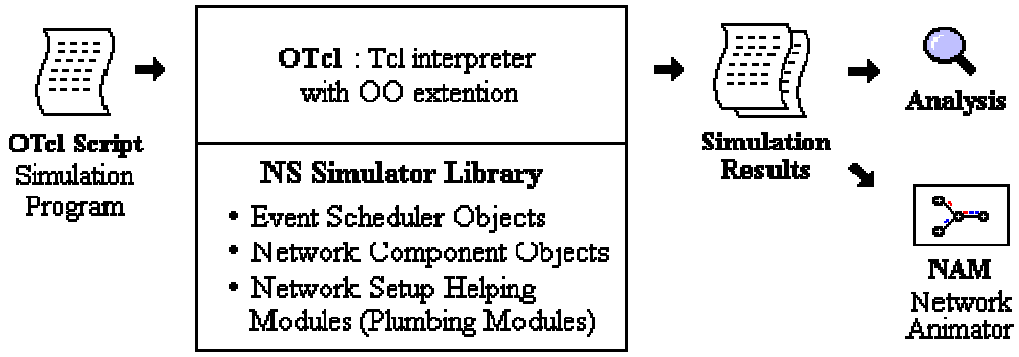


Figure 2.10 Simplified User's View of NS-2 (Chung & Claypool)

### 2.8.2. Glomosim Simulator Tool

In GloMoSim we are building a scalable simulation environment for wireless and wired network systems. It is being designed using the parallel discrete-event simulation capability provided by Parsec. GloMoSim currently supports protocols for a purely wireless network. In the future, we anticipate adding functionality to simulate a wired as well as a hybrid network with both wired and wireless capabilities.

Most network systems are currently built using a layered approach that is similar to the OSI seven layer network architectures. The plan is to build GloMoSim using a similar layered approach. Standard APIs will be used between the different simulation layers. This will allow the rapid integration of models developed at different layers by different people. The protocols being shipped with the current library include the following:

Table 4.1 The Protocols Being Shipped With The Current Library

| **Layers** | **Protocols** |
|---|---|
| Mobility | Random waypoint, Random drunken, Trace based |
| Radio Propagation | Two ray and Free space |
| Radio Model | Noise Accumulating |
| Packet Reception Models | SNR bounded, BER based with BPSK/QPSK modulation |
| Data Link (MAC) | CSMA, IEEE 802.11 and MACA |
| Network (Routing) | IP with AODV, Bellman-Ford, DSR, Fisheye, LAR scheme 1, ODMRP, WRP |
| Transport | TCP and UDP |
| Application | CBR, FTP, HTTP and Telnet |

### 2.8.3. Omnet++ Simulator Tools

OMNeT++ stands for Objective Modular Network Testbed in C++. OMNeT++ provides component architecture for models. Components (modules) are programmed in C++, and then assembled into larger components and models using a high-level language (NED). Reusability of models comes for free. It is a discrete event simulation tool designed to simulate computer networks, multi-processors and other distributed systems Its primary application area is the simulation of communication networks, but because of its generic and flexible architecture, is successfully used in other areas like the simulation of complex IT systems, queuing networks or hardware architectures as well.

OMNeT++ has extensive GUI support, and due to its modular architecture, the simulation kernel (and models) can be embedded easily into your applications. Although OMNeT++ is not a network simulator itself, it is currently gaining widespread popularity as a network simulation platform in the scientific community as well as in industrial settings, and building up a large user community.

### 2.9. The Reason to Choose NS-2

NS-2 is chosen as the simulation tool among the others simulation tools because of the following reasons:

1. NS-2 is widely used for routing protocol simulations
2. Ns-2 is suitable for designing new protocols because it supports modularity, reusability, and scalability.
3. NS-2 is developed as a collaborative environment.
4. NS-2 distributed freely and open source. A lot of professional around the world use NS-2 to simulate different area of network research.
5. There are lot upgrades done on NS-2 to meet different needs of markets.
6. There are versions are available in different platform for FreeBDS, Linux, Solaris, Windows, Mac OS X.
7. NS-2 also provides substantial support for Supports the simulation of intserv/diffserv, Multicast, Transport, Applications, Wireless (fixed, mobile, satellite)

## 2.10. Simulation Model

### 2.10.1. Scripts In Ns-2 Simulation

There are three main scripts required in network simulator 2 which is TCL, C++ and AWK script. In the TCL script is a front end interpreter to defined network scenario such as mobility and topology (Simulation scenario) configuration. It is event driven which means periodic or triggered action. It manipulates existing C++ objects. The advantages of tcl script are easy to write and edit.

The C++ script is a back end network simulator engine. It is core and data part of NS-2. Code in C++ script is easy to modify because it is no fully layered and structured. It supports packet processing and execution.

The AWK script is a general purpose programming language that is designed for processing test-based data, either in files or data streams. The name AWK is derived from the surnames of its authors – Alfred Aho, Weinberger, and Brian Kernighan.

Figure 2.11 illustrate the functional diagram of network simulator. Due to problem in the network, a topology network is setup and executed using network simulator. Then, the result is generated and analyzed. If the problem still exists, the process of modifying network topology's protocol and environment will be continued before generating and finalizing the result.

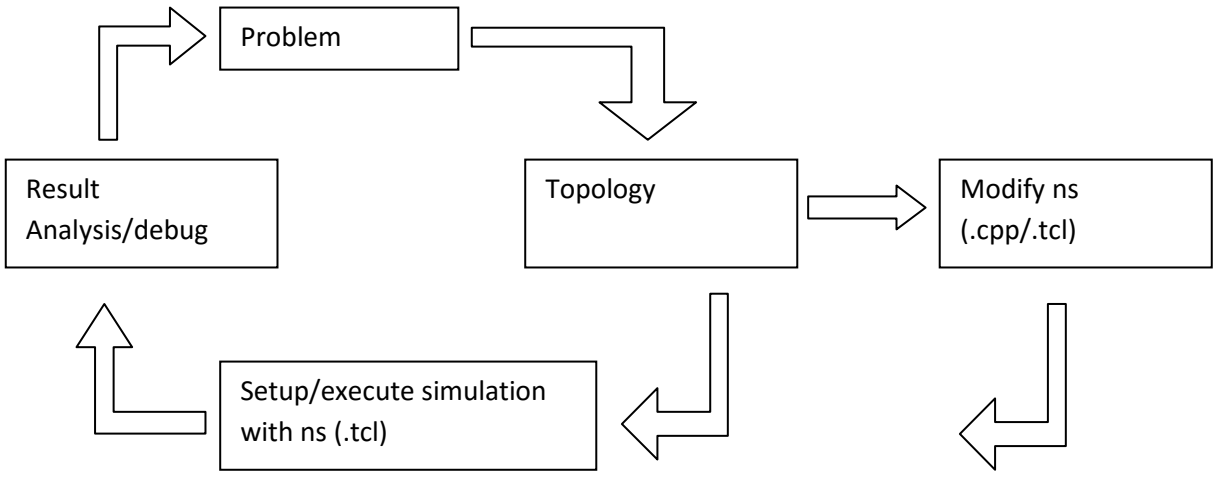


Figure 2.11 Functional Diagram of NS-2

## 2.11. Network Animator

Network Animator (NAM) is a very good visualization tool that visualizes the packets as they propagate through the network. Figure 2.12 shows the example of node broadcasting route request packet (RREQ) in order to establish reverse path to the source node. In this simulation tool, the random position and movement of network nodes can be observed. Figure 2.13 shows proposed protocol environment with some of node battery depleted which showed with red color (battery almost die or die). Node with depleted energy will not involve in any packets transmission and reception.

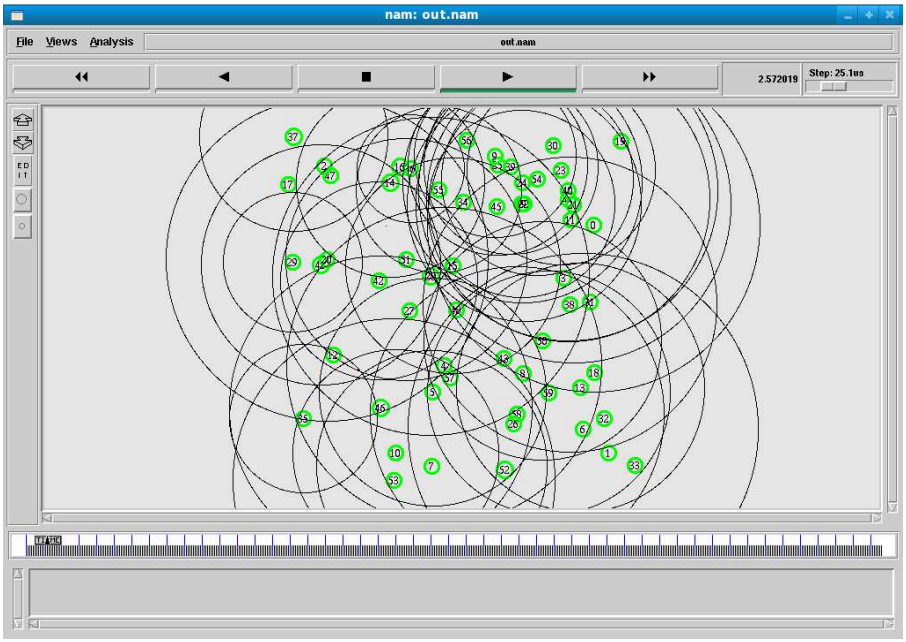


Figure 2.12 Node Broadcasting RREQ


Figure 2.13 Different Color of Show Node Remaining Energy

## 2.12. Summary

This chapter explained the importance of energy efficiency in ad hoc network. Besides that, the definition of ad hoc network and routing protocols are also being described in detail in this chapter. The reactive routing protocols in ad hoc network such as AODV and DSR will play important role in achieving the objectives of this research. The importance of energy improvement in wireless ad hoc network and other research works on enhancing node battery power saving are also being analyzed.

# CHAPTER 3

# THE PROPOSED MEL-AODV AND ALMEL-AODV SCHEMES

## 3.1. Introduction

The algorithms of two proposed schemes Maximum Energy Level Ad Hoc Distance Vector (MEL-AODV) and Alternate Maximum Energy Level Ad Hoc Distance Vector (ALMEL-AODV) have been proposed and to be explained in detail in this chapter. The primary objective of proposed schemes is to increase efficiency in battery conservation and network lifetime. In principle, the proposed schemes utilize the energy capacity as important metric during route determination and node participation to alleviate the unfair usage of energy which is commonly happened in conventional protocol.

## 3.2. Link Quality AODV

Existing routing protocols and motivation to create these proposed schemes have been discussed in previous section. In this section, the proposed link quality AODV schemes based on energy efficiency design will be explained. The main difference between the proposed protocols with the existing conventional protocols is that it uses energy as a routing decision rather than hop based routing. A new scheme called Maximum Energy Level Ad Hoc Distance Vector (MEL-AODV) is proposed. Then it is further enhanced by proposing the Alternate Route Maximum Energy Level Ad Hoc Distance Vector (ALMEL-AODV).

### 3.2.1. MEL-AODV

**A. Protocol Overview**

As described before, this scheme focuses on selecting the highest energy path for deciding how to route data packet to the destination. In order to prevent certain node from receiving control packet from previous hop with battery below energy level, those hop will stop from broadcasting packet to neighbor nodes. The objective is to balance the energy usage and reduce unwanted energy wastage. Furthermore, a higher energy path on the route may lead to a more stable route and longer network lifetime connection compared to the shortest path approach with no energy consideration (Cao, Dahlberg, & Wang, 2007).

**B. Route Discovery and Maintenance**

As the RREQ message is broadcasted by the source, each intermediate node forwards or rebroadcast the RREQ packet by adding its current remaining energy in the packet. Hence at any point the RREQ or the receiving node will have accumulated energy path. The routing table is updated for each intermediate node visited by the RREQ in addition to the destination node. As an example, consider five nodes A, B, C, D and E as shown in Figure 3.2. Node A wants to send data to node E. Since A does not have a route for E in its routing table, it broadcasts a route request. B receives the route request, updates its routing table for the reverse route to A, and forwards the request since it also has no route to E. However before forwarding, it adds its remaining energy to the route request packet (RREQ). When C receives the RREQ, it updates its routing table with the information in RREQ and adds its own remaining energy to request packet. Similarly, when D receives the request it update its routing table for total energy of nodes A, B and C, while E learns about nodes A, B, C and D. When destination node E receives RREQ, it will wait for more incoming RREQ which have

higher energy probability before unicast back RREP. Forwarding route with higher total remaining energy will be constructed to improve efficiency of AODV in prolonging network lifetime.

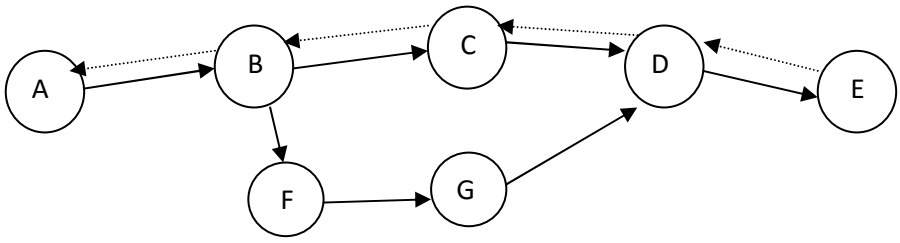


Figure 3.1 Route establishment

The proposed computation of the energy link is as follows: the wireless ad-hoc network in consideration is modeled as a directed graph $G= (V, E)$, where $V$ is the set of all nodes and $E$ is the set of all directed links $(i, j)$ where $i, j \in V$. A path $L=v_1, v_2 \ldots v_n$exists between the source node, $S=v_1$ and the destination node, $D=v_n$. Let $E_{(i,j)}$be the largest energy sum which ensure longer communication time between node $v_i$and node $v_j$. The largest energy sum of the link when $j = i + 1$, $E_{(1, n)}$may be represented as

$$Max \ E_{(1,n)} = \sum_{i=1}^{n-1} E_{(i,j+1)} \qquad (1)$$

A simple flowchart of MEL-AODV is shown at Figure 3.2. First, source node broadcast route request packet through the network and the targeting destination node. When intermediate nodes receive broadcasting packets, it will add the received total energy value from the previous node with its current energy capacity value. The intermediate nodes also set up

backwards pointers to the source node by updating its route table. After the destination node receive more routes from the source, it unicasts route reply packet (RREP) back to the source by choosing the higher energy route. When generating RREP, a node copies the Destination IP Address, Originator IP address, Originator Sequence Number and accumulated path list from the RREQ into corresponding field of RREP message. As the RREP propagates back to the source, nodes will set up forward pointers to the destination. Once the source node receives the RREP, it may begin to forward data packets to the destination.

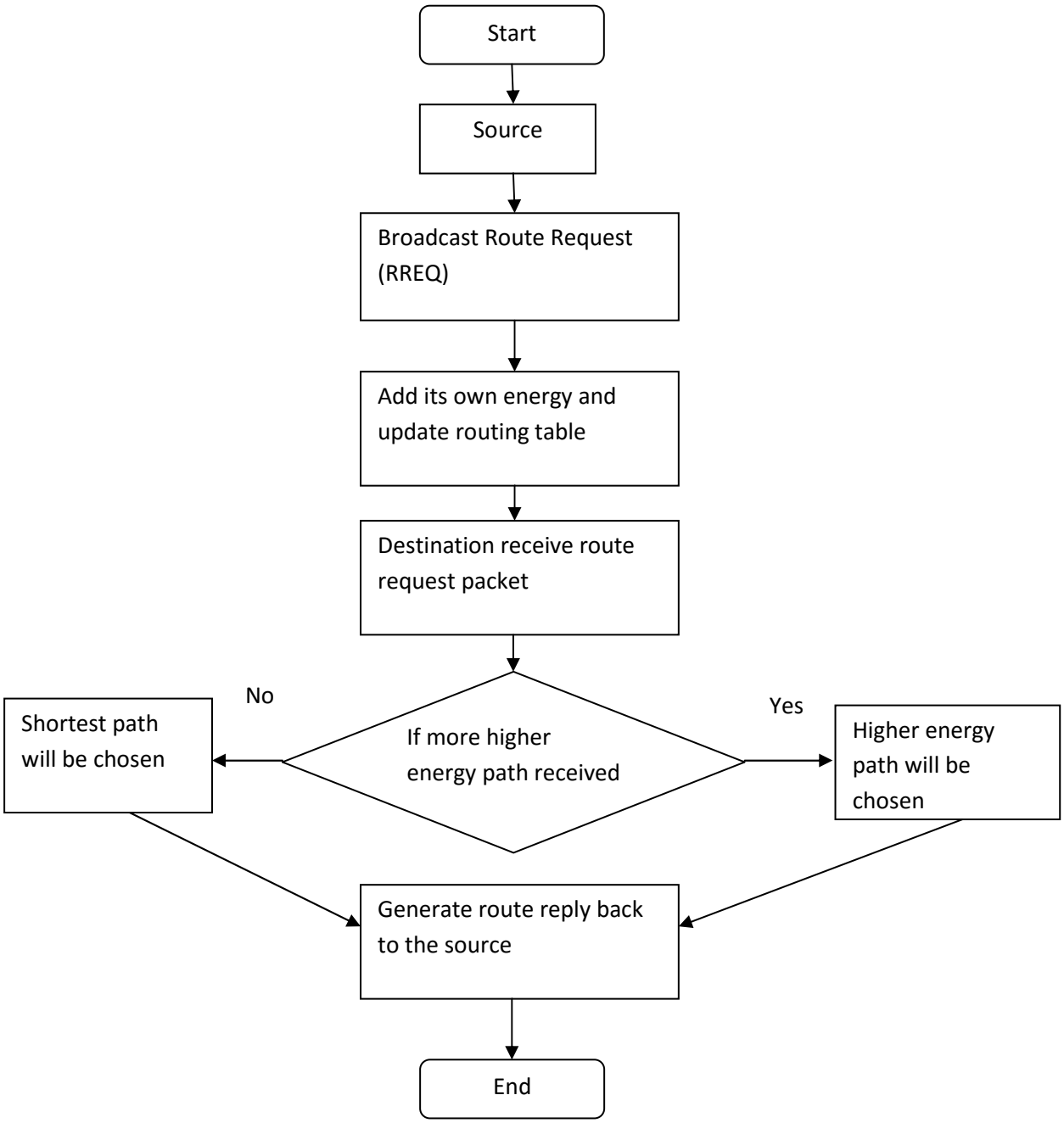


Figure 3.2 Flow of MEL- AODV Process

Figure 3.2 shows the process of the energy accumulation. First the source broadcasts the route request message (RREQ) to find the most suitable route to reach the destination. Intermediate nodes append its own remaining energy to the received RREQ before rebroadcast to other intermediate node and this process is repeated until it reaches the destination. After RREQ

have reached the destination, it waits for a minimum of two or a maximum of three RREQ packets to arrive. The highest energy path will be selected before replying the message (RREP) to the source. In this simulation environment, if any of intermediate node has remaining energy capacity less than the specified threshold value $(E_r<Th_r)$, the route request packet will be dropped. The threshold value has been fixed at 0.5 joule and it proved to have prolonged the expiration time of connection. The purpose is to reduce unwanted broadcast and high possibility of link breakage.

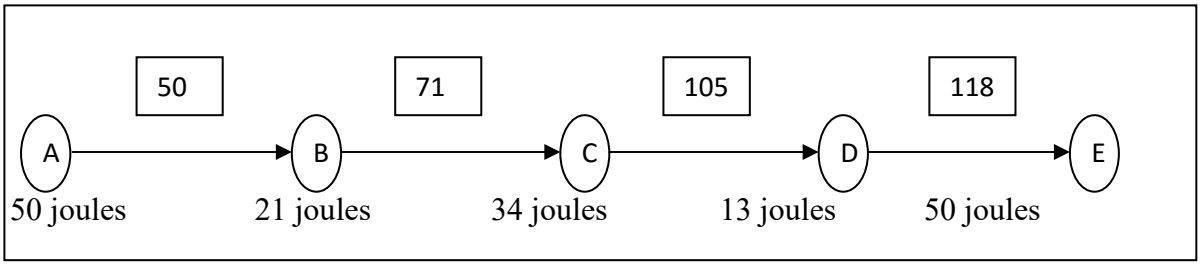


Figure 3.3 Energy Accumulation Process

### 3.2.2. ALMEL-AODV

**A. Protocol Overview**

The advantage of Alternate Link Maximum Energy Level Ad-hoc On Demand Distance Vector (ALMEL-AODV) over conventional protocol is that node's route table contains more than one route to the destination. In this research, AODV routing table entry contains the destination address, next hop, number of hops, destination sequence number, and active neighbors for this route and expiration time for this route table entry (Perkins & Royer, 2001).

In order to improve energy efficiency, the route with better energy level will be added to route table and used for routing purposes. The source node can quickly route data packet to the destination whenever the route is available in route table. If there are better route found, the data packet will continue to select the better route which have higher energy level compared to previous route. This greatly balances the energy usage among nodes in the network and reduces the burden of certain route. However, previous route will remain in the route table to be used as backup route if the current route is broken.

Although alternate route has no relatively high energy path, it reduces unnecessary time and energy usage to rediscover new route to the destination. This scheme also prevent node with energy below certain threshold from broadcasting control packet which may result in higher probability of node breakage. At the same time, neighbor nodes will refrain from spending extra energy on receiving and processing packet from nearly depleted node during route establishment.

This routing protocol is more advantageous in large network with low mobility. Backup route is critical to maintain network connectivity as low mobility network ensure the freshness of the backup route. As the number of nodes increase in the network, the network lifetime will be increased. This is because there are higher chances of new route to be found to maintain the overall network connectivity.

**B. Route Discovery and Maintenance**

The Alternate Route Maximum Energy Level Ad Hoc Distance Vector scheme has similar energy accumulation method as shown in Figure 3.1 above. The source node broadcasts route

discovery to its neighbors whenever it has no routing information in its table. Every node maintains two separate counters: a node sequence number and a broadcast ID. In our scenario, we maintain intermediate nodes to receive higher sequence number of RREQ to prevent infinite loop and to prevent stale route information. The near death nodes with threshold less than 0.5 joule remaining energy are disallowed from broadcasting any control packets. This is because the participation of low energy node will lead to early breakage of network connection and at the same time nearby nodes may be wasting energy to receive the broadcasting packet.

In Figure 3.4, the various thresholds have been evaluated via simulation carried out on a topology of 1000m×1000m with 70 nodes. Expiration time of connection is being used to measure the performance of different threshold value. It is defined as the time when there are no connection exits between source and destination node due to lack of survived nodes. From the graph, the optimum threshold value 0.5 joule is determined as it has longest expiration time of connection in ALMEL-AODV compared to other threshold value.

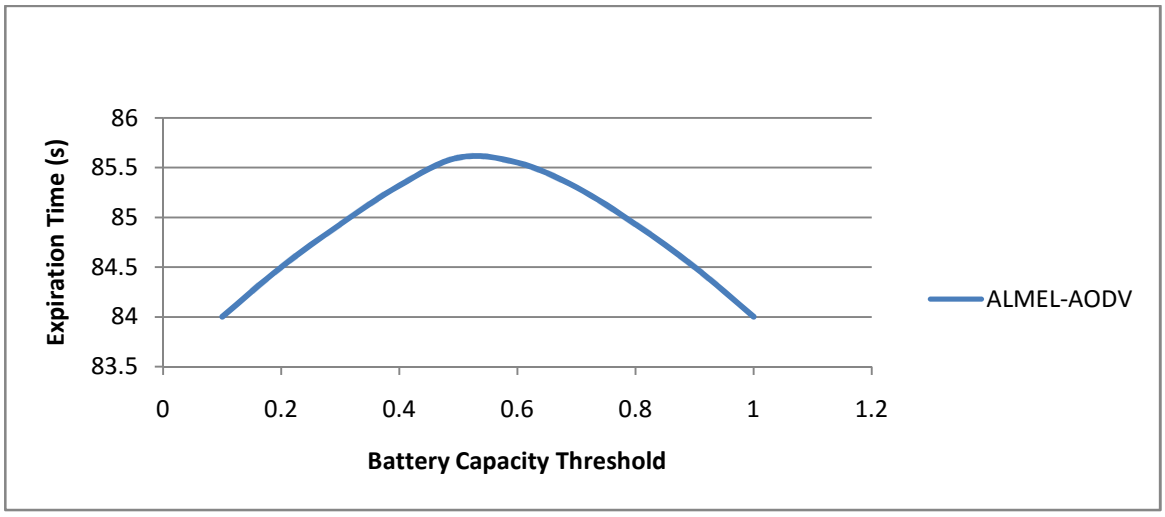


Figure 3.4 Expiration Time(s) vs Battery Capacity Threshold

Meanwhile intermediate node obtains current node energy information, it adds to the accumulated energy field in the route request packet using the energy function (1). In order to increase the entire network lifetime, each intermediate node employ delaying method of RREQ flooding by considering the node's energy state. Delaying method can be defined as the duration of waiting time on node in order to delay the broadcast of control packets. Let $c_i(t)$ be the battery capacity of host $n_i$ at time $t$. We define $f_i(t)$ as a battery cost function of host $n_i$. The less capacity it has, the more delay it is to forward the RREQ. The proposed value is: $f_i(t) = 1/c_i(t)$. As the battery capacity decreases, the value of cost function for node $n_i$ will increase. Therefore, lower cost node can be defined as better battery capacity node and it has high tendency to be selected during route establishment. The motivation behind this is to increase the probability of higher remaining battery capacity node being selected as the forwarding node.

Destination nodes are designed to allow receiving more than one route request from neighboring nodes. This process is continuing until destination node receives the RREQ packet or the intermediate nodes route information towards the destination. Upon receiving first RREQ packet, the node will calculate and update the accumulated energy field on the destination node route table. If there is a route with better energy sum received, the destination node will insert new information into its route table. Then, destination node will send RREP to the source node reversely after gathering route information with the satisfactory condition.

As the RREP travels back to the source each node along the path sets up a forward pointer to the node from which the RREP came. Figure3.5 represents the forward path setup as the

RREP travels from the destination D to the source node. After the route table is updated with the new route, the source node can start sending data packet to the destination node based on the forwarding path. This process continues until source node stop receiving further route replies which contain forwarding paths from neighbors. For example, after node A receives the second RREP, the source node can send data through the forwarding path with energy sum larger than the first RREP. This process is repeated until node A stop receiving RREP from destination D.

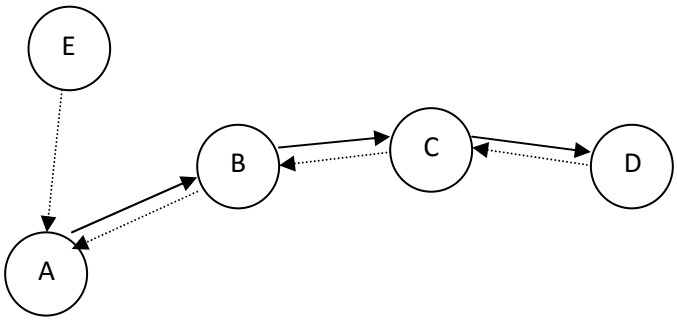


Figure 3.5 Forwarding Path Formations

If there are broken link, a node floods RRER packets towards the source of the path. Any nodes receiving this packet mark this route as invalid and only source node may choose alternate route in its route table or reinitiate route discovery for that destination if a route is still desired.

This scheme is enhancement of the previous MEL-AODV by allowing route table to store more than one route. Figure 3.6 below show the simple flowchart of ALMEL-AODV. When a source node desires a route to a destination for which it does not already have a route, it broadcasts a route request (RREQ) packet across the network. Nodes receiving this packet

update their information for the source node and set up backwards pointers to the source node in the route tables. Similar to MEL-AODV, intermediate node add its remaining energy to the data packet. When destination node wait for better energy routes, destination node unicast RREP back to the source after receiving first RREQ packet. Source node start sending data packet as the route is established. Source node will continue to redirect its transmission to the better route if there are newly arriving higher energy route. The purpose of this step is to prolong network lifetime while distribute traffic load to better energy route discovered. If there are link breakage due to node movement and depleted node, it will find its route table for alternative route which it previously use for transmitting data packet to the destination. This greatly improves energy efficiency as it reduces the number of retransmission.

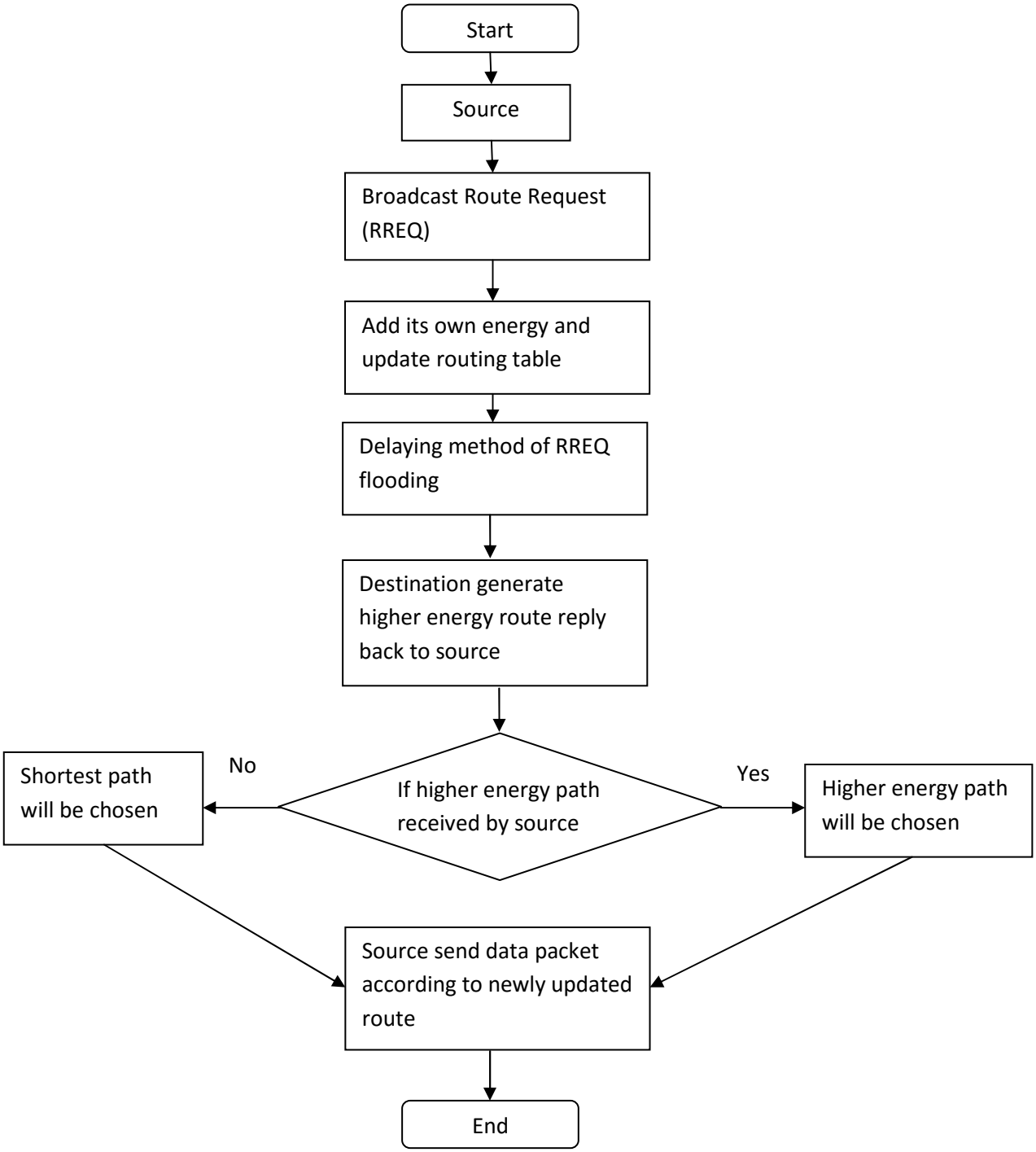


Figure 3.6 Flow of ALMEL- AODV Process

### 3.3. Estimation of Energies

The networks interface (Bharghavan, Demers, Shenker, & Zhang, 1994) of the node use the following formula to compute the energy consumption

$$Energy = Power \times time \quad (2)$$

When a node is transmitting or receiving a packet, the energy consumption of node is calculated by the transmitting power or the receiving power multiply the transmitted or received time. $T_{tx}$ and $T_{rcv}$ are transmitted and received time of packet respectively based on formula (3). Packet size is normally quoted in Bytes so have to be converted by multiplying with 8 (1 Byte = 8 Bits). Packets size (Bits) is divided by bandwidth (Mbps) in order to get the time for transmitting or receiving a packet.

$$Time = 8 \times Packet\ size / Bandwidth \quad (3)$$

So formula (4) (5) (6) and (7) are used to calculate and deduct transmission and reception energy. We able to know the amount of energy used for packet transmission by multiplying transmit Power ($Power_{tx}$) with transmit time ($T_{tx}$). Then we can summarize the remaining energy of node after the successful transmission.

Energy in transmit mode, $E_{tx} = Power_{tx} \times T_{tx}$ (4)

Remaining energy, $E_{node} = current\ energy - E_{tx}$ (5)

Energy in receive mode, $E_{rcv} = Power_{rcv} \times T_{rcv}$ (6)

Remaining energy, $E_{node} = current\ energy - E_{rcv}$ (7)

On the other hand, if a node forwards a packet, the energy consumption is equal to the sum of the receiving and retransmitting of the packet, which formula is shown in (8)

Energy in forwarding mode, $E_f = E_{tx} + E_{rcv}$ (8)

### 3.4. Conclusion

In this chapter, the proposed schemes MEL-AODV and ALMEL-AODV have been explained as well as their process on maximizing energy efficiency to improve network lifetime of ad hoc network. The improvements of AODV with added energy metric are needed to prolong the lifetime of network during route establishment. Furthermore, we also explain the advantages of proposed schemes in wireless ad hoc network. Since the existing routing protocols cannot be applied in battery operated nodes, our schemes provide great advantages on prolonging the lifetime of each mobile node in the network as well as the entire network itself.

# CHAPTER 4

# SIMULATION MODELING AND RESULTS ANALYSIS

## 4.1. Introduction

In this chapter, we will start by giving a framework and overview of some techniques that are chosen for evaluating network performance. There are three techniques involved in evaluating the network performance which are analytical modeling, simulation and measurement (Surayati, Usop, & Ahm, 2009). The reason for choosing simulation as a technique for performance evaluation in this thesis is also explained in this chapter.

This chapter makes comparison between the DSR, AODV, MMBCR and with proposed schemes MEL-AODV and ALMEL-AODV based on first dead lifetime, expiration time of connection and percentage of depleted node. DSR performance has also been included for standard benchmarking purpose. AODV and DSR are familiar conventional protocols in ad hoc routing, so both protocols will be simulated and compared in this chapter. Simulation (Law & Kelton, 2000) can be defined as "Imitating or estimating how events might occur in a real situation". Moreover, it can involve complex mathematical modeling, role-playing without the aid of technology, or combinations. This modeling is important phase in this research project in order to get accurate and successful evaluation of different simulation network. During simulation, different parameters of network scenario are inputted into the network simulator to evaluate and compare the existing and the proposed protocol. NS2 is used because it is widely used in routing based simulation for ad hoc networks. The design of network scenario and traffic generation in NS-2 used is closed to the real network environment (Hughes, 20 February 2009).

Lastly, simulation output and its results with the analysis focusing on first dead lifetime, expiration time of connection, and percentage of depleted node are described and explained.

### 4.2. Network Performance Evaluation

Performance is a main criterion in the computer system design and implementation. Network performance evaluation is important for computer professional to select the best performance design of network such as delay, energy efficiency, or throughput. There are three available techniques for evaluating network performance, which are analytical modeling, simulation and measurement.

Simulation had being chosen because it is the most suitable technique to get more details that can be incorporate and less assumption is required compared to analytical modeling (Patel & Dubey, 2012). Accuracy, times available for analysis and cost allocated for the thesis are also another reason why simulation is chosen. (Dhandekar, 2015).

### 4.3. NS-2 Simulation Concept

A scenario environment is generated in network simulator 2. This environment defines node communication pattern, network topology and event scheduling. Different numbers of node are generated in a 1000×1000 meter network topology. The communication pattern randomly chooses sender and receiver to generate and setup traffic flow between them. Each of nodes is randomly located in different location. It also accept node mobility pattern in random position and movement. Then, nodes are setup in order to have CBR/UDP traffics between them. Constant bit rate (CBR) is a traffic source. CBR does not create a connection before sending the packets, it sends the packets continuously and it does not guarantee the packets will be

delivered to the receivers. For this reason, CBR is chosen because route failures and route changes due to node mobility may be frequent events in ad hoc network. User datagram protocol (UDP) is a transport agent and it is created to attach to the node. The traffic agent configures number of packets and packet size before connecting source node and sink node.

In this research, different type of protocols will be adopted for this simulation environment. There are some example implementations of conventional routing protocols available in the current network simulator such as Dynamic Source Routing (DSR), Ad Hoc on Demand Distance Vector (AODV). Min-Max Battery Cost Routing (MMBCR) scheme which consider the remaining battery power of nodes to prolong the lifetime of each node is used as energy efficiency comparison. In this research, AODV protocol has been chosen and being modified to improve its performance in term of energy efficiency. Hence, Maximum Energy Level Ad Hoc Distance Vector (MEL-AODV) and Alternate Route Maximum Energy Level Ad Hoc Distance Vector (ALMEL-AODV) are proposed. These ad hoc routing protocols are configured in each node to allow them to follow certain communication rules during route establishment and data packet transmission.

Then, simulation time is defined to schedule the starting and ending time of network simulation. Upon completion, simulation result is generated. Simulation result is used to calculate the number of depleted nodes and network connection time, as well as other additional information about the internal functioning of each scripts executed. The processes of route establishment, packet transmission and reception, link breakage and depleted node are visualized based on the simulation results that match the real life network scenario. Each line in the simulation results represents a message being sent, received, drop and forwarded.

Thus, an analyzer is used to analyze each packet to obtain the first dead lifetime, expiration time of connection, and percentage of depleted node.

Figure 4.1 explains the process of network simulation model used. Scenario generator generates the scenario file and communication file which consist of random position of nodes, connection patterns between nodes, traffic speed, network interface and etc. Prior to the generation simulation result, a routing protocol is chosen to run with the simulation. The result can be visualized in order to view its communication pattern graphically. The simulation will also be analyzed using performance metrics such as network lifetime.

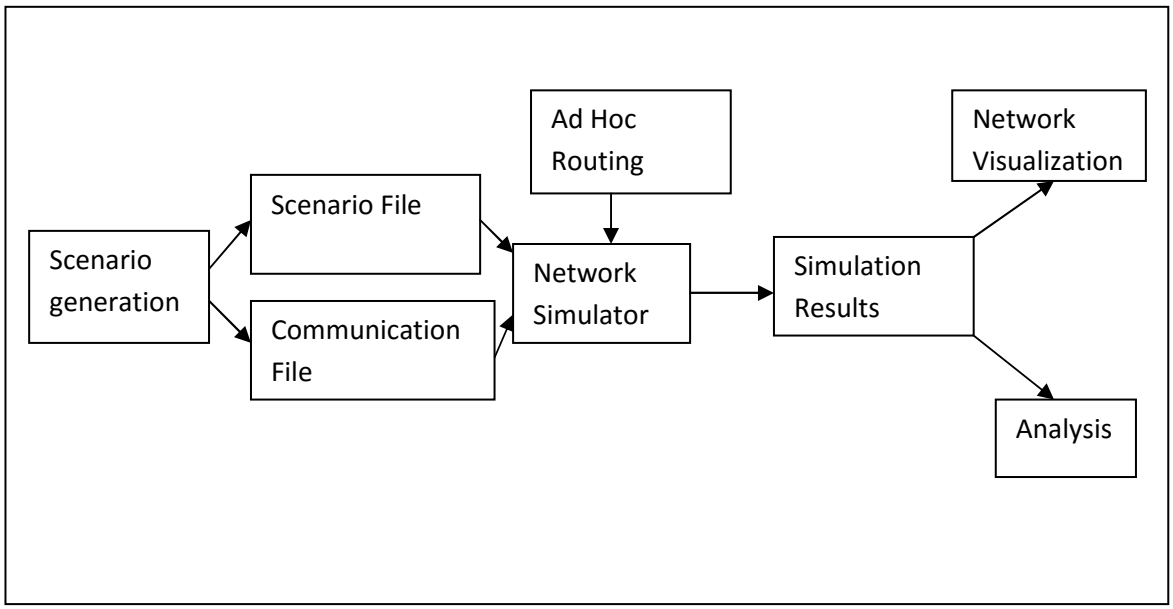


Figure 4.1 Overview of Simulation Model

This simulation models has been built to allow it run under a nominal bit rate of 2 Mbps. Each node generates fixed number of packet sizes (512-bytes). Different number of nodes which are 30, 40, 50, 60, 70, 80, 90, 100 nodes are generated in order to have better

comparison between different ad hoc routing protocols. Packets are transferred at the rate of 2 packets per seconds. As mentioned before, constant bit rate (CBR) traffic source are generated by traffic-scenario generator script to route from source to destination.

The mobility model used is a random waypoint model in a rectangular field. The field configurations used is 1000m X 1000m and the stations are assumed to be randomly distributed in the area. Here, each packet starts its journey from a random location to another random destination with low velocity of 1ms. Thus, this mobile network assumed a low mobility speed. After the destination is reached, another random destination is targeted after a pause time. Simulations are run for 100 simulated seconds. Identical mobility and traffic scenarios are used across all protocols to be compared for fair comparison.

Table 4.2 below list the common simulation parameter with the value used in simulation environment. In Mac Layer, IEEE 802.11 protocol is implemented (Dongkyun, Garcia Luna Aceves, & Obraczka, 2002). NS 2 use Phy/WirelessPhy to simulate IEEE802.11b type of wireless channel. Two Ray Ground model is used as radio propagation in order to consider line-of-sight path exists and reflection of ground.

PriQueue is implemented to give priority to routing protocol packets and it supports filter to remove packets destined to specific address. Maximum number of packets in queue is 50 packets. Link layer is used and it runs data link protocols. Meanwhile, it also runs the Address Resolution Protocol (ARP) to resolve IP address to MAC address conversions. Omni directional antenna is implemented in order to sends or receives signals equally in all directions. Furthermore, Ad-hoc network routing protocols configure multi hop routes for

packets in 1000m × 1000m size of topology. The traffic source that is being used is constant bit rate.

Table 4.2 Simulation Parameters of Network Simulation 2

| Type | Parameter |
|---|---|
| Channel Type | Wireless Channel |
| Radio Propagation | Two Ray Ground |
| Network Interface | Wireless interface |
| MAC Type | 802.11 |
| Interface Queue Type | Queue/<br>Drop Tail/<br>Priqueue |
| Link Layer type | Link Layer |
| Antenna Model | Omni Antenna |
| Number of mobile nodes | 30-100 |
| Routing Protocol | AODV/DSR/MMBCR/MEL-<br>AODV/ALMEL-AODV |
| X dimension topology | 1000 |
| Y Dimension Topology | 1000 |
| Simulation End | 100 |
| Maximum packet in queue | 50 |
| Type of Traffic source | Constant Bit Rate |

`

### 4.4. The Simulation Assumptions

The following assumptions are considered when building the Tcl script for simulation:

1. For simplicity, all flows in the system are assumed to have the same type of traffic source. Each sender has constant bit rate (CBR) traffic with the rate of data rate/number of stations packet per second;
2. Each node have different random movement position to make sure data packet still be able delivered to destination while intermediate node move out of range.
3. Random initial energy is assigned to each node in scenario file.

### 4.5. Performance Metrics

The thesis focuses on three performance metrics which are quantitatively measured. The performance metrics are important to measure the performance and activities that are running in NS-2 simulation. The performance metrics are:

#### 4.5.1. First Dead Lifetime

First dead lifetime defined by the time when the first node died occurred. (T.Girici & A.Epheremides, 2002) After death of the first node, other nodes are loaded more heavily and deaths occur much faster. Therefore maximizing the time until the death of the first node is crucial for ad hoc wireless networks. Network lifetime is important performance metrics to evaluate energy efficiency of existing routing protocol and proposed routing scheme. Higher network lifetime is better to reduce the cost of battery power to successfully transmit packets to destination. The significance of using first dead lifetime as one of measurement for network lifetime is because other nodes will be more overloaded if one of the nodes dies.

*First dead lifetime = Time (first dead node)* *(1)*

Expiration of lifetime is lifetime of connections where it is measured by the duration of time when source node start transmitting packets to the destination node before the connection is expired and unable to reinitiate connection with the destination node (Cano & Kim, 2002).

*Expiration Time of Connections= Time (CBR recv) - Time (CBR sent)* *(2)*

Percentage of Depleted Node is different from above metrics which considers the number of dead nodes at the end of simulation over the total number of nodes in a network (Butty, 2007). The higher number of depleted nodes will cause low performance of network because dead node unable to receiving or transmitting packet from any neighbor nodes. Thus, source will has low possibility of delivering data packet to the destination. This metric describes the percentage of depleted node: the lower the percentage of depleted nodes the better the application performance.

$$Percentage\ of\ Depleted\ Node(\%) = \frac{Total\ number\ of\ depleted\ node}{All\ number\ of\ nodes} \times 100 \quad (3)$$

### 4.6. Simulation Result Analysis

This section will focus on analysis of simulation results on first dead lifetime, expiration time of connections and percentage of depleted node in term mobility.

### 4.6.1. First Dead Lifetime

The first dead lifetime simulation is extended from Mornach research group at Carnegie Mello University's NS-2 simulation which include: node mobility, a realistic physical layer that includes a radio propagation model, radio network interfaces and IEEE 802.11 Medium Access Control (MAC) protcol using Distributed Coordination Function (DCF). The radio network interace card (NIC) model is based on the Lucent WaveLan. Node movement was modeled using the Random Waypoint model.

The simulation incorporate different number of nodes scenarios range from 30 to 100 nodes at same size of topology with pause time of 2.0 seconds. The size of the topology network is 1000 × 1000 m. Each node move with a low mobility speed of 1ms. The source generates 2 packets per second with 100 second simulation times. Random connections were established using CBR trafic with packet size of 512 bytes. In order to accurately simulate the network lifetime, the battery capacity has to be taken into consideration. So, network nodes will be assigned with different battery capacity in the initial stage.

When the battery capacity of the node reaches zero units, the correspodding node cannot take part any more in the communication, and is regarded as dead. In addition, since the simulaton is focusing on network lifetime, the energy level of the source and destination nodes will not be considered.Thus source can continue to establish a new route with destination node if the existing route is disconnected. Each node has a radio propagation range of 250 meters with fixed transmit power.

Table 4.3 shows the comparison result for different routing protocols on different number of nodes range from 30 to 100 accordingly. The routing protocols that are compared and analyzed in order to generate the following result are DSR, AODV, MMBCR, MEL-AODV and ALMEL-AODV.

Table 4.3 First Dead Lifetime (S) Vs Number Of Nodes

| Node | DSR | AODV | MMBCR | MEL-AODV | ALMEL-AODV |
|---|---|---|---|---|---|
| 30 | 14.07s | 12.80s | 17.68s | 13.71s | 18.55s |
| 40 | 26.76s | 23.67s | 30.30s | 31.13s | 31.29s |
| 50 | 24.87s | 22.87s | 25.92s | 26.52s | 29.05a |
| 60 | 24.55a | 22.36a | 25.46a | 25.81s | 29.82s |
| 70 | 26.31s | 24.26s | 26.86s | 27.35s | 29.54s |
| 80 | 23.44s | 20.36s | 24.15s | 25.04s | 30.05s |
| 90 | 22.29s | 20.57s | 29.04s | 29.59s | 37.34s |
| 100 | 27.57s | 26.93s | 27.62s | 33.25s | 34.20s |

The perfomances of various conventional routing protocols are compared in the Figure 4.2. The routing protocol with longer first death lifetime is better in this simulation. From the graph, it shows that the Dynamic Source Routing (DSR) performs slightly better than the Ad Hoc Distance Vector (AODV) for node range of 30 to 100 nodes in first node dead lifetime simulation.

The DSR and AODV protocols both use on-demand route discovery, but with different routing mechanisms. In particular, DSR uses source routing and route caches, and does not depend on any periodic or timer-based activities. DSR exploits caching aggressively and maintains multiple routes per destination. AODV, on the other hand, uses routing tables, one route per destination, and destination sequence numbers, a mechanism to prevent loops and to determine freshness of routes. DSR often perform better than AODV in low velocity movement environment i.e, 1m/s because the chances of finding a route in one of the caches is much higher. DSR also have alternative routes which stored in the node's cache if there are breakup link between source and destination node.

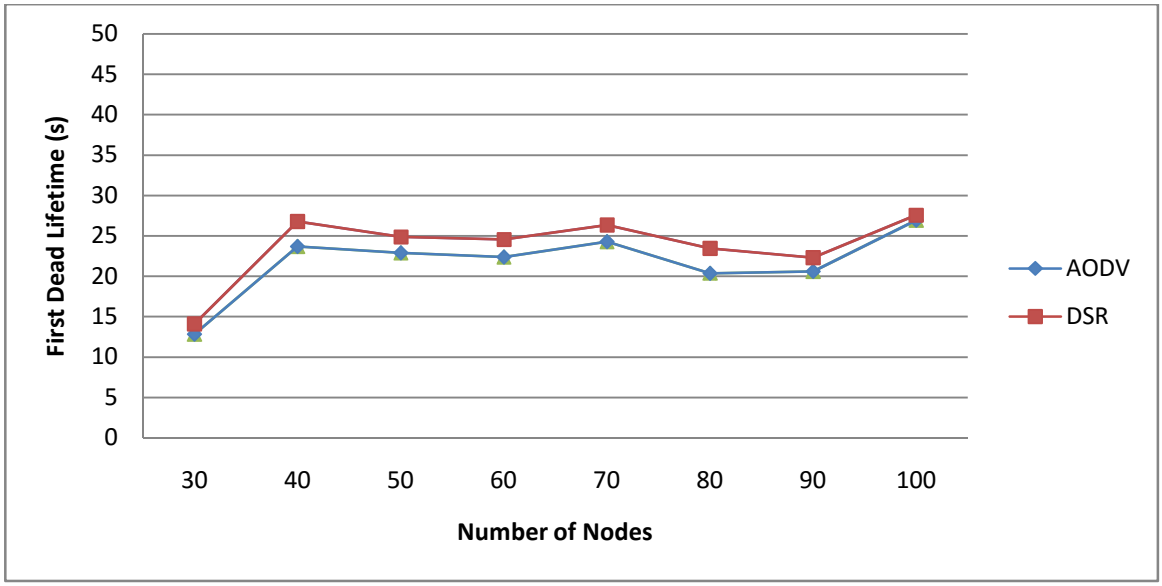


Figure 4.2 Comparison between DSR, AODV On First Dead Lifetime

The result in Figure 4.3 shows that the ALMEL-AODV has better performance because it reduces the number of rebroadcasting and thus reduces energy wastage. Beside that, ALMEL-AODV delay broadcasting of control packets to neighbour nodes based on its battery cost. By using delaying method, nodes with low battery cost are mostly selected as forwarding nodes

during link establishment. As it consider total remaining battery capacity, it can reduce the total transmission power by utilizing routes with more hops having short transmission ranges. In addition, MEL-AODV has slightly poorer performance if compared to MMBCR because intermediate nodes' battery cost are not being taken put into consideration during route establishment. However, the MEL-AODV performs better than other conventional protocols because it consider energy metric before deciding which path for data packet forwarding.

From the graph, we can also concludes the performances of the ALMEL-AODV is more significance under larger network environment because the source and destination nodes can have more neighbors to help forwarding and receiving the packet. Hence we can analyse from the graph that the time for the first node to die is faster when there are less than 40 nodes in the network topology. This mainly due to the less chances of successful establishment of connection between transmitting and receiving nodes in sparse environment.

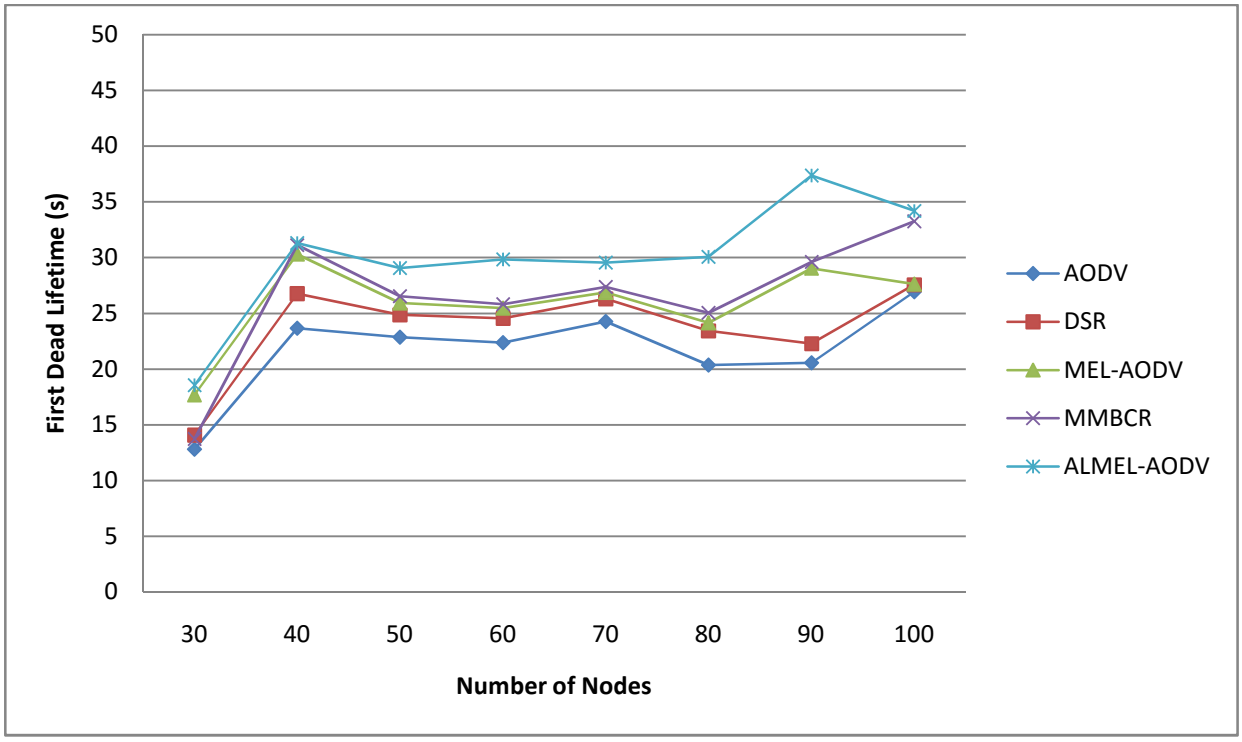


Figure 4.3 Comparisons between Existing Protocols and Proposed Schemes On First Dead Lifetime

### 4.6.2. Expiration Time of Connections

Expiration time of connection is one of performance ration to define the lifetime of connection between the source and the destination nodes. This lifetime of connection captures the effects of disconnections due to lack of possible routes (Dongkyun, Garcia Luna Aceves, & Obraczka, 2002). The simulation also choose different population of nodes range from 30 to 100 nodes to measure the performance of different routing protocols. Table 4.4 also show quantitative result of different routing protocols with the range of nodes from 30 to 100 nodes. The table 4.4 is analysed and drawn in different graphs in order to show the performance comparison between different routing protocols graphically.

Table 4.4 Expiration Time of Connections Vs Number of Nodes

| Number of Nodes | DSR | AODV | MEL-AODV | MMBCR | ALMEL-AODV |
|---|---|---|---|---|---|
| 30 | 44.24s | 33.03s | 43.97s | 43.99s | 40.31s |
| 40 | 55.08s | 48.68s | 55.56s | 58.08s | 58.91s |
| 50 | 63.46s | 62.06s | 63.75s | 63.33s | 63.95s |
| 60 | 82.35s | 82.34s | 83.26s | 83.22s | 83.32s |
| 70 | 86.01s | 82.70s | 86.21s | 87.04s | 87.13s |
| 80 | 84.90s | 84.25s | 84.90s | 85.44s | 86.32s |
| 90 | 93.83s | 93.76s | 93.83s | 95.28s | 95.55s |
| 100 | 93.17s | 91.22s | 93.17s | 94.92s | 95.11s |

The result in Figure 4.4 shows that slight better performance has been achieved by the DSR compared to AODV in term of expiration time of connections. The reason why DSR has outperfomed in most topology is due to higher chances of routes to destination available on node cache. Higher expiration time of connection increase the time for source node to communicate with destination during data transmission. This greatly improves efficiency of network connection.

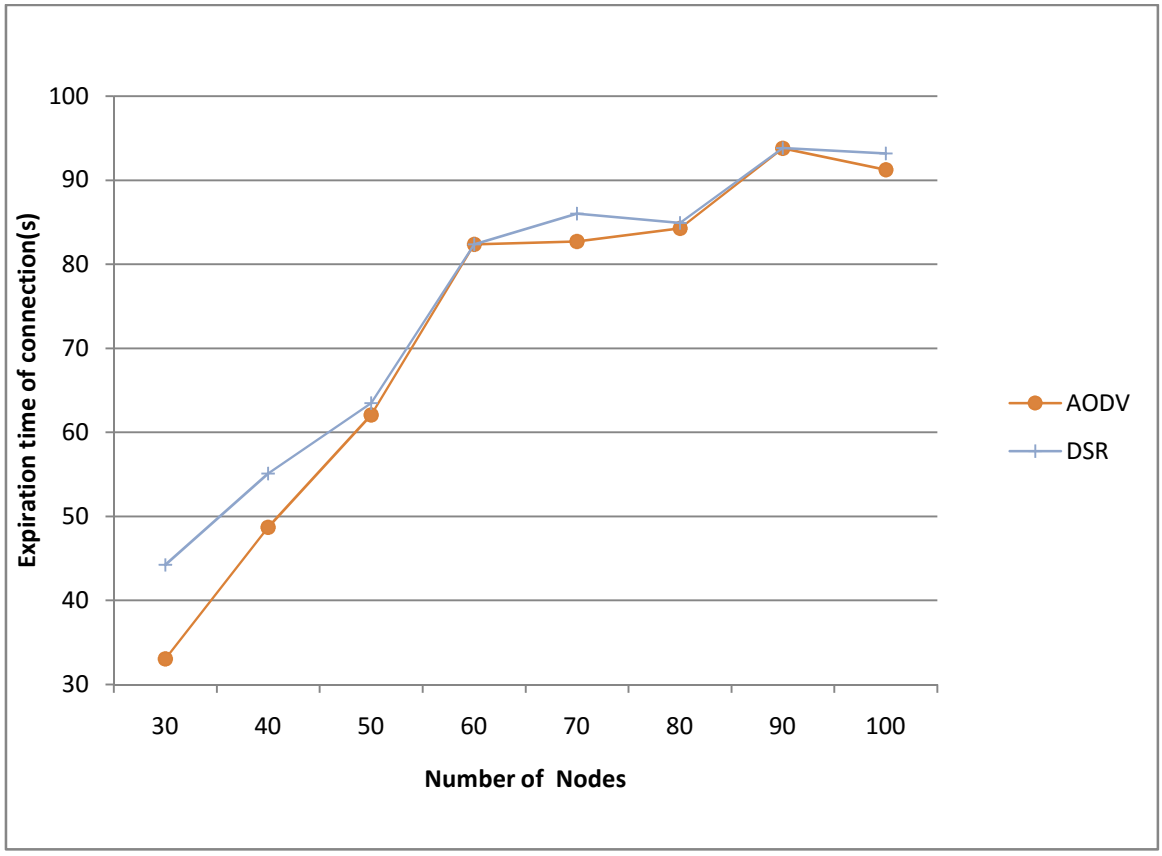


Figure 4.4 Comparison between DSR And AODV on Expiration Time Of Connection

Figure 4.5 shows that the ALMEL-AODV is performing better in the expiration time of connections simulation as compared to other schemes. From the aspect of expiration time of connections, since there exist many other possible paths in denser networks during the finding new routes process, so the graph show that as the number of nodes increases, it will improve the expiration time of connections.

Although all schemes have a slightly lower expiraton time of connection when number of nodes are below 40 nodes, their performance also increase accordingly. As the network size increases, the expiration of network connection also increases in general. This is because fewer numbers of nodes can affect the longevity of network connection. In general, the graph

shows that MEL-AODV has slight performance improvement than DSR and AODV protocol. MEL-AODV spent some time before deciding a better energy route to route data packet to the destination.

However, MMBCR outperform MEL-AODV slightly as it first finds the node having minimum battery capacity in each of the possible routes and selects the route having the maximum value among the selected routes. That means the route having maximum lifetime is selected. ALMEL-AODV is different because it based on current node energy state to delay forwarding or broadcasting the control packets. Hence, there will be higher remaining capacity nodes being selected as forwarding nodes during path establishment. By taking total remaining power into consideration, the expiration time can be improved.

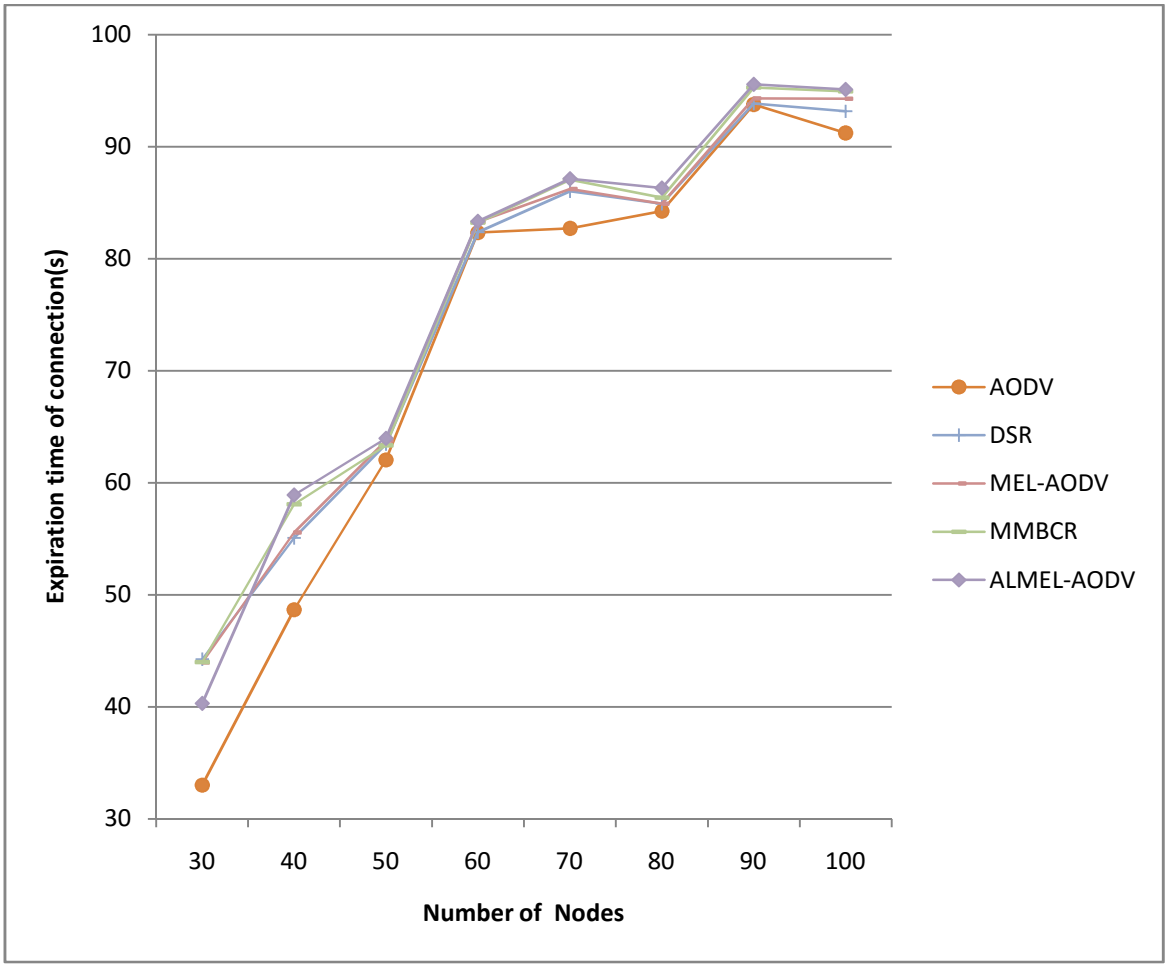


Figure 4.5 Comparisons between Existing Protocols and Proposed Schemes on Expiration Time of Connection

### 4.6.3. Percentage of Depleted Node

The percentage of depleted node is another important performance ration used to define the number of dead node over total number of nodes in one network topology. Our objective is to conserve node energy and to reduce the number of depleted nodes at the end of simulation. Less number of depleted nodes in one topology will increase the percentage of successful route establishment betweeen source and destination.

Table 4.5 shows the percentage of depleted node on the table by comparing different routing protocols on NS-2. The simulation is run on different number of nodes range from 30 to 100 nodes respectively.

Table 4.5 Percentage of Depleted Node vs number of nodes

| Number of Nodes | DSR | AODV | MEL-AODV | MMBCR | ALMEL-AODV |
|---|---|---|---|---|---|
| 30 | 57% | 60.33% | 56.79% | 56.44% | 55.89% |
| 40 | 37.42% | 41.17% | 36.58% | 36.08% | 35.25% |
| 50 | 24.46% | 28.93% | 24.46% | 23.53% | 22.73% |
| 60 | 22% | 27.78% | 20.11% | 19.72% | 19.66% |
| 70 | 18.10% | 25.95% | 16.76% | 16.62% | 16.57% |
| 80 | 15.63% | 15.96% | 15.63% | 15.53% | 15.46% |
| 90 | 13.44% | 14.70% | 12.81% | 12.11% | 11.30% |
| 100 | 14.13% | 14.3% | 13.63% | 12.17% | 11.97% |

From Figure 4.6, we can see that DSR is outperform AODV in reducing the number of depleted node at the end of simulation and lower percentage of depleted node is better. DSR is more effective compared to others conventional protocols because each mobile node maintains its own route cache that contains the source routes destined for other mobile nodes. The purpose of route cache is to reduce unwanted traffic surge due to route discovery procedure as the query is propagated throught the network. The graph show that the percentage of depleted nodes gradually decrease as the number of nodes in the ad hoc network

increases. Less number of nodes in one topology will lead to higher number of unsuccessful transmission between source and destination node. Source node waste most of its energy to find limited avaiable route to the destination by rebroadcasting route request. Increasing number of broadcasting will affect other nodes's valuable remaining energy.

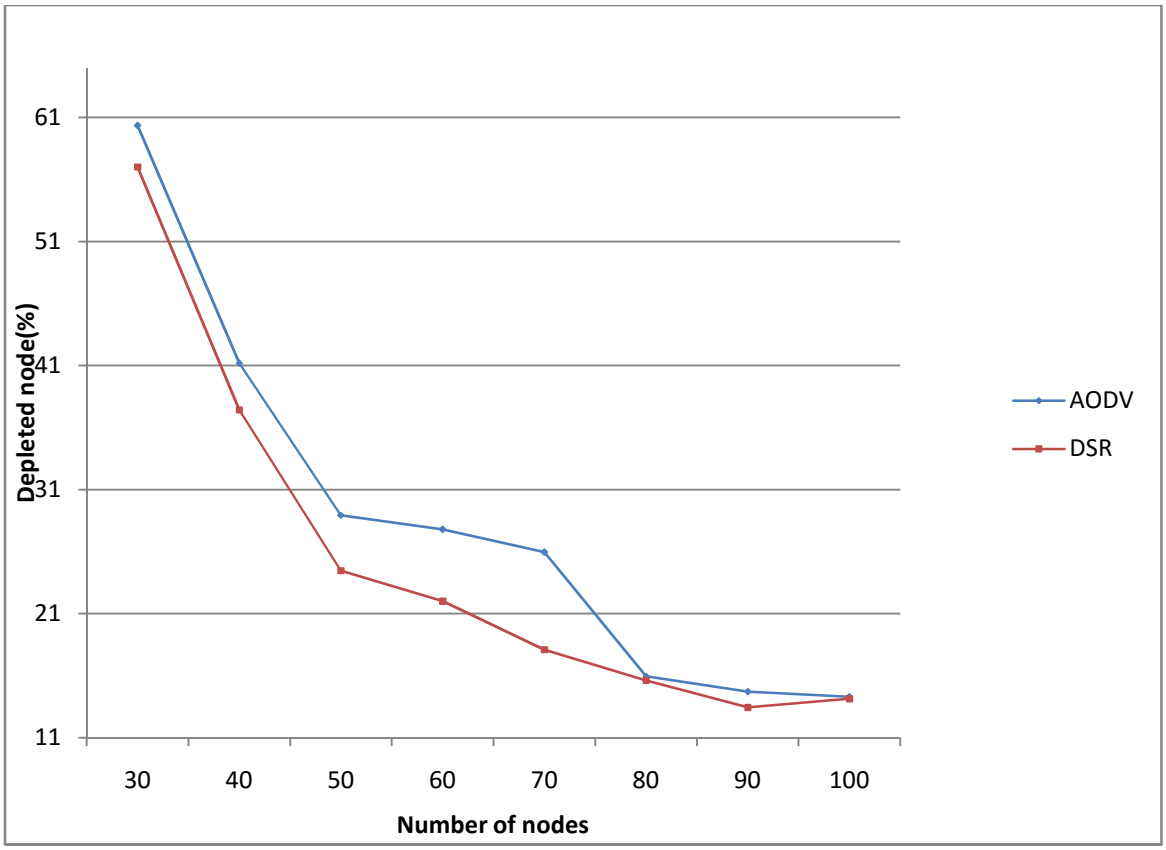


Figure 4.6 Comparison between DSR And AODV on Percentage Of Depleted Node

As we can see from Figure 4.7, the proposed scheme MEL-AODV and ALMEL-AODV have better performance than AODV and slightly better compare to DSR. This is because MEL-AODV and ALMEL-AODV choose maximum energy path as main route selection to reduce the number of rebroadcast which may waste nodes' energy. Furthermore, the schemes prevent node with nearly depleted energy from involving in route construction. Neighbor

nodes will get unwanted energy usage if receiving route discovery message from less energy node as it may cause link breakage and retransmission. However, MMBCR performs slightly better than MEL-AODV as it tries to choose a path whose weakest node has the maximum battery capacity among the other routes. On the other hand, there is no guarantee that MMBCR minimizes the total energy consumed over a path.

ALMEL-AODV has the least percentage of depleted node compared to other schemes. Beside selecting a better energy path, it also allow data packet to route more than one path during entire route construction. As a result, the burden of energy usage can be evenly distributed to more nodes in order to successfully send data packet to destination. ALMEL-AODV also employ delaying method during broadsting route request. If intermediate node's battery capacity is lower than other nodes, it will have longer time of delay during broadcasting of RREQ.

Hence, intermediate node with lower battery cost will be selected as forwarding node during route establishment. From Figure 4.7, we can again conclude that less number of nodes in same size of topology has less percentage of depleted nodes compared to more number of nodes. Less number of nodes cause less involvement of some nodes in broadcasting control packet or transfering data packet as some of nodes are out of range from source and destination.

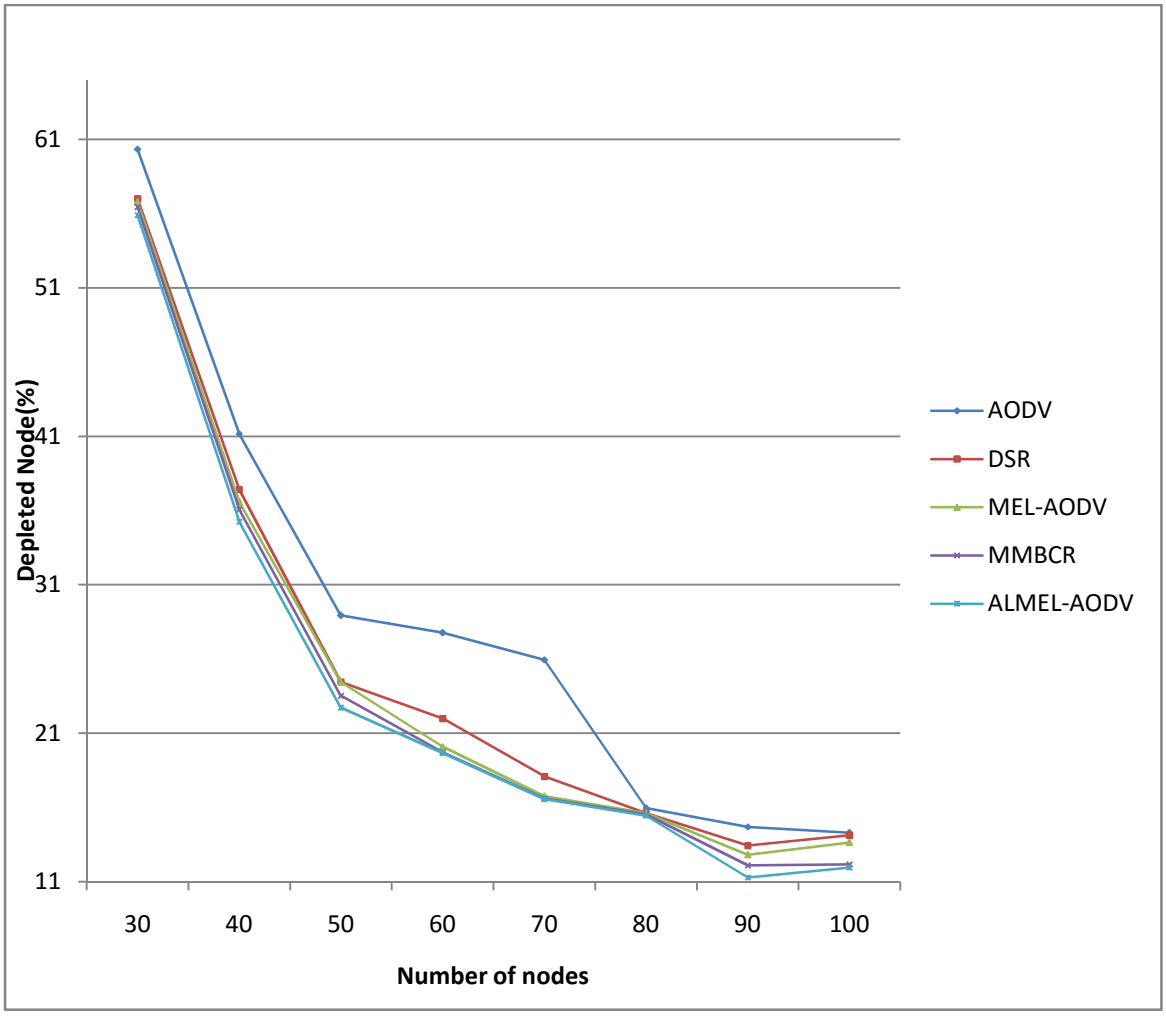


Figure 4.7 Comparisons between Existing Protocols and Proposed Schemes on Percentage of Depleted Node

### 4.7. Summary

In this chapter, we know that network performance evaluation is needed to analyze performance of our schemes and existing protocols. Thus, the most suitable technique is chosen to evaluate the network performance. In this research, we choose network simulation technique because it has better evaluation characteristic compared to analytical modeling. We only choose network simulator 2 (NS-2) among others simulator in the market because it is popular software to evaluate wireless ad hoc network.

The next part explains about Simulation Model. In NS-2, simulation model with different parameters and settings is used to get accurate and comparable result on different protocol schemes. In order to do the comparison, three performance metrics were chosen such as first dead lifetime, expiration time of connections and percentage of depleted node. Besides that, we also describe deeply on how to install Network Simulator-2 and working with trace files for collecting the results. In order to run the simulations, appropriate traffic and scenario should be generated and selected to do network simulation comparisons

This chapter described about the analysis of the conventional routing protocols, existing energy efficiency scheme and proposed schemes. Using the performance metrics as measurements, the results of the routing protocols was plotted using the graph. The analysis was carried out from the plotted graph and discussion and conclusion was made at the end of analysis.

From the graph it was obvious to show that the proposed schemes always have better performance over other routing protocols. Proposed schemes confirmed to be better

performing routing protocol in saving battery energy in a dense network. When there are breakage on the link, there are always have backup route found on the routing table to continue forwarding the packet. Compared to conventional protocol, the used of backup route can help to reduce the unwanted rebroadcasting of route discovery which may depleted the battery of forwarding node.

In sparse network, energy management is critical issue for the deployment of this network because the nodes are small battery power devices. Some nodes may be especially critical for forwarding these packets because they provide the only path between certain pair of nodes. ALMEL-AODV control unwanted broadcasting of RREQ and balance the node's energy consumption. As a result, we can make conclusion that proposed protocol is a most suitable protocol that can be used to prolong network lifetime and improving nodes' battery capacity.

# CHAPTER 5

# CONCLUSIONS & FUTURE WORK

Wireless ad hoc network does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in infrastructure wireless networks. The network is ad-hoc because each node is willing to forward data for other nodes, and so the determination of which nodes forward data is made dynamically based on the network connectivity.

Comparison of three routing protocols DSR, AODV, MMBCR and proposed schemes MEL-AODV and ALMEL-AODV have been made on this thesis. We use popular network simulator tool (NS-2) to show that our simulation results meet the expected results based on theoretical analysis. As our proposed schemes include energy metric, so they have better performance compared to conventional routing protocols. From the analysis of conventional routing protocols, DSR has better performance than AODV because it maintains route cache to reduce unwanted broadcast. For our proposed scheme, ALMEL-AODV outperforms MEL-AODV and MMBCR because it applies delaying method and does not wait for more routes to come before sending data packet.

From this research, we prove that by considering remaining energy metric and reduce unwanted broadcasting in AODV will increase network lifetime. Overall, proposed schemes have better performance in dense network. From analysis, ALMEL-AODV prolong first node dead time up to 81% compared to AODV. In addition, 5% increased on expiration time of connection when there are more nodes in same topology. ALMEL-AODV reduces the percentage of depleted node at the end of simulation up to 36% compared to current AODV.

For the future work, this research will not only investigate the comparison between conventional protocols DSR, AODV with our proposed schemes. Besides comparing existing energy efficiency routing protocol MMBCR, we will also compare other energy related routing protocols in research area.

There are a lot of works done by other researchers to improve energy efficiency and battery lifetime in wireless ad hoc network. BER and throughput analysis will also be considered in future work to further improve the network performance. We will also survey different settings of network environment while simulating our proposed schemes. Different network settings such as mobility speed and topology size may give different comparison results for our analysis.

## REFERENCES


Aaron, A., & Weng, J. (2010) *Performance Comparison of Ad-hoc Routing Protocols for Networks with Node Energy Constraints*. Retrieved October 20, 2015, from Stanford Network Group: http://ivms.stanford.edu.

Abolhasan, M., Wysocki, T., & Dutkiewicz, E. (2004). A review of routing protocols for mobile ad hoc networks. In *International Journal of Information and Education Technology,* 3(1), 3-4.

Anupama, M., & Sathyanarayana, B. (2011). Survey of Cluster Based Routing Protocols in Mobile Ad hoc Networks. In *International Journal of Computer Theory and Engineering*, 3(6), 11-13.

Basagni, S., Conti, M., Giordano, S., & Stojmenovic, I. (2004). Mobile Ad Hoc Networking. *IEEE Press*, *Wiley Interscience Publication*, 46-47.

Bharghavan, V., Demers, A., Shenker, S., & Zhang, L. (1994). MACAW: A media access protocol for wireless LAN's. In *Proc. of the SIGCOMM '94 Conference on Communications Architectures, Protocols and Applications*, 2, 212–225.

Butty, a. (2007). PANEL: Position-based Aggregator Node Election in Wireless Sensor Networks. In *Proc. of IEEE MASS*, 721-724, Pisa, Italy: IEEE.

Cano, & Manzoni. (2002). A low power protocol to broadcast real-time data traffic in a clustered ad hoc network. *Global Telecommunications Conference. GLOBECOM '01* IEEE, 6, 37-42.

Cano, J., & Kim, D. (2002). Investigating Performance of Power-Aware Routing Protocols for Mobile Ad Hoc Networks. In *Proc. of IEEE/ACM MASCOTS Workshop (Mobility and Wireless Access Workshop)*, 623-638, USA: IEEE.

Cao, L., Dahlberg, T., & Wang, Y. (2007). Performance Evaluation of Energy Efficient Ad Hoc Routing Protocols. *2007 IEEE International Performance, Computing, and Communications Conference*, 69-72, Italy: IEEE.

Castaneda, R., & Das, S. R. (1999). Query Localization Techniques for On-demand Routing Protocols in Ad Hoc Networks. In *Proc. of the 5th International Conference on Mobile Computing and Networking (MobiCom'99)*. ACM.

Chakrabarti, S., & Mishra, A. (2001). QoS Issues in ad hoc Wireless Network. *2001 IEEE Communications Magazine*, 6(5): 21-23

Chen, B., Jamieson, K., Balakrishnan, H., & Morris, R. (2001). SPAN: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks. In *Proceedings of the 7th annual international conference on Mobile computing and networking*, 85-96, Rome, Italy: ACM.

Chung, J., & Claypool, M. (n.d.). *NS by Example*. Retrieved October 16, 2013 from Worcester Polytechnic Institute (WPI): http://nile.wpu.edu/NS/purpose.

CMU Monarch Group. *CMU Monarch extensions to the NS-2 simulator*. Retrieved November 5, 2000 from CMU Monarch Group: http://monarch.cs.cmu.edu/cmu-ns.html.

Corson, S., & Macker, J. (1999). Mobile Ad Hoc Netwroking (MANET): Routing Protocol Perfomance Issues and Evaluation Consideration. Request For Comments (RFC) 2501. Internet Engineering Task Force: MANET Workign Group.

Couto, D. D., Li, J., Blake, C., Lee, H., & Morris, R. (2001). Capacity of Wireless Ad Hoc Wireless Networks. *Proceedings of the 7th annual international conference on Mobile computing and networking,* 61–69, Rome, Italy: ACM

Dhandekar, R. C. (2015). Simulation Based performance analysis in wireless. *International Journal For Engineering Applications*, 7(3): 61-70

Dongkyun, K., Garcia Luna Aceves, J., & Obraczka, K. (2002). Performance Analysis of Power-Aware Route Selection Protocols in Mobile Ad Hoc Networks. *Proc. IEEE Networks 2002 Conf,* 2, 17-22.

Fall, K., & Varadhan, K. *The VINT Project.* Retrieved October 20, 2013, from The Virtual InterNetwork Testbed Group: http://www.isi.edu/nsnam/ns/ns-documentation.html.

Haas, Z. J., & Pearlman, M. R. (1998). The Performance of Query Control Schemes for the Zone Routing Protocol. *In Proc. of the ACM SIGCOMM '98 Conference*, 7, 167–177.

Hughes, J. *Network Simulation Introduction*. Retrieved February 20, 2009 from The Standard Network Group: http://www.openxtra.co.uk/articles/network-simulation.

Johansson, P., Larsson, T., Hedman, N., Mielczarek, B., & Degermark, M. (1999). Routing Protocols for Mobile Ad-hoc Networks. A Comparative Performance Analysis. In *Proc. of the Fifth International Conference on Mobile Computing and Networking (MobiCom'99)*, ACM.

Johnson, D. B., & Maltz, D. A. (1996). *Dynamic Source Routing.* Ad Hoc Wireless Networks, *Mobile Computing, T. Imielinski and H. Korth (Eds.)*, Chapter 5, pp. 153–181, Kluwer Academic Publishers.

Johnson, D. B., Maltz, D. A., & Broch, J. (2001). *DSR:* The Dynamic Source Routing Protocol for Multihop Wireless Ad Hoc Networks. *Ad Hoc Networking, C. E. Perkins (Ed.)*, pp. 139–172, Addison-Wesley.

Jubin, J., & Tornow, J. (2002). The DARPA Packet Radio Network Protocols. *Proceedings of IEEE Networks 2002 Conf*, 17-22, Paris, France: IEEE.

Karadge, P. S., & Dr Sankpal, S. (2013). A performance comparison of energy efficient AODV protocols in mobile ad hoc networks. *International Journal of Advanced Research in Computer and Communication Engineering,* 2(1), 13-15, India: IEEE.

Kathiravan, D. K., Divya, V., & Selvi, D. S. (2009). Energy Efficient Integrated Routing Protocol for MANETs. *Fifth International Conference on Mobile Ad-hoc and Sensor Networks*, 7, 23-25, Fujian: IEEE.

Khattak, M., Iqba, K., & Khiyal, S. (2008). Challenging Ad-Hoc Networks under Reliable & Unreliable Transport with Variable Node Density. *Journal of Theoretical and Applied Information Technology*, 7(3), 76-78.

Ko, Y.B., & Vaidya, N. (1998). Location-Aided Routing (LAR) in Mobile Ad Hoc Networks. *In Proc. 4th International Conference on Mobile Computing and Networking (MobiCom'98)*, 66–75, New York: ACM.

Li, Q., Aslam, J., & Rus, D. (2001). Online power-aware routing in wireless ad-hoc networks. *In The 7th Annual International Conference on Mobile Computing and Networking (MOBICOM 2001)*, 2-5, Rome, Italy: ACM.

M.Stemm, & Katz, R. (1997). Measuring and reducing energy consumption of network interfaces in hand-held devices. *In IEICE Transactions on Communications*, 7, 1125-1131, Boston: ACM.

Mansouri, S., Pakravan, H., & M.R. Sharif Univ. of Technol, T. (2007). Network Coding Based Reliable Broadcasting in Wireless Ad-hoc Networks. *2007 15th IEEE International Conference on Networks,* 523-530, Adelaide: IEEE.

Memarzadeh, H., Dehghan, M., & Jabbehdari, S. (2010). A New Quorum-Based Power Saving Protocol to Maintain QoS for MANETs with Burst Traffics. *IEEE 24th International Conference on Advanced Information Networking and Applications Workshops*, 6, 23-44.

Ogier, R. G., Templin, F. L., & Lewis, M. G. (2004). Topology dissemination based on reverse-path forwarding (TBRPF). *IETF RFC3684 Experimental Standard*.

P. Sinha, R. S., & Bharghavan, V. (1999). CEDAR: a Core-Extraction Distributed Ad hoc Routing Algorithm. *IEEE Journal on Selected Areas in Communications*, 4(2), 42-43.

Patel, B., & Dubey, P. (2012). Various Routing Protocols Performance Analysis for WiMAX Network. *International Journal of Management, IT and Engineering*, 3(5), 21-25.

Pearlman, M., & Deng, J. (2002). Elective Participation in Ad Hoc Networks Based on Energy Consumption. *Proceedings of IEEE Globecom/SAWN,* 43-47, Chicago: IEEE

Perkins. (2001). *Ad Hoc Networking:* Addison-Wesley,1-28.

Perkins, C. E., & Bhagwat, P. (1994). Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers. *In Proc. of ACM SIGCOMM Conference on Communications Architectures, Protocols and Applications,* 234-244, London, England: ACM.

Perkins, C. E., & Royer, E. M. (2001). The Ad Hoc On-Demand Distance-Vector Protocol (AODV). In C. E. (Ed.). Addison-Wesley.

Perkins, C. E., & Royer, E. M. (1999). Ad-Hoc On Demand Distance Vector Routing. *In Proc. 2nd IEEE Workshop on Mobile Computing Systems and Applications*, 90–100, IEEE Computer Society.

Ramanathan, R., & Rosales-Hain. (2002). Topology control of Multihop Wireless Networks using transmit power adjustment. *IEEE INFOCOM 2000*, 2, 404-413, Tel Aviv: IEEE.

Ramanathan, S., & Streenstrup, M. (1996). A Survey of Routing Techniques for Mobile Communication Networks. ACM/Baltzer Mobile Networks and Applications, special issue on Routing in *Mobile Communication Networks*, 1(2): 89-104.

Rodoplu, V., & Meng, T. H. (1999). Minimum energy mobile wireless networks. *IEEE Journal on Selected Areas in Communications*, 17(8), 1333-1344, NJ, USA: ACM.

Singh, S., Mke Woo, S., & Mghavend, C. (1998). Power aware routing in mobile ad hoc networks. *MobiCom '98 Proceedings of the 4th annual ACM/IEEE international conference on Mobile Computing and Networking*, 181-190, New York, USA: ACM.

Subbarao, M. W. (1999). Dynamic Power-Conscious Routing for MANETs: An Initial Approach. *Proceedings of the 50th IEEE Vehicular Technology Conference, VTC,* 2, 1232–1237, Amsterdam, The Netherlands.

Sundrani, K., Awasthi, L., & Govil, M. (2005). A Novel Scheme for Location Management in Ad hoc Networks. *ACCST Research Journal*, 7(2): 199-204.

Surayati, N., Usop, M., & Ahm, A. A. (2009). Performance Evaluation of AODV, DSDV and DSR Routing Protocol in Gird Environment. *IJCSNS International Journal of Computer Science and Network Security*, 9(7): 732-737.

T.Girici, & A.Epheremides. (2002). Joint routing and scheduling metrics for ad hoc wireless networks. *Proc. of the 2002 Asilomar Conference on Signals, Systems and Computers*, 2, 1155-1159, Pacific Grove, CA, USA: IEEE.

Talook, V., Marques, H., Rodriguez, J., Água, H., Blanco, N., & Campos, L. (2010). An Energy Efficient Flat Routing Protocol for Wireless Ad Hoc Networks. *2010 Proceedings of 19th International Conference on Computer Communications and Networks (ICCCN).*

Tamilarasi, M., & Palanivelu, T. (2008). Integrated Energy-Aware Mechanism for MANETs using On-demand Routing. *International Journal of Computer and Information Engineering*, 2(10): 77-79.

Traganitis, V. A. *Extending the Dynamic Source Routing (DSR) Protocol to Deal with Node Selfishness in Ad Hoc Networks*. Retrieved January 24, 2007 from http://www.ics.forth.gr/~angelak/files/AngelakTragani_DSR_selfishness.pdf

Widmer, J., Fragouli, C., & Boudec, J.-Y. L. (2005). Low-complexity energy efficient broadcasting in wireless ad-hoc networks using network coding. *Proc. Workshop on Network Coding, Theory, and Applications.*

Xie, B., Kumar, A., Agrawa, D., & Srinivasan, S. (2006). Secured Macro/Micro-Mobility Protocol for Multi-hop Cellular IP. J. of *Pervasive and Mobile Computing*, 2(2): 111-136.

Xu, J., Heidemann, & Estrin, D. (2001). Geography-informed energy conservation for ad hoc routing. *Proceedings of The Seventh Annual ACM International Conference on Mobile Computing and Networking*.

Y.F, W., & Liao, W. (2011). Minimum power multicast algorithms for wireless networks with a Lagrangian relaxation approach. *International Journal of Computer and Information Engineering*, 17(6): 1401-1421.

Zhonglin, H., & Yuhua, H. (2010). Study on Key Technologies of MANET. *2010 International Conference of Information Science and Management Engineering*, 112-115, Xi'an: IEEE.

Zhu, Y., Huang, M., Chen, S., & Wang, Y. (2010). Cooperative energy spanners: energy-efficient topology control in cooperative ad hoc networks. *2010 IEEE Transactions on Mobile Computing,* 231-235, Shanghai: IEEE.

Zhu, Y., Huang, M., Chen, S., & Wang, Y. (2012). Energy-efficient topology control in cooperative ad hoc networks. *IEEE Transactions on Parallel and Distributed Systems*, 23(8), 1480-1491.