ADDIS ABABA

UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

ACTIVE COMMUNICATION ENERGY EFFICIENT ROUTING PROTOCOL OF MOBILE AD HOC NETWORKS (MANETS)

By

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A thesis submitted to the school of Graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Electrical and Computer Engineering

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List of Acronyms

ACK	Acknowledgement
AODV	Ad Hoc On-demand Distance Vector Routing
CA	Collision Avoidance
CBR	Constant Bit Rate
CMMBCR	Conditional Max-Min Battery Capacity Routing
CMU	Carnegie Mellon University
CSMA	Carrier Sense Multiple Access
CTS	Clear-to-Send
DSDV	Destination-Sequenced Distance Vector Algorithm
DSR	Dynamic Source Routing
ECSDD	Energy Consumption per Successful Data Delivery
EEDSR	Energy Efficient DSR
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
LPR	Lifetime Prediction Routing
MAC	Medium Access Control
MANET	Mobile Ad Hoc Network
MBCR	Minimum Battery Cost Routing
MMBCR	Min-Max Battery Cost Routing
MRPC	Maximum Residual Packet Capacity
MTP	Minimum Transmission Power
MTPR	Minimum total power routing
NAM	network animator
NL	Network Lifetime
NS-2	Network Simulator-2
OLSR	Optimized Link State Routing

OS	Operating System
OSPF	Open Shortest Path First
OTCL	Object oriented TCL
PDF	Packet Delivery Fractions
PSR	Power-aware source Routing
QoS	Quality of Service
RC	Route Cost
RERR	Route Error
RF	Radio Frequency
RIP	Routing Information Protocol
RREP	Route Reply
RREQ	Route Request
RTS	Request To Send
SINR	Signal to Interference plus Noise Ratio
SMA	Simple Moving Average
TCL	Tool Command Language
TCP	Transmission Control Protocol
TORA	Temporally-Ordered Routing Algorithm
TRG	TwoRay Ground
VINT	Virtual InterNetwork Testbed
VRBE	Variance of Residual Battery Energy in Joules
WRP	Wireless Routing Protocol
ZRP	Zone Routing Protocol

Abstract

One of the main design constraints in mobile Ad Hoc networks (MANETs) is that they are power constrained. Hence, every effort is to be channeled towards reducing power. More precisely, network lifetime is a key design metric in MANETs. The typical MANET routing protocols of (AODV, DSR and DSDV) are shortest routing protocols, that is, the least hops but do not consider the energy efficiency of the routes.

Our goal in this thesis is to propose Active Communication Energy Efficient routing mechanisms and protocols, satisfying less energy consumption from the viewpoints of nodes and network. To achieve our goal, first, we studied the three typical MANET routing protocols (AODV, DSR and DSDV) using performance and energy aware metrics. The simulation results show that DSR outperforms the other two routing protocols in majority of the scenarios and evaluation metrics.

Our main contribution in this thesis is energy efficient routing protocol. It addresses energy aware link cost computation and route discovery. The link cost is derived based on energy aware parameters such as transmission power between the nodes, the residual battery energy of nodes, receiving power and queue length. The routing mechanism also addresses delay forwarding to minimize broadcast storm. This energy efficient routing protocol is named Energy Efficient Dynamic Source Routing (EEDSR). It modifies the Dynamic Source Routing (DSR) protocol by taking into consideration the results of the pre-simulation, the existing feature of DSR for implementation of the design, and the previous works on MANETs routing protocols.

Subsequently, we studied the performance evaluation of our proposition. The simulation results show that the energy efficient routing protocol, EEDSR outperforms the original DSR, in limited battery energized nodes. EEDSR saves about 25.97%-70.5% of ECSDD and prolongs the network lifetime about 15.74%-84.71% compared to DSR. In addition, EEDSR provides better PDF than DSR.

Keywords: Ad-Hoc, MANET, Active Communication, Energy Efficient, Transmission power control, DSR, and EEDSR

CHAPTER- 1: INTRODUCTION

1.1 Overview

The explosion of wireless communication and mobile devices in recent years has opened the door of research on self-organizing networks that do not require a pre-established infrastructure. Those spontaneous networks, normally called Ad Hoc networks. These networks provide mobile users with everywhere communication capacity and information access regardless of location.

The most important characteristic of such networks is the independence of any fixed infrastructure or centralized administration. An Ad Hoc network is capable of operating autonomously and is completely self-organizing and self-configuring. Therefore, it can be rapid and easily deployable. Another important property of an Ad Hoc network is multi-hop capability. Unlike the cellular networks, which are single –hop wireless networks, an Ad Hoc network does not guarantee that a mobile node can directly communicate with destinations all the time. A mobile node, which lies outside the transmission of its specific destination, would need to relay its information flow through other mobile nodes. This implies that mobile nodes in Ad Hoc networks bear routing functionality so that they can act both as routers and hosts. The Ad Hoc networks can be seen in to two categories whether dynamically changing their position or not, once create communication link. These are wireless sensor networks and Mobile Ad Hoc networks (MANETs). Wireless sensor networks' mobile nodes are deployed in large number on small area. Once the nodes are deployed, they are static. In Mobile Ad Hoc networks the nodes are dynamically change their position.

An Ad Hoc network can be used in an area where infrastructures for mobile communication are not available, probably due to high deployment costs or disaster destruction. The typical application of Ad Hoc networks includes battle field communication, emergency relief and extension of the coverage area of cellular networks [4]

Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. Ad-hoc routing algorithms broadly can be categorized into pro-active and on-demand routing algorithm. The on-demand routing algorithms initiate to find out the suitable route when a route is requested [18]. The pro-active routing algorithm exchanges routing information periodically and generates the routing table in advance of route request [15]. These protocols select the routes based on the metrics of minimum hop count.

Energy efficiency routing is of paramount significance for MANETs' design, since the mobile nodes in such networks are typically battery powered. Power failure of a mobile node does not only affect the node itself but also its ability to forward packets on behalf of others and thus the overall network lifetime [8]. For this reason, many research efforts have been devoted to prolong the mobile node battery capacity at different aspects. These aspects include communication energy consumption and Non communication energy consumption. Design and manufacturing of less energy consume components of mobile nodes such processors, memory and OS power management strategies [5, 6, 31], used to reduce non communication energy consumption. During communication, energy is consumed in either inactive state of communication or active communication states. The energy consumption of active communication is more significant than the others for high traffic environment. Energy efficient routing protocols are designed to formulate energy efficient active communications. Energy efficient active communications prolong the network life time. The network life time is defined as the time when a node runs out of its own battery power for the first time [40, 47]. The energy efficient routing protocols should consider the power consumption from the viewpoints of both the network and the node. Hence, active communication energy efficient routing protocols can be categorized into two based on their advance and role [8]:

- Transmission power control approach
- Load distribution approach.

For protocols that belong to the former category, the active communication energy can be reduced by adjusting each node's radio power just enough to reach the receiving node but not more than that. This transmission power control approach can be extended to determine the optimal routing path that minimizes the total transmission energy required to deliver data packets to the destination. The specific goal of the load distribution approach is to balance the energy usage of all mobile nodes by selecting a route with underutilized nodes rather than the shortest route. So that both approaches prolong the network life time in different ways. But one approach may result the negative of the other approach have been trying to solve. Hence, the two approaches are mutually contradicting each other with some extent.

In this thesis, firstly, we investigate the energy efficiency of existing well known MANET routing protocols (AODV, DSR, and DSDV) from viewpoint of the network and the node. We discuss the results of the simulations and select one routing protocol for implementation of active communication energy efficient routing. Secondly, we look for the loopholes related with active communication energy efficiency of the routing protocol and propose energy aware link cost computation metrics and route discovery approach. The proposed solutions must compromises the *transmission power control approach* and *load distribution approach* to undertake the investigated loopholes. The link cost metrics must compromise important parameters which are associated with energy consumption. The route discovery must be originated from the selected routing protocol with modifications to handle energy aware route discovery. Thirdly, we integrate the proposed solution into the selected routing protocol. The goal of this solution is to maximize the network life time. We present new energy efficient routing protocol that uses the proposed solution. Finally, we simulate the energy efficient routing protocol. The simulation results are used to analyze its performance and behaviors by comparing with the original one.

1.2 General and specific objectives

General objective:

The general objective of this thesis is to evaluate the energy efficiency of the existing MANETs' routing protocols (DSDV, AODV and DSR) and improve the active communication energy efficiency of MANETs routing protocol from the view points of node and network.

Specific objectives:

The specific objectives of this thesis include:

- To make survey about the conventional routing protocols of MANET and their metrics response towards the energy-efficiency.
- To make survey on different categories of energy aware routing protocols, especially active communication energy aware routing protocols for MANET.
- To study different energy aware routing protocols metrics.
- To investigate energy efficiency of the existing routing protocols and selects one which outperforms for further enhancement.
- To propose a solution how to improve the active communication energy efficiency of the routing protocols.
- To study how to incorporate the proposed solution with the selected routing protocol.
- We simulate the enhanced routing protocol using Network Simulator (NS-2) and analysis it with original routing protocol.

1.3 Methodology

1.3.1 Literature survey in the area

A number of research journals are available on energy-aware routing protocols of MANETs. Different energy-aware routing protocols of MANETs are being proposed; the available active communication energy-efficient routing protocols from transmission power control and load distribution approaches have been examined through literature review. In this thesis, DSR routing protocol has been studied how to implement the energy-aware algorithms on it. Besides, different possible alternative energy-aware performance improvement techniques have been investigated through literature review; in order to propose an improved active communication energy-aware routing protocol for MANETs.

1.3.2 Analysis and Modeling

The performance of the existing routing protocols have been analyzed by simulation based on energy-efficient routing protocols' metrics (Energy consumed per Packet, Expiration time of node, and time to network partition). The DSR has been modified to the new energy efficient solution and analyzed.

1.3.3 Mechanism of Driving Conclusion

In this thesis, the performance of the above mentioned three IETF (AODV, DSDV and DSR) routing protocols for MANETs have been analyzed and an improving solution has been proposed. In this research, the following energy aware metrics have been considered to drive conclusion:

- Increased the life time of the node.
- Increased packet delivery fraction
- Reduced the Variance of the nodes residual battery Energy.
- Minimized energy consumed per packet.

1.4 Motivation

1.4.1 Statement of the problem

The purpose of energy-aware routing protocols is to maximize the network lifetime. The network lifetime is defined as the time when a node runs out of its own battery power for the first time. If a node stops its operation, it can result in network partitioning and interrupt communication. The energy-efficient routing protocols should consider energy consumption from the viewpoints of both the network and the node level. From the network point of view, the best route is on that minimum total transmission power is required. To achieve this, there is transmission power control approach. Transmission power control of transmitter minimizes the total transmission energy required to deliver data packet to the destination [8]. On the other hand, from node point of view, it is one that avoids the nodes with lower power. This can be handled by load distribution approach. The main goal of the load distribution method is to balance the energy usage among the nodes and to maximize the network life time by avoiding over utilized nodes when selecting routing path [8].

Minimizing the total energy consumption tends to favor the route that consumes minimum energy end-to-end. It leads to selection of particular routes frequently. Those routes may include a node regularly. If the min-total transmission energy routes include the same node regularly, the node will exhaust its energy much earlier than other nodes and the network life time will be declined [24]. On the other hand, a consideration only on the energy level of each mobile node's battery may select longer-hop routes, which spend more energy end to end. Therefore, the energy efficient routing protocols must have a mechanism to compromise these two objectives. Therefore our research has focused on energy efficiency of the existing routing protocols and how to compromise the above two mentioned objectives for one of these routing protocols during route discovery and maintenance. The existing routing protocols are evaluated using energy aware metrics. The proposed solutions are integrated into one of selected routing protocol for further enhancement. The routing protocol is selected based on the result driven from the pre simulation, previous works, and existing framework of the routing protocol for enhancement.

1.4.2 Contribution

This thesis presents a solution for energy efficient routing of MANETs on the viewpoints of the network and nodes. This solution improves one of the existing well known routing protocols of MANETs. The main contributions of this work are as follows.

- Metrics to compute the cost of energy efficient link and route. This metric is adopted from previous works. It is sufficiently generic to be used in any routing protocol.
- An implementation and simulation study in NS-2 of the improved energy efficient routing protocol sustaining considerable improvements in packet delivery fraction,

energy per packet consumption and network lifetime over the original standard routing protocols.

- The outcome of this thesis is Energy efficient MANETs routing protocol. It will be used in research related with QoS (mainly, QoS on demand of long life networks).

1.5 Thesis organization

The rest of the paper is organized as follows. Chapter -2 addresses very important related works to this thesis. This chapter is the foundation of this work problem definition and includes the related works under power aware and cost aware routing protocols. In chapter 3, we discuss the background information to understand the subject matter of this thesis work. This chapter covers wireless networks mainly MANETs and MANETs' routing protocols. We also cover the energy models and important issues for saving of energy consumption. This chapter is the corner stone of this work. Chapter 4 explains the simulation environment and scenarios design to simulate the existing well known MANETs routing protocols and the new energy efficient routing protocol later. In addition, this chapter includes simulation and analysis of the well known MANETs' routing protocols with respect to energy and performance metrics. Chapter 5 discusses the main work of the thesis. In this chapter, we exhibit the new link cost computation approaches and route discovery to provide energy efficient routing protocols of MANETs. It addresses the design and implementation of Energy Efficient DSR (EEDSR). In chapter 6, we give the simulation results of EEDSR in NS-2 comparing with the original DSR. Chapter 7 concludes the work of this thesis and points out future works.

CHAPTER- 2: RELATED WORKS

The main focus of research on routing protocols in MANETs has been network performance. The conventional MANETs routing protocols have been designed based on performance optimization rather energy efficiency. A number of routing protocols have been proposed to provide multi-hop communication in wireless Ad Hoc networks [10, 11 and 19]. Traditionally these protocols are evaluated in terms of packet loss rates, routing message overhead, and route length [27, 39, and 42]. A growing emphasis on long-lived networks has added energy consumption as an important metric. A number of studies have been done on power-aware routing protocols of MANETs. In this section, we present a brief overview on the most relevant energy aware routing protocols.

Conventional routing protocols for wired: Metrics used by conventional routing protocols for wired Internet typically do not consider any energy-related parameters besides node mobility. Thus, RIP [23] uses hop count as the sole route quality metrics, thereby selecting minimum-hop count between the source and destination. On the other hand, OSPF [29] can support additional link metrics as available bandwidth, link propagation delay etc. Clearly, in fixed power scenarios, the minimum-hop path would also correspond to the path that uses the minimum total energy for a single transmission of packet. But for variable transmission power scenario, the minimum hop route takes large amount of energy per packet.

Minimum total power routing (MTPR): A number of power aware routing proposals for MANETs are investigated in [12]. One of these routing proposals is MTPR. If the total transmission power for route R is P_R, then the route can be obtained from

$$p_{MTPR} = \min_{R \in S} P_R \qquad (2.1)$$

Where, S is the set containing all the possible routes. This routing approach main goal is minimize the total transmission power for route R. But it does not consider the energy level of the mobile node battery source during energy efficient route computation. This approach may select the route that includes one or more mobile node with least energy level (i.e. MTPR has a similar problem to min-hop routing in that it makes no effort to use energy evenly among the nodes.) This leads to "die" of the first node sooner and it causes partition of the network early.

Power aware localized routing: This routing protocol was proposed on [26]. The authors assumed that the power needed for transmission and reception is a linear function of d^{α} where d is distance between the two neighboring nodes and α a parameter that depends on the physical environment. The authors make use of GPS position information to transmit packets with the minimum required transmit energy. The key requirement of this technique is that relative positions of nodes are known to all nodes in the MANET. However, this information may not be readily available. In addition, the GPS based routing algorithm has two drawbacks. The first is that GPS cannot provide useful information about the physical environment and the second is that the power dissipation overhead of the GPS device is an additional power draw on the battery source of the mobile node.

Minimum Battery Cost Routing (MBCR): It was proposed in [12]. It tries to use battery power evenly by using a cost function which is inversely proportional to residual battery power. One possible choice for the cost function of a node i is given as

$$f(bi)=1/bi \tag{2.2}$$

where, ***bi*** is the residual battery energy of node i. the total cost of the route is defined as the sum of costs of nodes that are the components of the route, and MBCR selects a route with minimum total cost. This method seems to extend the network lifetime because it chooses the route composed of the nodes whose remaining battery power is high. The drawback of this algorithm is that it may select a rather short path containing mostly nodes with high remaining battery capacity but also a few nodes with lower remaining battery capacity. The cost of such a routing solution may be lower than that of a path with a large number of nodes all having medium level of remaining battery capacity. However, the former routing solution is in general less desirable from the network longevity point of view because such a path will become disconnected as soon as the very first node on that path dies.

The Min-Max Battery Cost Routing (MMBCR): This algorithm is a modification of the minimum battery cost routing to address the above mentioned weakness.[12] introduced a new path cost, which is defined as

$$R_j = \max_{i \in route\_j} f(B_i) \qquad (2.3)$$

It selects the route with the minimum path cost among possible routes. Because this metric takes into account the remaining energy level of individual nodes instead of the total energy, the energy of each node can be evenly used. The limitation of this algorithm is that since there is no guarantee that paths with the minimum hop-count or with the minimum total power are selected. It can select paths that results in much higher power dissipation in order to send traffic from a source to destination nodes. This feature actually leads to in shorter network lifetime because in essence the average energy consumption per delivered packet of user data has been increased.

Conditional Max-Min Battery Capacity Routing (CMMBCR): It was proposed in [12].It tries to balance the total transmission power consumption and the individual node power consumption. This algorithm operates in two modes according to the residual battery power. If there are nodes that have more battery power than threshold power, it applies MTPR to the nodes. Otherwise, it mimics MMBCR. Roughly speaking, when battery power is plentiful, it minimizes the total energy consumption like MTPR, and the other case it considers the nodes with lower energy like MMBCR. The performance of CMMBCR is heavily influenced by the threshold value. In case where the threshold value is 0, it is identical to MTPR and shares the drawback of it. As the threshold value grows by infinity, it is transformed into MMBCR and shares its limitation.

The max-min zPmin algorithm [40] is another balancing power-aware routing protocol. This scheme selects the route that maximizes the minimal residual power fraction under the constraint transmission power. This algorithm is much more complex than the others mentioned before, and it is not easy to choose a suitable *z* value.

Maximum Residual Packet Capacity (MRPC) was proposed in [3]. MRPC is conceptually similar to the conditional min-max battery cost routing. However, MRPC identifies the capacity of a node not only by the residual battery capacity, but also by the expected energy spent in reliably forwarding a packet over a specific link. This algorithm has two modes according to the battery power as CMMBCR. Instead of MTPR, it proposed another cost metric which considers the expected energy spent in reliably forwarding a packet over a specific link. Performance of MRPC, like that of the conditional min-max battery cost routing, depends on a threshold value. This threshold value determines exactly when either the min-max battery cost routing or the reliable minimum total transmission power is applied for route selection.

Power-aware source Routing (PSR): It was proposed in [33]. It is an on-demand source routing that uses state of the charge of battery to maximize the life time of a MANET. PSR solves a problem of finding a route π at route discovery time t as follows:

$$\min_{\Pi} = C(\Pi, t) = \sum_{i \in \Pi} c_i(t) \qquad (2.4)$$

$$\text{Where} \quad c_i(t) = \sigma_i \left(\frac{F_i}{E_{r,i}(t)}\right)^{\alpha} \qquad (2.5)$$

σ_i : transmit power of node i

F_i : Full-charge battery capacity of node i

$E_{r,i}(t)$: Remaining battery capacity of node i at time t

α : a positive weighting factor

PSR use an accumulative graded cost function. α is defined as a function of ratio of the remaining battery capacity over full-charge battery capacity. One of the drawbacks of this algorithm is that it only considers the transmission and the battery energy capacity of the sender node. Significant amount of energy is consumed during receiving of packet. Hence, the receiving energy consumption and the energy level of the receiver node must be considered in the cost computation of link. The second drawbacks are that the generic limitation of accumulative result based analysis. This algorithm may select the route that has mostly links with low value of $c_i(t)$ but also a few links with large value of $c_i(t)$. The cumulative value of this routing solution may be lower than that of a path with a large number of links all having medium level of link cost. However, the former routing solution is in general less desirable from network longevity point of view and total transmission energy consumption because the link with large value of link cost has come from either low energy residual of the node which leads to early network partition or from large transmission power which take much energy per packet.

Lifetime Prediction Routing (LPR): This routing protocol is an on demand source routing protocol that uses battery life prediction [32]. It maximizes the network lifetime by founding routing solutions that minimize the variance of the remaining energies of the nodes batteries in the network. Each node tries to estimate its battery lifetime based on its past activity. This is achieved based using a Simple Moving Average (SMA) predictor by keeping track of the last N values of residual energy and the corresponding time instance for the last N packets received by each mobile node. The objective of function of the routing protocols as follows:

$$\max_{\Pi} T_{\Pi}(t) = \min_{i \in \Pi} (T_i(t)) \qquad (2.6)$$

Where

$$T_i(t) = \frac{E_{r,i}(t)}{\frac{1}{N-1} \sum_{k=i-N+1}^{i} R_k(t)} \qquad (2.7)$$

$E_{r,i}(t)$: Remaining energy at the ith packet is being sent or relayed through the current node

$R_k(t)$: Rate of energy depletion of the current node when the kth packet was sent and is calculated by as the ratio of the difference between residual energies of the nodes for the packets k-1 and k and the difference between arrival times of these two packets

N : Length of the history used for calculating the SMA. The first drawback of this routing protocol is that it introduces additional traffic for route maintenance. The second and most important is that it doesn't include the transmission power to minimize total energy consumption per packet. Large amount of energy consumption per packet may lead to die node sooner. The third is that the history may not predict accurately for high mobility of nodes in the network

Energy Saving dynamic source routing: This protocol makes the DSR is energy/power aware [36]. In this protocol senders can adaptively adjust the transmission power level to suite the current need of communication rather than using fixed level. The system uses energy saving cost metrics, which selects the route with maximum "life" remaining. Remaining life of a node in route defined as remaining node energy divide by power required to transmit packet to the next node. This becomes known as the max-min algorithm. The cost of the route is calculated as follows.

$$C(R, t) = \max_{j} R_j(t) \tag{2.8}$$

Where

$$R_j(t) = \min_{i} \left(E_i(t) / P_{i,j}(t) \right) \tag{2.9}$$

$E_i(t)$: the remaining energy of node i assumed known from hardware

$P_{i,j}(t)$: the transmit power of node i in route j as determined from receiver feedback

Energy saving dynamic source routing does not consider the energy capacity of the receiver nodes. Significant amount of energy is consumed to receive the packet. The process of receiving packets drains out the battery energy of the receiver nodes. So, energy efficient routing protocols have got to consider the receiving node battery energy capacity for route cost computation.

In addition to the drawbacks mentioned under each power aware routing protocol, all protocols share the limitation that they don't consider the energy level of the receiving nodes and the queue length for link cost computation. The receiving node energy level is vital since the receiving node consumes significant amount of energy during receive a packet. This work addresses energy aware parameters those must be incorporated in the link cost and a mechanism of route cost computations. The queue length is an important parameter to predict the energy consumption in the future in addition to load balancing. The transmission power is incorporated in the link cost computation to select minimum transmission power routes. The residual battery energy of the sender and receive nodes are incorporated in the link cost computation for appropriate energy aware load balancing. The minimum transmission power and energy aware load balancing must be optimized in the link cost computation to provide long lived network.

CHAPTER- 3: WIRELESS NETWORKS and ENERGY SAVING MECHANISMS

3.1 Wireless Networks

Wireless technology has been one of the hottest topics these years. The most obvious advantage of it is mobility. Wireless network users can connect to the existing network and are then allowed to travel freely inside the coverage area of the network. Wireless network can also make network deployment easily and rapidly since it does not involve running cables for each user.

Basically, there are two types of wireless networks [33] – *infrastructure network* and *Ad Hoc network*. With the infrastructure network, each node just communicates with the base stations providing internodes routing and fixed network connectivity. So for each node in the network, there should be at least one base station in its transmission range. Base stations are responsible for coordinating access to one or more transmission channel(s) for mobiles located within their coverage area.

For Ad Hoc networks, every node communicates with other nodes directly or indirectly through intermediate nodes that relay its packets because of transmission power limit. Thus, all nodes are virtual routers participating in computing and maintaining the routes. The obvious advantages of Ad Hoc networks are convenience and low cost since no base station or fixed network infrastructure is required. An Ad Hoc network is very useful for places where pre-deployment of infrastructure is difficult or even impossible. One scenario often mentioned is in a meeting room without access point deployed, the notebooks equipped with 802.11. Wireless LAN card can form a temporary Ad Hoc network to share the files. Ship holding a party, battlefield, and natural disasters are also places for useful scenarios. Figure 3.1 shows an example of Ad Hoc network architecture.

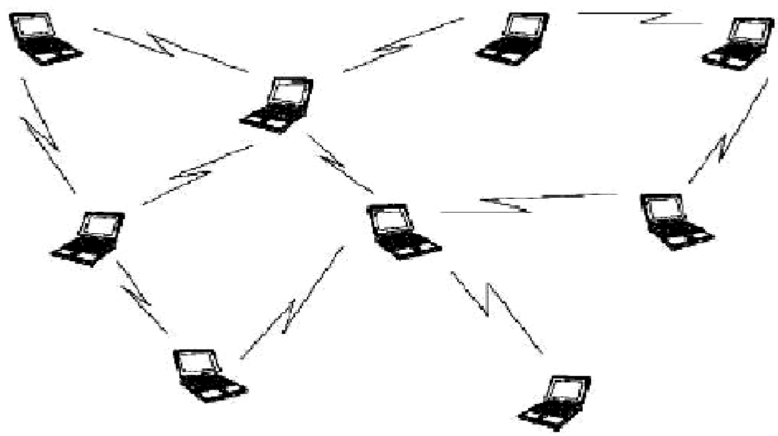


Figure 3.1: Ad Hoc network architecture

Depending on node mobility, there are two types of Ad Hoc networks: *static Ad Hoc network* and *mobile Ad Hoc network* (MANET). Sensor network is a typical static Ad Hoc network since most sensors don't move at present. Typically, a sensor network is equivalent to a static Ad Hoc network in some extent, but high density is the additional property of sensors. For other Ad Hoc networks it is not the common assumption. Some protocols designed for sensor network aren't suitable for other Ad Hoc networks. The next section discuss about MANET.

3.1.1 Mobile Ad Hoc Networks (MANETs)

A MANET consists of mobile platforms (e.g., a router with multiple hosts and wireless communications devices) herein simply referred to as "nodes" which are free to move about arbitrarily. The nodes may be located in or on airplanes, ships, trucks, cars, perhaps even on people or very small devices, and there may be multiple hosts per router. A MANET is an autonomous system of mobile nodes. The system may operate in isolation, or may have gateways to and interface with a fixed network. In the latter operational mode, it is typically envisioned to operate as a "stub" network connecting to a fixed internetwork. Stub networks carry traffic originating at and/or destined for internal nodes, but do not permit exogenous traffic to "transit" through the stub network.

MANET nodes are equipped with wireless transmitters and receivers using antennas which may be omnidirectional (broadcast), highly- directional (point-to-point), possibly steer able, or some combination thereof. At a given point in time, depending on the nodes' positions and their transmitter and receiver coverage patterns, transmission power levels and co-channel interference levels, a wireless connectivity in the form of a random, multihop graph or "Ad Hoc" network exists between the nodes. This Ad Hoc topology may change with time as the nodes move or adjust their transmission and reception parameters.

MANETs have several salient characteristics [12]:

1. *Dynamic topologies*: Nodes are free to move arbitrarily; thus, the network topology which is typically multihop may change randomly and rapidly at unpredictable times, and may consist of both bidirectional and unidirectional links.

2. Bandwidth-constrained, variable capacity links: Wireless links will continue to have significantly lower capacity than their hardwired counterparts. In addition, the realized throughput of wireless communications after accounting for the effects of multiple access, fading, noise, and interference conditions, etc. is often much less than a radio's maximum transmission rate.

One effect of the relatively low to moderate link capacities is that congestion is typically the norm rather than the exception, i.e. aggregate application demand will likely approach or exceed network capacity frequently. As the mobile network is often simply an extension of the fixed network infrastructure, mobile Ad Hoc users will demand similar services. These demands will continue to increase as multimedia computing and collaborative networking applications rise.

3. Energy-constrained operation: Some or all of the nodes in a MANET may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system design criteria for optimization may be energy conservation. Lack of energy in MANET mobile nodes causes a serious problem in the network. A node in MANET acts as both a router and host. So, died node leads to network partition besides itself out of the network. This thesis focuses on these challenges.

4. Limited physical security: Mobile wireless networks are generally more prone to physical security threats than are fixed- cable nets. The increased possibility of eavesdropping, spoofing, and denial-of-service attacks should be carefully considered. Existing link security techniques are often applied within wireless networks to reduce security threats. As a benefit, the decentralized nature of network control in MANETs provides additional robustness against the single points of failure of more centralized approaches.

In addition, some envisioned networks (e.g. mobile military networks or highway networks) may be relatively large (e.g. tens or hundreds of nodes per routing area). The need for scalability is not unique to MANETS. However, in light of the preceding characteristics, the mechanisms required to achieve scalability likely are.

These characteristics create a set of underlying assumptions and performance concerns for protocol design which extend beyond those guiding the design of routing within the higher-speed, semi-static topology of the fixed Internet.

3.2 Routing protocol in mobile Ad Hoc networks

A mobile Ad Hoc network is a co-operative network of mobile nodes that communicate over a wireless medium. Ad Hoc networks differ significantly from other existing networks. First, the topology of the nodes in the network is dynamic. Second, these networks are self-configuring in nature and require de-centralized control and administration. Such networks do not assume all the nodes to be in the direct transmission range of each other. Hence these networks require specialized routing protocols that provide self-starting behavior. Energy constrained nodes, low channel bandwidth, node mobility, high channel error rates, and channel variability are some of the limitations in an Ad Hoc network. Under these conditions, existing wired network routing protocols would fail or perform poorly. Thus, Ad Hoc networks demand special routing protocols. Ad Hoc routing protocols are classified based on the manner in which route tables are constructed, maintained, and updated [21]. Figure 3.2 shows the broad classification of MANET routing protocols.

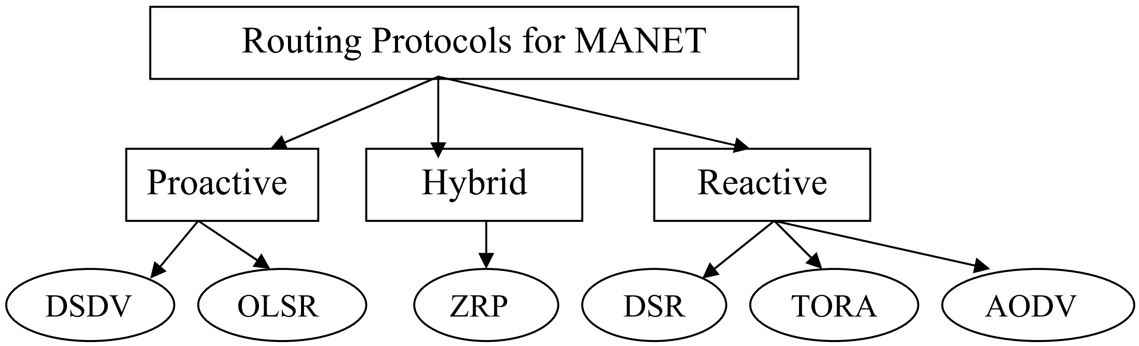


Figure 3.2: Broad classification of MANET routing protocols

The following sections describe the protocols and group them according to their characteristics.

3.2.1 Proactive (Table-Driven) routing protocols

These routing protocols are similar to and come as a natural extension of those for the wired networks. In proactive routing, each node has one or more tables that contain the latest information of the routes to any node in the network. Each node has the next hop for reaching to a node/subnet and the cost of this route. Various table-driven protocols differ in the way the information about change in topology is propagated through all nodes in the network. The two kinds of table updating in proactive protocols are the periodic update and the triggered update [9]. In periodic update, each node periodically broadcasts its table in the network. Each node just arriving in the network receives that table. In triggered update, as soon as a node detects a change in its neighborhood, it broadcasts entries in its routing table that have changed as a result. Examples of this class of Ad Hoc routing protocols are the Destination-Sequenced Distance-Vector (DSDV) [15] and the Wireless Routing Protocol (WRP) [37]. Proactive routing tends to waste bandwidth and power in the network because of the need to broadcast the routing tables/updates. Furthermore, as the number of nodes in the MANET increases, the size of the table will increase; this can become a problem in and of itself. In addition, it needs control traffic for continually update stale route entries. Unlike the Internet, an Ad Hoc network may contain mobile nodes and therefore links are continuously broken and reestablished.

3.2.2 Reactive (on-demand) routing protocols

Reactive routing protocols take a lazy approach to routing. They do not maintain or constantly update their route tables with the latest route topology. Instead, when a source node wants to transmit a message, it floods a query into the network to discover the route to the destination. This discovery packet is called the *Route Request (RREQ)* packet and the mechanism is called Route Discovery. The destination replies with a *Route Reply (RREP)* packet. As a result, the source dynamically finds the route to the destination. The discovered route is maintained until the destination node becomes inaccessible or until the route is no longer desired.

The protocols in this class differ in handling cache routes and in the way route discoveries and route replies are handled. Reactive protocols are generally considered efficient when the route discovery is employed rather infrequently in comparison to the data transfer. Although the network topology changes dynamically, the network traffic caused by the route discovery step is low compared to the total communication bandwidth. Examples of Reactive routing protocols are the *Dynamic Source Routing (DSR)* [9, 18], the *Ad Hoc on-demand Distance Vector Routing* (AODV) [10] and the *Temporally-Ordered Routing Algorithm* (TORA) [50]. Since the route to destination will have to be acquired just before communication can begin, the latency period for most applications is likely to increase drastically.

3.2.3 Hybrid routing protocols

Both the proactive and reactive protocols work well for networks with a small number of nodes. As the number of nodes increases, hybrid reactive/proactive protocols are used to achieve higher performance. Hybrid protocols attempt to assimilate the advantages of purely proactive and reactive protocols. The key idea is to use a reactive routing procedure at the global network level while employing a proactive routing procedure in a node's local neighborhood. Zone Routing Protocol (ZRP) [9] is an example of the hybrid routing protocols.

3.2.4 Well known MANETs routing algorithm

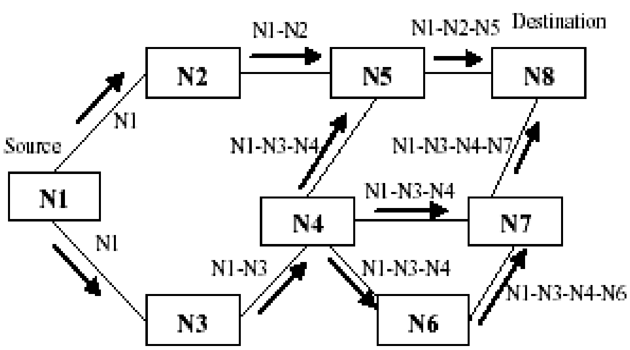
One of objectives of this thesis is that investigating the energy efficiency of the well known MANET (IETF) routing protocols. These routing protocols are DSR and AODV from reactive routing protocol and DSDV from proactive. These protocols are some of the few Ad Hoc routing protocols that have been implemented and evaluated in a real test-bed. The following sections discuss these routing protocols briefly.

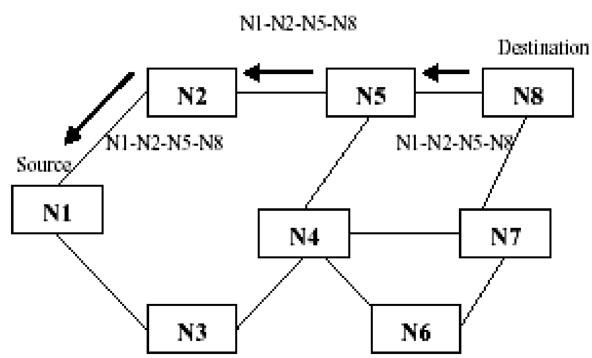
3.2.4.1 Dynamic Source Routing Protocol

DSR [18] protocol is an on-demand routing protocol, based on the concept of source routing. Each data packet follows the source route stored in its header, giving the address of each node through which the packet should be forwarded in order to reach its final destination. Mobile nodes maintain route caches containing the source routes that the nodes have learned. DSR uses no periodic routing messages, and relies on the MAC layer support for link failures detection. DSR was used in many performance comparisons, evaluating studies, and was used as reference for a lot of other protocols. Further, it was used as reference protocol for investigation to find general improvements for MANETs (like reduced energy consumption) [27, 44, 16, 20].

DSR has two basic modes of operation, which are ***route discovery*** and ***route maintenance***. When a node wants to send a packet to a destination, it checks its routing cache if there is an existing route to that destination. If it finds a route, then it uses it to send the packet to the destination. Otherwise it starts the route discovery process.

Figure 3.3 shows the route discovery process from the source node *N1* to the destination node *N8*. In Figure 3.3 (a), *N1* broadcasts a route request (*RREQ*) packet containing the source address, the destination address and a unique identification number so that each node processes the *RREQ* only once. Each intermediate node appends its address to the route record of the packet, which is formed during the *RREQ* propagation, and forwards it to its neighbors. A route reply (*RREP*) is generated when the destination node or an intermediate node with routing information about the destination is reached. At that time the *RREQ* packet is containing a route record yielding the sequence of hops taken. In Figure 3.3 (b), the destination node *N8* generates the *RREP* back to the source by placing the route record from route request packet into the route reply packet. Otherwise, if an intermediate node generates the *RREP*, then it appends its cached route to the destination to the route record in the *RREQ* packet and then generates the *RREP* packet. In the *RREP* return, if symmetric (bi-directional) links are supported, the replying node reverses the route in the route record. If symmetric links are not supported, the node checks if it has a route to the initiator, it uses it. Finally, the source caches the route carried by the *RREP* that it receives for future use.





(a) (b)

Figure 3.3: Creation of the Route Record in DSR: (a) Route record construction during route discovery, (b) Propagation of RREP

When the data link layer encounters a fatal transmitting problem, route error (*RERR*) packets are generated at a node to the original sender of the packet encountering the error. A node receiving a *RERR*, removes the hop in error from its cache and all routes containing the hop are truncated at that point.

DSR employs some optimizations to the basic operation of the route discovery and route maintenance, which can reduce some overhead and improve the efficiency of the used routes.

These optimizations take the form of promiscuous mode, non-propagating route requests, salvaging, and gratuitous route repair [27, 14].

DSR uses no periodic routing messages, i.e. no route advertisements, thereby reducing network bandwidth consumption, minimizing control overhead, conserving battery power and avoiding large routing updates throughout the Ad Hoc network. DSR takes a great advantage from the source routing concept, where intermediate nodes do not need to maintain up-to-date routing information, as the packets themselves contain all routing decisions [27]. Moreover, loop formation is eliminated and the source learns all possible routes to the destination as well as to the intermediate nodes, however, each packet carries a considerable routing overhead due to carrying the source route, which is directly proportional to the path length. Although, DSR makes an aggressive use of caches, replying to all requests reaching a destination from a single request cycle, stale route cache information may cause inconsistency during the route construction phase. We note that the DSR route maintenance mechanism does not locally repair a broken link [14].

3.2.4.2 Destination-Sequence-Distance-Vector (DSDV) Routing Protocol

DSDV [15] is a hop-by-hop distance vector routing protocol. Each mobile node maintains a routing table that stores for all reachable destinations the next-hop and number of hops to reach that destination, and the sequence number assigned by the destination. The routing tables' updates are time-driven and event-driven, in which each mobile node transmits periodically its tables to its neighbors, periodically broadcasting routing updates. This transmission takes place also in topology change cases. DSDV applies two types of routing updates [27]: full dump or incremental update. Full dump carries the full table with all available routing information and this is suitable for fast changing networks. Incremental dump carries only the updated entries since last dump, which must fit in a packet and is suitable when network is stable.

DSDV possesses routes availability to all destinations at all times, which involves much less delay in the route setup process. The use of sequence number distinguishes stale routes from new ones, where routes with higher sequence numbers are favorable. However, the updates due to broken links lead to a heavy control overhead during high mobility, proportional to the number of nodes in the network and therefore affecting scalability.

3.2.4.3 Ad Hoc On-Demand Distance Vector Routing (AODV)

The Ad Hoc On-Demand Distance Vector routing protocol as described in [10] is a modified version of the DSDV described in Section 3.2.4.2 and aims at reducing system-wide broadcasts that are a feature in DSDV. Routes are discovered on an as- needed basis and are maintained only as long as they are necessary. Each node maintains monotonically increasing sequence numbers and this number increases as it learns about a change in the topology of its neighborhood. This sequence number ensures that the most recent route is selected whenever route discovery is initiated.

AODV uses routing table. This route table is used to store the destination and next-hop IP addresses as well as the destination sequence number. Associated with each routing table entry is a lifetime, which is updated whenever a route is used. Routing in AODV is carried out by the process ***of Route Discovery*** and ***Route Maintenance***.

When a node wishes to send a packet to some destination node, it checks its route table to find whether it has a route to the destination node. If it does, it forwards the packet to the next hop towards the destination. However if the node does not have any valid route to the destination, it must initiate a route discovery process. The source node creates a route request (RREQ) packet that contains the source node's IP address, current sequence number, destination's IP address and last known sequence number. The RREQ also contains a broadcast ID and this is incremented every time the source node initiates a RREQ. Thus, the broadcast ID and the source IP address uniquely identify a route request. Once the RREQ is created, the node broadcasts this packet and sets a timer to wait for a reply.

When a node receives a RREQ, it first checks whether it has seen it before noting the source IP address and broadcast ID pair. If it has already seen a RREQ with the same source IP address and broadcast ID, it silently discards the packet. Else, it records this information and processes the packet. The node sets up a reverse route entry for the source node in its route table. This reverse route entry contains the source node's IP address and the IP address of the neighbor from which the RREQ was received. If the route entry is not used within a certain timeout period, it is deleted to prevent the presence of stale routing information in the route table.

The destination node responds with a unicast route reply (RREP) packet to the source. If the node is not the destination node, it increments the RREQ's hop count by one and re-broadcasts this packet to its neighbors. If the RREQ is lost, the source node is allowed to re-broadcast a route discovery again. The number of retries is fixed and if there is no route to the destination after the maximum number of retries, the destination is labeled unreachable.

Once a route has been discovered for a given source/destination pair, it is maintained as long as needed by the source node. Movement within the Ad Hoc network affects only the routes that contain those nodes. If the source node moves, it can re-initiate a route discovery to establish a new route to the destination. When a link breaks, a route error (RERR) message is sent to the affected source nodes whenever a packet tries to use the link.

3.2.5 Energy efficiency of Table-driven vs. Source-Initiated Protocols

Table-driven protocols have the overhead of route updates with no regard to the frequency of forwarding packets that take place in the Ad Hoc network. The routing information is constantly propagated within the network. This is not the case with on demand protocols where routing information is exchanged only when the source wishes to send some information to the destination and has no information about the destination in its route cache. On the other hand, since routing information is constantly propagated and updated in table-driven protocols, information about a particular source-destination route is always available regardless of whether or not this information is required. This feature leads to significant signaling overhead and power consumption. Since both battery and bandwidth are scarce resources in Ad Hoc networks, this becomes a serious limitation.

From the discussion of table-based protocols provided in Section 3.2.1 and on demand protocols presented in Section 3.2.2, table-based protocols incur significantly high routing overhead and hence lead to increase the energy consumption compared to the on-demand protocols.

3.3 Energy save Mechanisms

Without a fixed infrastructure, ad hoc networks have to rely on portable, limited power sources. What's more, a node in an ad hoc network has to relay messages for other nodes in the same network. The issue of energy-efficiency therefore becomes one of the most important problems in ad hoc networks. Energy can be consumed during processing and communication. The energy consumed during communication is more dominant than the energy consumed during processing. So, the communication system should be energy efficient by optimizing the energy consumption at different states of the communication. The following sections briefly discuss energy models and some important techniques that used to design energy efficient routing protocols related with transmission power control and load balancing.

3.3.1 Energy model

In this section, we discuss about energy model for the communication subsystems of wireless network device. The energy model of communication has three power components. These are:

- Transmission power : It is required to send data
- Receive power: It is required to receive or listen data
- Idle power: It is required to wakeup.

Transmission power includes both power required to drive the circuit and the transmission power from antenna. The transmission power from antenna is computed based on the distance between sender and receiver using one of the models stated below.

RM-model: Rodophu and *Meng* [51] proposed a general model in which the power consumption between two nodes at a distance d is

$$u(d) = d^{\alpha} + C \qquad (3.1)$$

For some constant α and c, it describes several properties of power transmission that are used to find neighbors for which direct transmission is best choice in terms of power consumption. In their experiments, they adopted the model based on equation 3.1 with

$$u(d) = d^4 + 2*10^8 \qquad (3.2)$$

This will be referred to as *RM-model.*

HCB-model: In the simple radio model [53], radio dissipates $E_{elec} = 50nJ/bit$ to run the transceiver circuitry. Both sender and receiver nodes consume E_{elec} to transmit one bit between them. Assuming d^2 energy loss, where d is the distance between nodes, transmit amplifier at the sender node consumes $E_{amp}d^2$ further, where E_{amp} =100pJ/bit/m2. Thus, to transmit one bit message at distance ***d,*** the radio expends $E_{elec} + E_{amp}d^2$ and, to receive the message, the radio expends E_{elec}. In order to normalize the constants, divide both expressions by E_{amp} so that the radio expands

$$T = E + d^2, \quad \text{for transmission} \qquad (3.3)$$

$$P=E \quad , \quad \text{for reception.} \qquad (3.4)$$

Where $E = E_{elec}/E_{amp} = 500m^2$

Based on the equations (3.3) and (3.4), the total energy is given by

$$T + P = 2E + d^2 \qquad (3.5)$$

Therefore, this model referred to as *HCB model*, the power needed for transmission and reception at distant d is given as

$$u(d) = 2E + d^2 \qquad (3.6)$$

We use the energy model that has been used in [35]. The model shows that the energy expended in sending data-packet of size D bytes at a transmit power of p_t can be expressed as

$$E(D, p_t) = k_1 p_t D + k_2 \qquad (3.7)$$

Where the typical values for k_1 and k_2 in two frame exchange 802.11 MAC environment at full power(280mW) and 2 Mbps bit rate are 4µs/byte and 42µJoules respectively. We focus on the energy consumption related to data packet. This includes the network layer related packets (RREQs and RREPs). Since the MAC layer related packets (CTS, RTS, ACK) are very smaller in size compared with the size of a data packet, we ignore the energy consumption related to MAC layer packets in our model.

For a given threshold power, p_r, the minimum transmit power, p_t, required for successful reception varies with distance and is given by

$$p_t(d) = p_r d^{\alpha} k \tag{3.8}$$

Where d is the distance between the sender and receiver nodes.

α is path loss exponent. Typically takes 2-4.

K is constant

In this thesis, we use α=4.0, which represents path loss exponent for two-ray ground model. The typical value of P_r in LAN 802.11 is 3.652e-10mW. Substituting the value of P_t into equation 3.7, we get the minimum energy consumption as

$$E_{\min} = k_3 d^4 + k_2 \tag{3.9}$$

Where k_3 has the value of $2.8\text{x}10^{-10}$ *μJ/ (byte-m⁴).* Equation 3.9 shows that the minimum energy consumption depends on the distance between two nodes.

3.3.2 Transmit power control [52]

If the transmit power is fixed and equal for all the nodes, then minimum hop is the minimum energy route. To gain maximum energy savings, the minimum energy routing protocol should transmit the data-packet at power P_t instead of the fixed transmit power. This can be achieved by employing dynamic transmit power control on the link. Now if dynamic transmit power control is employed, the energy cost of each link can be computed using P_t and other parameters. Though some protocols allow link metrics other than minimum hop, the existing on-demand protocols do not offer any mechanisms to compute and propagate the parameters necessary to compute the per packet energy cost. Hence the dynamic transmit power control feature cannot be supported by the existing versions of the on-demand protocols. Besides dynamic transmit power is used energy conservation, it is used to utilize the network resource efficiently. That is by allowing a greater number of simultaneous transmissions, the power control increase the total network capacity. Only computing the ***pt*** value is not sufficient activity, the transmission power control should be handled by WLAN interface cards. The next section discusses about how transmit power control relates with energy conservation.

3.3.2.1 The need of transmission power control for Energy Conservation

The mobile battery lifetime is becoming an increasingly important issue to manufacturers and consumers, as mobile devices are being used more frequently in our everyday lives. The power amplifier, as compared to other mobile device components, consumes a significant portion of the device power. The power consumed by the power amplifier is directly proportional to the strength (power) of the transmitted signal. Therefore, it is becoming of great interest to control the transmission power level such that the lifetime of mobile terminals is maximized. As an example, consider Figure 3.4, which shows a schematic of the WLAN network interface card components and their typical power levels. Notice that the power amplifier may take more than three times the power of any other individual component and consumes almost half the total energy consumed by the network interface card. This ratio is expected to continue to increase for future WLAN interfaces cards, as the processing components become more power efficient. Furthermore, there will be dedicated devices such as wireless sensors, where the RF (radio frequency) output power amplification process takes the largest share of the overall power budget. Therefore, there is a significant energy saving potential in controlling the RF output power.

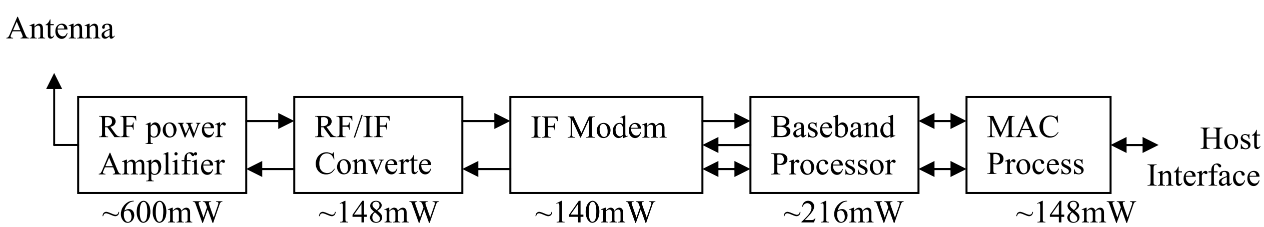


Figure 3.4 Power distribution of a WLAN network interface card

To obtain a better idea of the degree of reduction in transmission power (and therefore energy savings) that power control can provide, we must look at the basic path loss model since this dictates the relationship between the transmission range and the required transmission power. The path loss typically causes the signal to attenuate with distance on the order of $1/d^{\alpha}$ [51], where d represents distance between transmitter and receiver, and α, the path loss factor is typically between 2 and 6. As a result, modest differences in transmission ranges will result in significant differences in required transmission power to maintain the same signal quality (power level at the receiver). It can then be concluded that either minimizing the power to that need to reach the destination or utilizing multiple intermediate hops will produce significant savings in power consumption by the power amplifier (as much as several orders of magnitude).

3.3.2.2 Transmission power control at network layer

Vikas Kawadia et al. [52] have stated that the transmission power control is complex and affects many aspects of the operation of the network and listed fifteen of them. One of the aspects among 15 in the list is network layer since transmission range affects routing due to transmit power control determines the range of the transmission. So, power control regarded as a network layer problem. Numerous approaches [32, 33] attempt to solve the power control problem at the MAC layer. The strategy is to adjust SINR at the intended receiver is just enough for decoding the packet. The claim is that this minimizes the interference as well as saves energy. One point to note though is that the intended receiver is determined by the network layer, i.e., by routing entry or source route, and not by the MAC layer. The job of the MAC layer is only to transmit the packet to the receiver specified by the high layers. Thus, placing power control at MAC layer does not give the routing protocol the opportunity to determine the optimal next hop or intended receiver. In the other words, the MAC approach to power control only does a local optimization whereas network layer power control is capable of a global optimization. Therefore, this thesis implements the power control at the network layer.

3.4 Required Features of a energy efficient routing protocol

This section enumerates the required features of an Active Communication Energy Efficient routing protocol. We also show that the existing versions of routing protocols do not support most of these required features and hence justify our argument that existing protocols cannot qualify as Active Communication Energy Efficient routing protocols by taking sample protocol.

3.4.1 Energy-based routing cost computation

Energy Efficient routing protocols should take into consideration the energy cost of a route while choosing a route. The energy cost of a link in a route can be computed in different ways based on the objective of the routing protocol. The link cost can be computed by including important parameters. *Chokhawala* et al. [28] classified the existing power aware metrics and routing algorithms as power aware, cost aware and cost and power aware routing.

- Power aware routing: In this case, the routing decisions are based on the transmission power. The transmission power depends on the distance between the source and the destination.
- Cost aware routing: In this case, the remaining life-time of nodes is used as a decision making metric.
- Combining power and cost aware metrics: In this case, the transmission power and the node life-time are combined in link cost computation and used as a metric. There are two ways to combine them.
    - Power*cost:

$$\text{Power-Cost}(B, A) = f(A) * u(r) \tag{3.8}$$

Where A and B are source and destination nodes
r is the distance between B and A
f(A) life-time of node A
u(r) transmission power require at a distance r

    - Power + Cost

$$\text{Power-Cost}(B, A) = \alpha u(r) + \beta f(A) \tag{3.9}$$

Where α and β weighting factors for transmission power metric and node life-time metric

3.4.2 Energy aware route discovery

Energy Efficient routing protocols compute the link and route cost by taking energy aware parameters. Energy efficient routing protocols [12,40,36] use min-max route selection technique. Consider a case as shown in Fig. 3.5 where there are 4 nodes ***a, b, c, d*** in a straight line. Assume the route request from ***a*** is heard by all the three nodes in the network and the link cost c(***a,b***)=5,c(***a,c***)=20,c(***a,d***)=12, c(***b,c***)=8, c(***b,d***)=15 and c(***c,d***)=3, there are four possible routes from ***a*** to ***d***. These are

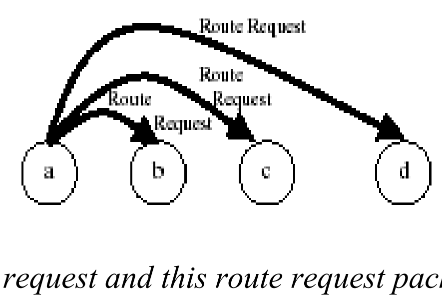
R1***:*** ***a-d***, the route cost=max {c(***a,d***)=12}=12

R2: ***a-b-d***, the route cost= max {c(***a,b***)=5, c(***b,d***)=15}=15

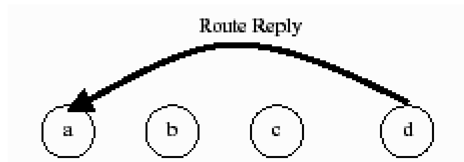
R3: ***a-c-d***, the route cost=max {c(***a,c***)=20, c(***c,d***)=3}=20

R4**:** ***a-b-c-d***, route cost=max { c(***a,b***)=5, c(***b,c***)=8, c(***c,d***)=3}=8

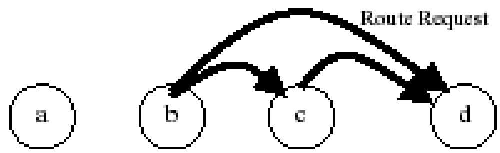
Among these four routes, R4's route cost is minimum .So that, the energy efficient route from ***a*** to ***d*** is a multi hop route ***a-b-c-d***. The route discovery mechanisms of existing on-demand protocols are similar in the way the route discovery is initiated. For finding a route from node ***a*** to node ***d***, the mechanisms initiate a Route Request packet broadcast from node ***a***. Assuming that this packet is heard by nodes ***b*** and ***c***, both nodes rebroadcast the packet. The packets broadcasted by nodes b and c are heard by all nodes. However, since node ***c*** has already broadcast the same request earlier, it ignores the request packet from node ***b*** and node ***d*** replies back to the requests it hears from nodes ***b*** and ***c***. Hence, the on-demand routes discovered by node ***a*** are ***a-d***, ***a-b-d*** and ***a-c-d***: The energy efficient route ***a-b-c-d*** is not discovered by the route discovery mechanism of the existing on-demand routing protocols. Therefore, the route discovery mechanism of these protocols must be customized to be energy efficient.



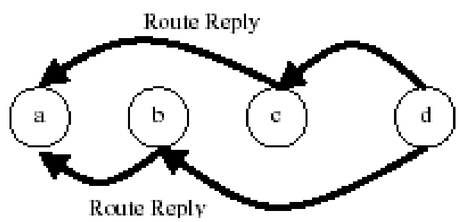
*a) Node **a** sends a route request and this route request packet is heard by **b, c** and **d.***



b) Node d sends a route reply a-d to node a.



c) Nodes b and c propagate this route request they hear from node a. However, node c does not propagate the route request that b broadcasts.



d) *Node d also sends the replies a-c-d and a-b-d to node a.*

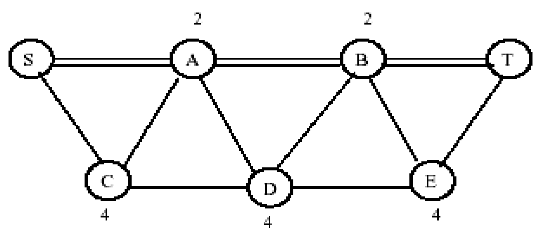
Figure 3.5: Route Discovery in the existing version of the DSR protocol

3.4.3 Energy Aware route maintenance

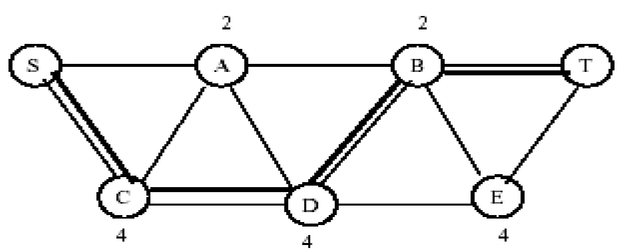
In the current version of on-demand Ad Hoc routing protocols, route maintenance is carried out by the route error packets only when the links are broken. No route maintenance is done to indicate a change in the quality of a link. No mechanism updates the information about the changing energy cost requirements that occur on that route due to node mobility. Even after the minimum energy cost routes are discovered, the changes in the energy costs of the links have to be tracked so that the energy expended is as close to the minimum value as possible. As nodes move closer together or further apart on a link the transmit power should decrease (to increase energy savings) or increase (to maintain the link) accordingly. Further, as the energy cost of a link rises due to the nodes moving apart, the route may no longer be the minimum energy cost route. Therefore, these changes in the energy cost need to be conveyed to the source node, so that it can choose other lower energy cost routes as needed. Hence an energy efficient routing protocol must have a mechanism for tracking the link energy cost changes. Mobility also causes the creation of new lower energy cost routes.

3.4.4 Energy Aware Load Balancing [46]

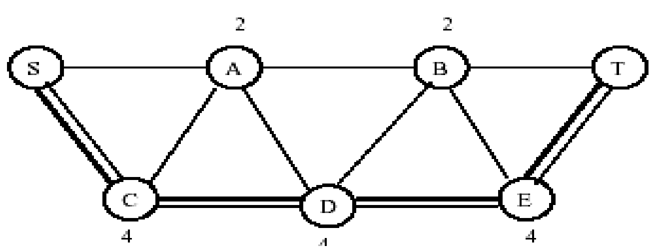
The specific goal of Energy Aware Load Balancing is to balance the energy usage of all mobile nodes by selecting a route with underutilized nodes rather than the shortest route. This may result in longer routes but packets are routed only through energy-rich intermediate nodes. Protocols based on this approach do not necessarily provide the lowest energy route, but prevent certain nodes from being overloaded, and thus, ensures longer network lifetime.



A) Initial path that drains the residual energy at nodes A and B.



b*) After route redirection, node A is circumvented.*



c) After route redirection, node B is circumvented. a node disjoint new path is found

Figure 3.6: Example of successive local route redirection operations

For example, consider a part of a MANET shown in figure 3.6(a), the path S-A-B-T is optimal path for a connection from S to T. The metric for optimality can be hop count for shortest path routing. Thus, node A and B will continuously be used in forwarding the traffic, leaving the other nodes free from the traffic load. As a result, the residual energy levels of the nodes become widely varied. If the routing is not energy-aware, it will keep using the path for S-A-B-T connection. Nodes A and B will eventually be the drained out of battery supply and die early. However, an energy-aware routing scheme will try to divert the traffic to other nodes.

3.4.5 Flooding Wave

The problems of flooding wave are discussed by Gobriel et al. [43] and Tseng et al. [41]. Flooding wave is broadcast storm which increase the collision rate. The network performance will be degraded as the rate of collision is increased.

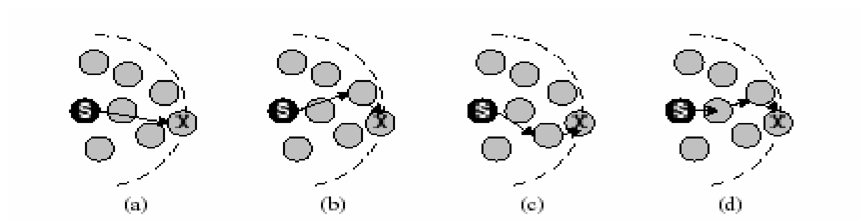


Figure 3.7: Flooding Waves Problem

For example, consider a part of a MANET shown in figure 3.7, when a source node *S* needs to transmit a packet and it doesn't know the route to the destination, it sends out a route request. All the nodes in the transmission range of the source receive this request after time τ. In this case there is a difference in the behavior of the conventional DSR and that of an energy-efficient routing, as described next.

In DSR, at time τ, Node *X* receives the request transmitted by the source (as shown in Figure 3.7(a)) and it rebroadcasts the request to its neighborhood. Later, as shown in Figures (3.7(b)-3.7(d)), Node *X* will receive copies of the same request, however, it drops all these packets as they are redundant copies of a request it has already handled.

In energy-efficient routing, similar to DSR, Node *X* rebroadcasts the first request it gets after τ to its neighborhood. At time 2τ, and as shown in Figure 3.7(b), X receives another copy of the request. However, X doesn't discard the received packet. It first checks the cost of the new request received, if the new cost is less than the one already transmitted, the request is rebroadcast, otherwise, it is discarded. Since there is a non-linear relation between the transmission power and the transmission distance the cost of the request received at 2τ will probably be less than that received at τ and hence, it will be rebroadcast. Similarly, in subsequent time slots, as shown in Figures [3.7(c)-3.7(d)], Node *X* will receive copies of the request, and each one of those will have a lower cost than the one already transmitted. As a result, X will rebroadcast all the received route requests. It should be noted that, each request transmitted out of Node *X* completely floods the network (*Broadcast-Storm* [41]) until it reaches the destination. Moreover, the same behavior is repeated at each hop along the route (not only the source's neighborhood). As a result, these ***waves*** of requests represent a huge route discovery overhead and this overhead increases with the increase of the node-density. The wasted energy consumed in transmitting these flooding waves diminishes the energy gain resulted from using an efficient route.

CHAPTER 4: SIMULATION RESULTS of EXISTING WELL KNOWN ROUTING PROTOCOLs of MANETs

4.1 Simulation Environment

The primary approach for this study we is computer simulations. We use the network simulator ns-2[38] developed by the VINT research group at University of California at Berkeley. The Monarch research group at Carnegie Mellon University [13] extended the ns-2 simulator to include wireless scenarios with mobile nodes. The more established ad-hoc routing protocols were implemented in the CMU extension. Subsequent versions of the CMU wireless extension also included energy models, propagation models, mobility models and the underlying MAC layer protocol is defined by IEEE 802.11 standard [25] for the mobile nodes. We use Random WayPoint mobility model, Two Ray Ground propagation model and IEEE 802.11 for this work.

4.1.1 Network Simulator-2(NS-2)

NS-2 is the Network Simulator 2 [38] that emerged from the VINT project at. It can be used to simulate any kind of Internet communication, providing implementations for IP, TCP (different flavors), UDP, a variety of routing protocols, several QoS mechanisms, and more. A project at the CMU has provided wireless extensions, which now include mobile nodes and wireless communication with adequate models on layer one and two (radio propagation models, IEEE 802.11 link layer, etc). Some Ad Hoc routing protocols such as AODV, DSR and DSDV are implemented in NS-2. Figure 4.1 shows the simplified structure of NS-2 from the user point of view. The NS-2 model is partitioned as shown on the figure 4.1.

The implemented models are generally very detailed, which leads to high complexity in the software itself and in its calculations. NS-2 is written and developed in C++ and TCL. It has an embedded TCL interpreter, such that TCL scripts can be used to configure and control the simulator. The mix of C++ and TCL also increases the complexity of the software. This is one of the main drawbacks of NS-2. Despite being open source, the design of NS-2 is somewhat complex, making additions or improvements difficult to implement. Given that no clear guidelines are provided, contributions have tended to add code in a haphazard manner to best suit their own purposes at that time, which has resulted in a very complex C++/TCL jumble. In recognition of these drawbacks, there have been efforts to improve the structure and design of NS-2.

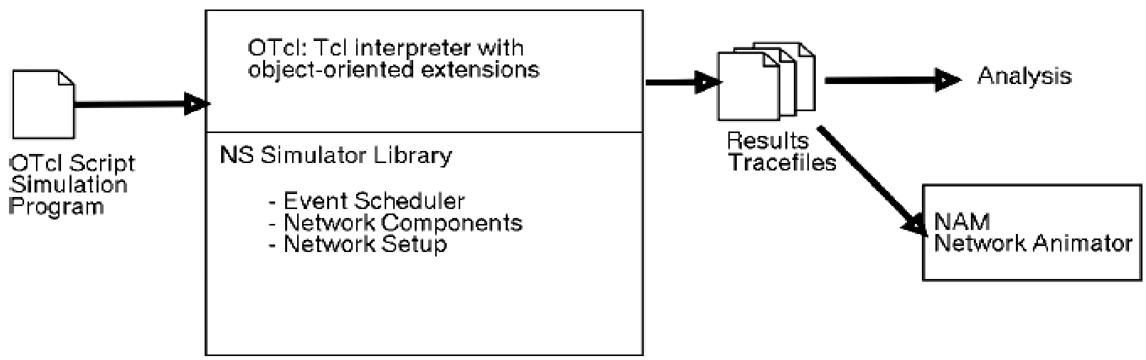


Figure 4.1: Simplified user view of NS-2

NS-2 does not provide any statistics, which could be mapped to performance measures. Instead every event produced by the simulation is written to a trace-file. The trace-file can then be processed to extract the desired information. This may appear as a reasonable approach; however, even with low scale simulation scenarios the trace-files become very large. In addition, the writing of the trace-file to disk actually slows down the simulation in some cases. Results obtained by ns 2 (trace files) have to be processed by other tools, e.g. the Network Animator (NAM), a Perl or an Awk script.

Still NS-2 is one of the most widely used simulators for mobile Ad Hoc networks and there is also an add-on called NAM (network animator), which provides a way to visualize simulated communications (and NAM was designed to operate on a particular kind of trace-file, thus for NAM trace-files are always required).

4.1.2 Random Waypoint mobility model

The random way point mobility model is widely used to evaluate the performance of MANETs. In Random Waypoint mobility model [38, 46], parameters to be specified are pause time, minimum speed and maximum speed. Each mobile node starts from a randomly chosen position and stay for the length of pause time. When pause time expires, a destination and moving speed are randomly picked. The speed is uniformly chosen between specified maximum and minimum speed. This work takes the average speed. It is the sum of minimum and maximum speed divided by two. The mobile node will move towards the destination with the chosen speed. Once it reaches the destination, the process of pausing, choosing destination and speed starts over again.

4.1.3 Two Ray Ground Propagation model

The Two Ray Ground (TRG) [38] is a model that improves the principle of functioning of Free Space. This model considers the distance between sender and receiver nodes, and heights of transmitter and receiver antennas. It represents the communication range as an ideal circle. The signals propagation model concerned, keeps into account both the direct path between Sender/Receiver and the ground reflection path. This model gives more accurate prediction at a long distance than the free space model. The additional feature of the TRG is that ground reflection negatively affects the receiving power due to the multipath effect. Two-ray Ground model predicts the received power as a deterministic function of distance. The receiver signal strength is inversely proportional to d^4 *(where **d** is the distance between the sender and receiver nodes)*. Assumption of Two-ray Ground propagation model makes the power prediction to more realistically resemble the real world situation than Free Space model.

4.1.4 IEEE 802.11

IEEE 802.11 [25] is an Ethernet-like distributed mechanism referred to as Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA). Since wireless LANs lack the capability of collision detection, collision avoidance (CA) mechanism tries to minimize access conflicts a priori.

In general if the channel is free, then a node with a packet to send senses the channel for a period of time and then transmits if the channel is free after. If the channel is busy or becomes busy during sensing, the MAC packet transmission has to be postponed until the channel becomes free and an additional waiting time has elapsed, during which the radio channel must remain free. Each node that wishes to transmit then backs off for a random interval and the first node whose back-off interval ends (the one with the shortest interval) acquires the channel.

A packet transmission can be preceded with an RTS/CTS control message exchange whereby the packet sender sends an RTS according to the aforementioned MAC rules and the intended receiver answers by a CTS. Thereby the sender and the receiver announce to their neighbors that a packet transmission will start. Only if the exchange of these control messages was successful the data packet transmission will start. The main objective of this mechanism is to avoid collisions in hidden terminal scenarios as well as reducing the collision phase when transmitting long packets, since only the tiny control messages can collide. The RTS/CTS message exchange should not be used for short packets since this would add unnecessary overhead. The RTS threshold value determines for what packet sizes the RTS/CTS message exchange should be used.

The IEEE 802.11 MAC protocol uses an immediate acknowledgment (ACK) to recover from transmission errors. After a successful data packet reception, an ACK is transmitted, indicating the correct reception. If the reception of a packet was not successful no ACK will be sent from the receiver and as a result the sender will retransmit the packet. The re-transmission is performed until the data packet was received correctly or the maximum number of retransmissions is reached.

4.1.5 Simulation tools and parameters

To evaluate the performance and energy-efficiency of existing routing protocols, we used the event driven simulator ns-2.29 for our simulations. Below is the list of parameters used in this thesis simulation work. The parameters are chosen on three basic considerations:

- Based on usage by other researchers [20,7,30], so that the results can be compared,
- Based on the capabilities of the systems used for the simulation. For example, the simulation seems to take much more time and memory when the number of nodes in the simulation is increased. So that limits the maximum number of nodes that can be used in this work.
- By considering most of the results to show the effect of the energy challenges. Hence, we try to reduce the dominancy of other factors, but we can not avoid completely coping with realistic environment.

The setup consists of a test bed of 50 nodes confined in a 670mX 670m in rectangular area. Maximum range of each node is assumed to be 250 m and the initial energy of each 1J. We use TwoRayGround because it is more liked realistic. The length of each simulation time is 500sec.

The simulations are implemented with speeds using the random way-point mobility pattern (section 4.1.1).We assume four average speeds with 4 sec pause time, which are defined at [2,7]. These average speeds are 1m/s (Walking), 5m/s (bicycle), 10m/s (motorcycle) and 15m/s (car).These scenarios are applicable to networks such as emergency situations in the city people moving as nodes. Each scenario is evaluated with respect to the number of connections (10-25 number of source-to-destination connections in interval of 5 connections).

Traffic is generated using constant bit rate (CBR).The traffic size is 4 packet/sec. The size of each packet is 512bytes. The network size and the number of nodes are kept constant while varying the number of sources-destination pairs within the network for each scenario. In effect, this model attempts to observe the relationship between traffic-density and system performance and energy efficiency.

parameter	value
Number of single simulation runs	10
Network size	670mX670m
Number of nodes	50
Node initial Energy	1 J
Number of connections	10-15 in interval of 5
Average speed of nodes	1m/s, 5m/s, 10m/s and 15m/s
Pause time	4sec
Source transmission rate	4 packet/sec
Packet size	512 bytes
Simulation Time	500sec
The propagation Model	TwoRayGround
Mobility model	Random Waypoint

Table4.1: Simulation parameters value

4.2 Evaluation Metrics [1, 2, 47]

The metrics used to evaluate the performance of the enhanced and the existing routing protocols are packet delivery fraction, energy per delivered packet, network lifetime and Variance of the remaining energy of the nodes at the end of simulation. Some of these metrics are used in almost every prior simulation works to evaluate their works.

4.2.1 Packet Delivery Fraction (PDF)

This is the ratio of total number of packets successfully received by the destination nodes to the number of packets sent by the source nodes. Packet delivery fraction is an important metric as it describes the loss rate. Thus packet delivery fraction in turn reflects the maximum throughput that the network can support. For all our simulations we have kept the number of data packets sent out as constant, so the number of packets successfully received at their destinations will give us a comparison as to how efficient the underlying routing algorithm is under similar traffic load. Packets may not be delivered to the destination mainly because of one of the following reasons: packet collisions in 802.11 layer, network partitions , routing loop and interface queue drop

$$PDF = \frac{Number\ of\ Packets\ \mathrm{Re}ceived\ by\ Destination}{Number\ of\ Packets\ Sent\ by\ Source} \quad (4.2)$$

An AWK program, attached in Appendix A, is used for calculation of PDF. This estimate gives us an idea of how successful the protocol is in delivering packets to the application layer. A high value of PDF indicates that most of the packets are being delivered to the higher layers and is a positive sign of the protocol performance.

4.2.2 Energy Consumption per Successful Data Delivery

It is denoted by ECSDD. It is the ratio of total network energy consumption to the number of data packets successfully delivered to the sink. The network energy consumption includes all the energy consumptions except MAC layer controls**.**

$$ECSDD = \frac{\sum_{k=1}^{N}(Ei_k - Er_k)}{Total\ Number\ of\ Packets\ \mathrm{Re}ceived} \quad (4.3)$$

Where Ei_K is initial energy of node *k*
Er_K is remain energy level of node *k* at the end of simulation
N is the number of nodes in the network

A less value of ECSDD indicates that most of that packets being delivered with less energy and is an achievement sign of protocol on energy efficiency.

4.2.3 The Variance of Residual Battery Energy in Joules (VRBE)

The VRBE of mobile nodes is a simple indication of energy balance and can be used to extend network lifetime. The computed value reflects whether the routing scheme overused any number of nodes or not. This is a very important performance measure since it is a measure of protocol fairness. Therefore, the sought value for this metric is one that is as close as possible to zero. The smaller ***VRBE*** indicates that all nodes in the network are equally important and no one node must be penalized more than any of the others.

$$VRBE = \frac{\sum_{k=1}^{N} (E_{rk} - \mu)^2}{N} \tag{4.4}$$

Where $$\mu = \frac{\sum_{k=1}^{N} E_{rk}}{N}$$

E_{rk} is the residual energy of node k

N is the network size (number of nodes)

4.2.4 Network Lifetime (NL)

This is one of important metrics to evaluate the energy efficiency of the routing protocols with respect to network partition. In wireless Ad Hoc networks, especially in those with densely distributed nodes, the death of the first node seldom leads to the total failure of the network. With number of dead nodes increasing, the network is partitioned. Even with partitioning, end-to-end transmissions may still be feasible in each partition Li et al [mp] argue that network is alive if there exists at least one pair of adjacent nodes working, since they could transmit to each other and keep the network a live. So, NL can be defined in the following ways

- It may be defined as the time taken for K% of the nodes in a network to die.
- The *lifetime of the network* under a given flow can be the time until the first battery drains-out (died) [40,47]
- It can also be the time for all nodes in the network to die.

Taking into consideration the statistical mean effect and the large number of repeated experiments under equivalent scenarios, we adopt the second definition for analysis of this thesis. Here, a node with less than 20% of its full battery capacity is considered as a dead node based on the definition in [49].

4.3 Scenarios Design

In this thesis, we consider four scenarios to evaluate the existing three well known routing protocols and the new one EEDSR. We take these scenarios by considering to date, previous works, and realistic application of MANETs with different node mobility speed.

These scenarios are designed based on the type of mobile node. The types of the mobile nodes represent the application of mobile nodes with average speed of 1m/sec, 5m/sec, 10m/sec and 15m/sec.The type of the mobile nodes include the following.

- *Person*: Those nodes are handled by pedestrian and its average speed is 1m/sec
- *Bicycle*: The nodes are in mobility with average speed of Bicycle (5m/sec)
- *Motorcycle*: The nodes are in mobility with average speed of Motorcycle(10m/sec)
- *Car*: the nodes are in mobility with average speed of car (15m/sec)

In each scenario, we vary the number of flows (source-to- destination connections.) and evaluate the three well known routing protocols (AODV, DSR and DSDV.)

Scenario-1: This represents the nodes with the average speed of pedestrian. This scenario is used to evaluate the performance of the existing routing protocols for average node speed of 1m/sec under different traffic density.

Parameters	Values
Types of node	Person
Node speed	1m/sec
Traffic Rate	4 packet/sec
Number of connections	10-25 with 5 interval

Table 4.2: Scenario-1's parameters and values

Scenario -2: This scenario design considers the application of MANETs with average node speed of Bicycle (5m/sec). The source-to-destination connections are varied.

Parameters	Values
Types of node	Bicycle
Node speed	5m/sec
Traffic Rate	4 packet/sec
Number of connections	10-25 with 5 interval

Table 4.3: Scenario-2's parameters and values

Scenario-3: It represents the application of MANETs with the nodes average speed of motor cycle (10m/sec).We evaluate the routing protocols by varying the traffic densities as just like the above two scenarios.

Parameters	Values
Types of node	Motorcycle
Node speed	10m/sec
Traffic Rate	4 packet/sec
Number of connections	10-25 with 5 interval

Table 4.4: Scenario-3's parameters and values

Scenario-4: This scenario represents the average speed of node mobility by car in the city. Here also the numbers of source-to-destination connections are varied.

Parameters	Values
Types of node	Car
Node speed	15m/sec
Traffic Rate	4 packet/sec
Number of connections	10-25 with 5 interval

Table 4.5: Scenario-4's parameters and values

4.4 Results and discussions

Scenario-1 results and discussions

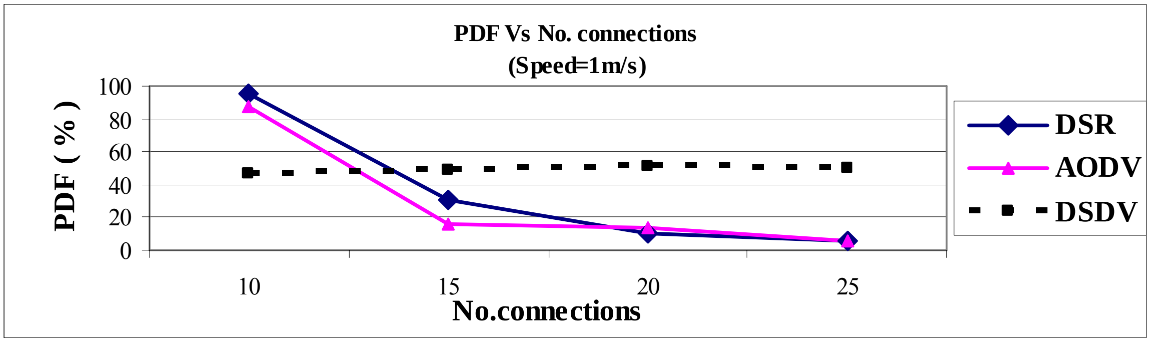


Figure 4.2: Packet Delivery Fraction of AODV, DSR and DSDV for Person

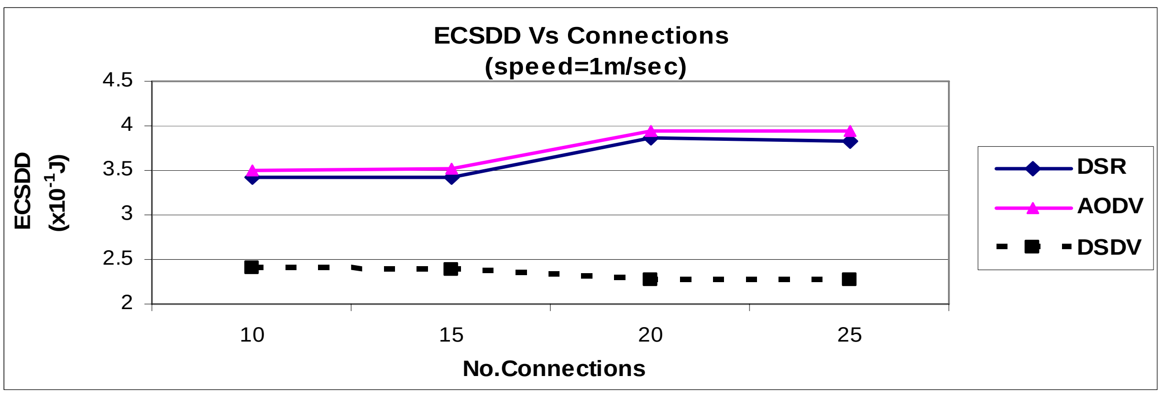


Figure 4.3: Energy per Packet of AODV, DSR and DSDV for Person

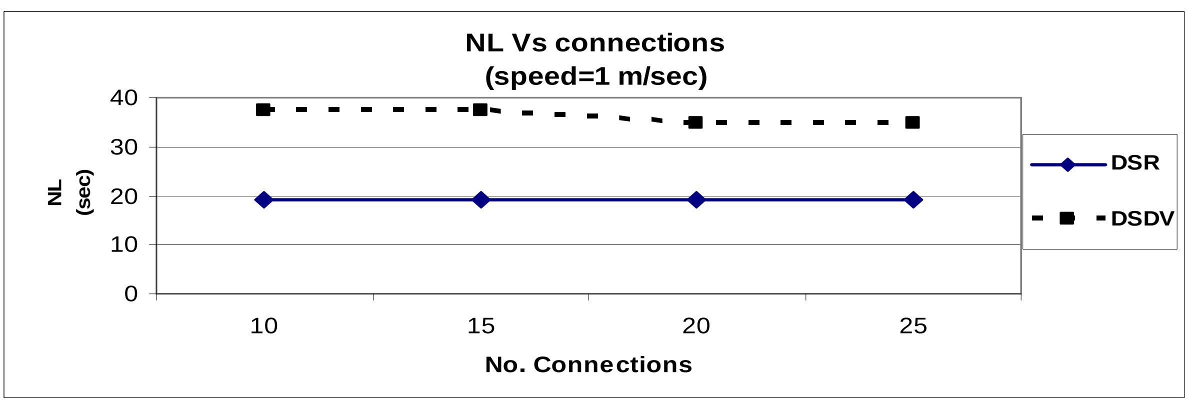


Figure 4.4 a: Network lifetime of AODV, DSR and DSDV for Person

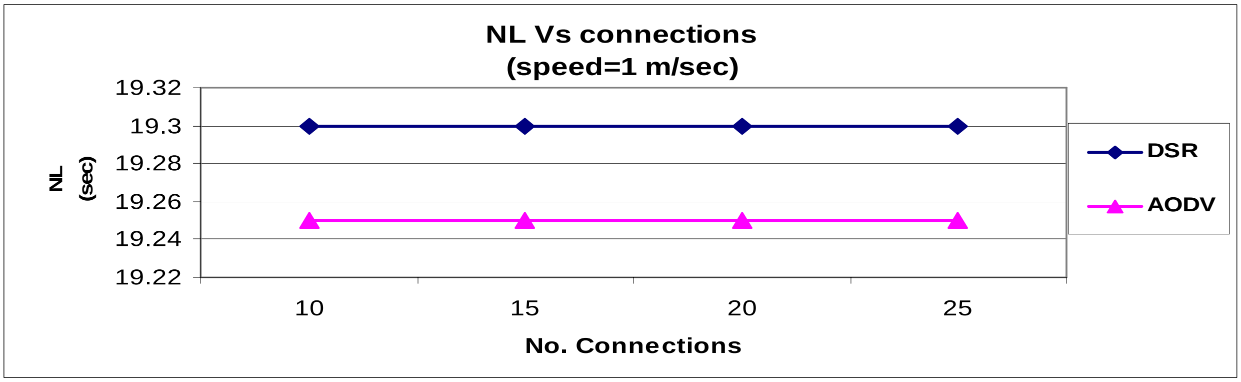


Figure 4.4 b: Network lifetime of AODV and DSR for Person

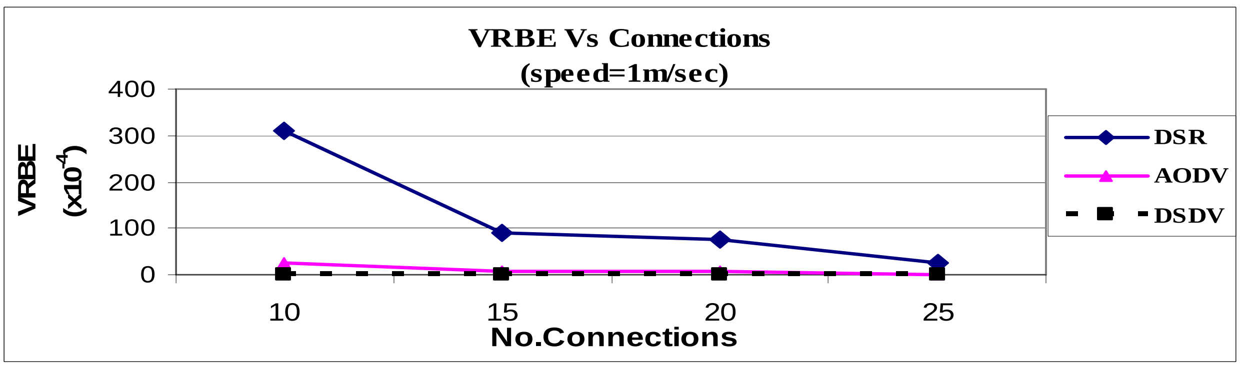


Figure 4.5: Residual Energy Variance of AODV, DSR and DSDV for Person

Figure 4.2 shows the packet delivery fraction of AODV, DSR and DSDV at low speed of mobility. PDF of DSDV is constant irrespective of the number of source-to-destination connections. This is due to the fact that DSDV maintains a constant routing overhead in any number of traffics. The DSDV routing overhead depends only the periodic update interval and the size of the network. For less number of connections, DSR and AODV score above 90% of PDF. Their performances are not persisted for large number of connections. Starting from 15 number of connections, the PDFs of DSR and AODV are below 40%. This value is less than the PDF of DSDV. This is due to the fact that routing overhead of on-demand routing protocols increases when the number of connections increases. The routing overhead degrades the PDF of the traffic. In addition, the routing table of DSDV is properly converged at lower mobility and available in advance. The PDF of the DSR is better than AODV almost for all number of connections.

Figure 4.3 shows the ECSDD of AODV, DSR and DSDV. For low speed of mobility, DSDV uses less energy per packet because the probability of the link breakage is less. The ECSDD of DSDV is decremented when the numbers of connections become large. This is due to the fact that once the routes are established; large number of traffic uses the routes without need additional energy consumption to construct new routes. The energy consumption of routing overhead is the same for large and less number of traffics for the case of DSDV. On-demand routing protocols consume a minimum of 3.4J/packet. This value is larger than the maximum ECSDD of DSDV (2.45J/packet). Energy consumption of AODV and DSR increase when the number of connections increases. This is due to the fact that these routing protocols are on-demand. Hence, this feature increases energy consumption of routing overhead. ECSDD of DSR is less than AODV because DSR uses less numbers of routing overhead than AODV.

Figures (4.4a, 4.4b) show the network life time of the three MANETs routing protocols. The network lifetime is the cumulative results of ECSDD and VRBE metrics. DSDV routing protocol makes the network energetic longer than the others two. This is due to the fact that DSDV energy consumption per packet is less than AODV and DSR. In addition, DSDV balances the energy consumption better than AODV and DSR as shown in the figure 4.5. For the case of DSDV, all nodes exchange the update whether they are active or inactive periodically. But DSR and AODV use only the active nodes for route establishment. This leads to particular nodes to be repeatedly to engage in route discovery and data packet transmission. This restricts appropriate load balancing. DSR scores longer network life than AODV. But AODV shows better load balancing than DSR as shown in figure 4.5. The network life time is determined by less energy consumption and appropriate load balancing. Here, the ECSDD of DSR dominates the load balance of AODV at this scenario.

Scenario-2 results and discussions

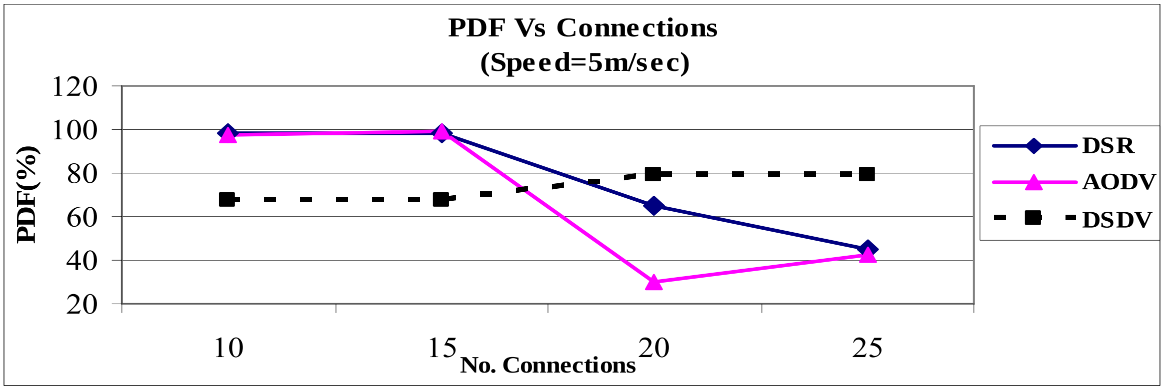


*Figure 4.6**:** Packet Delivery Fraction of AODV, DSR and DSDV for Bicycle*

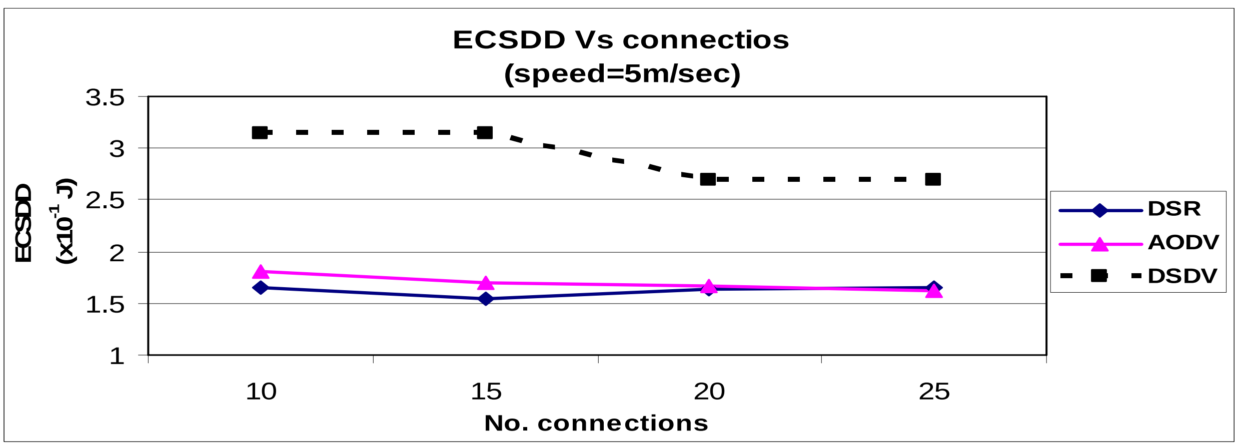


*Figure 4.7**:** Energy per Packet of AODV, DSR and DSDV for Bicycle*

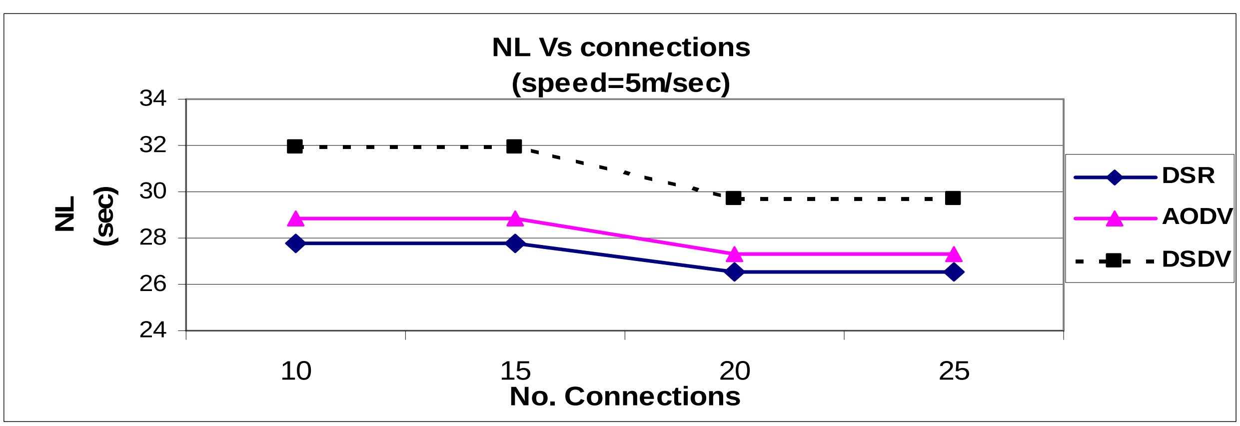


*Figure 4.8**:** Network lifetime of AODV, DSR and DSDV for Bicycle*

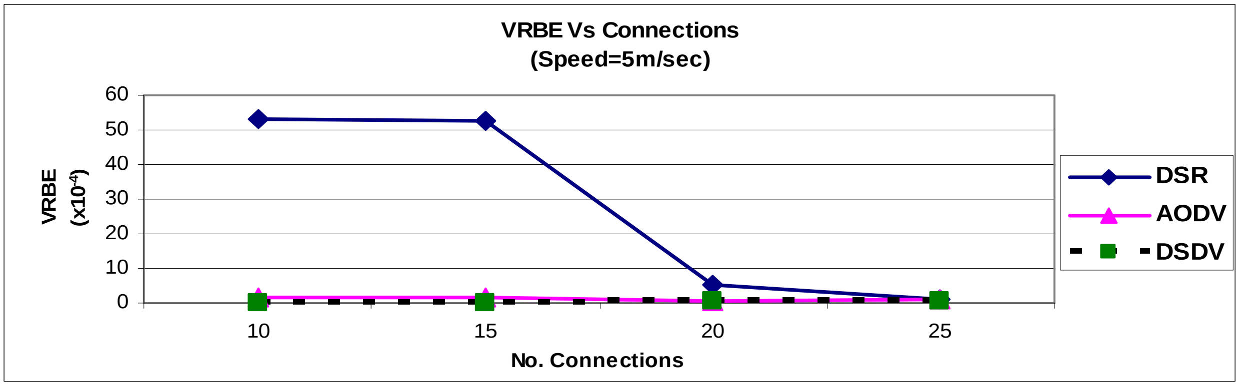


Figure 4.9: Residual Energy Variance of AODV, DSR and DSDV for Bicycle

This scenario is based on a faster mobility speed than scenario-1. Figure 4.6 shows the PDF of the routing protocols. At this scenario, DSR, AODV and DSDV scores maximum PDF of 99%, 99% and 80 % respectively. The minimum PDFs of DSR, AODV and DSD are 44%, 29% and 66% respectively. DSR and AODV show better performance than DSDV for 10 and 15 number of connections. This is due to the fact that DSR and AODV establish the routes on demand. This provides better chances to avoid usage of staled routes for DSR and AODV than DSDV. When the number of connections is greater than 15, the PDF of DSR and AODV degrade. This is due to the same reasons those are mentioned in scenario-1. However, The PDF of DSR is greater than AODV's. This is due to two facts. The first is that routing overhead of DSR is less than AODV. Secondly, AODV is aggressive to maintain broken links. AODV starts new route discovery for link breakage. Unlike AODV, DSR uses the cached route for route maintenance.

Figure 4.7 demonstrates the ECSDD of three MANETS routing protocols for bicycle mobility speed. The simulation result of this scenario shows that DSR consumes less energy per packet than the AODV and DSDV. DSR consumes 1.7 J/packet which is significantly lower than 2.7J/packet of DSDV. The probability of the link breakage goes up when increases speed of node mobility in case of DSDV. Because of staled routing table entries, packets are sent or forwarded over the broken links. This increases the retransmission attempts for successful transmission. It leads DSDV to consume large amount energy for unsuccessful communication. In addition, DSDV consumes significant amount of energy to construct unusable routes periodically. AODV and DSR start route discovery as soon as there is demand of routes. On demand route discovery avoid energy consumption to construct unusable routes. It also provides fresh route for data communication. Use of fresh route reduces the rate of retransmission that leads to consume significant amount of energy. Because of lower overhead and usage of route cached for route maintenance, DSR consumes smaller amount energy per packet than AODV.

Figure 4.8 shows the network life of scenario-2. The network is alive for 32 sec for the case of DSDV where as DSR and AODV make alive the network for 27.8 sec and 29 sec respectively. Figure 4.9 shows that VRBE of DSR is not distributed properly compared with AODV and DSDV. DSDV prolongs the network life time more than the others two too, as shown in the previous scenario also. Although DSDV consumes more total energy per packet than DSR, the energy consumption for routing overhead is distributed properly to all the nodes in the network. This minimizes the exploitation of specific node battery energy repeatedly. In DSR, the caching mechanism leads to exploit specific nodes battery energy repeatedly for data packet routing. So the network lifetime of DSR is very short compared to AODV. Hence, the lower ECSDD of the DSR is dominated by the load balance of DSDV in this scenario. The network life time of AODV, DSR and DSDV goes down when the source to destination connections increase. This is due to the fact that the collision rate and retransmission attempts increase for large number of traffics.

Scenario-3 results and discussions

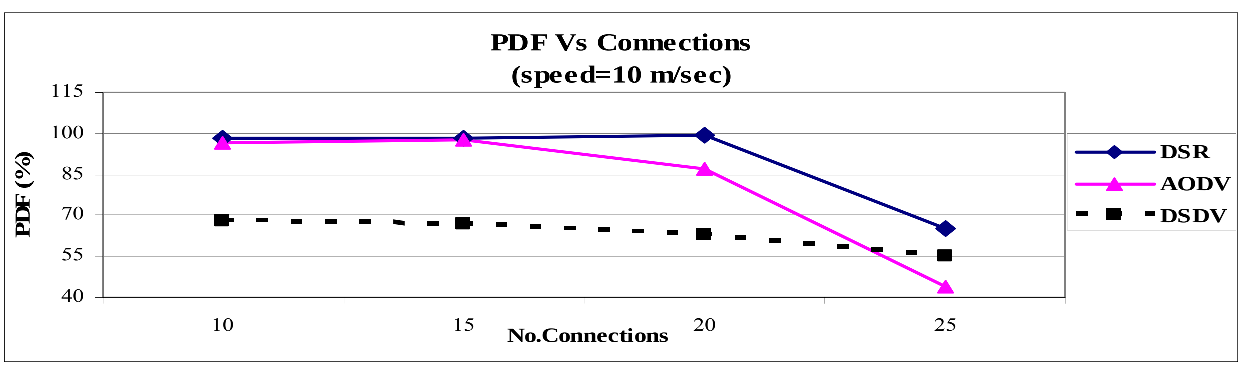


Figure 4.10: Packet Delivery Fraction of AODV, DSR and DSDV for Motorcycle

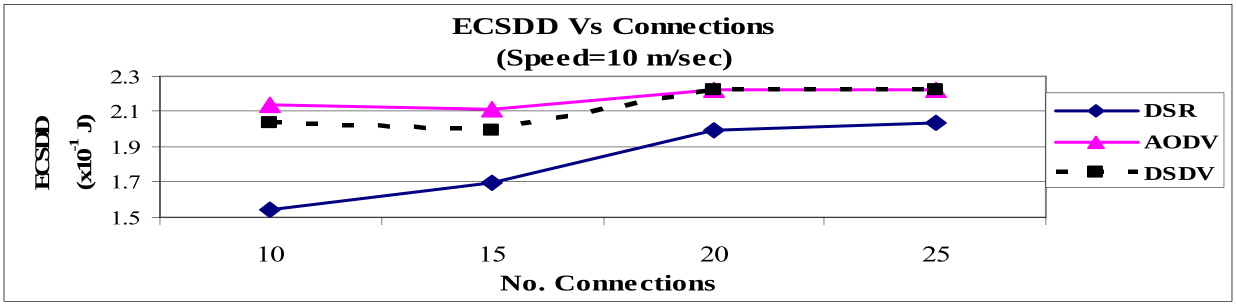


Figure 4.11: Energy per Packet of AODV, DSR and DSDV for Motorcycle

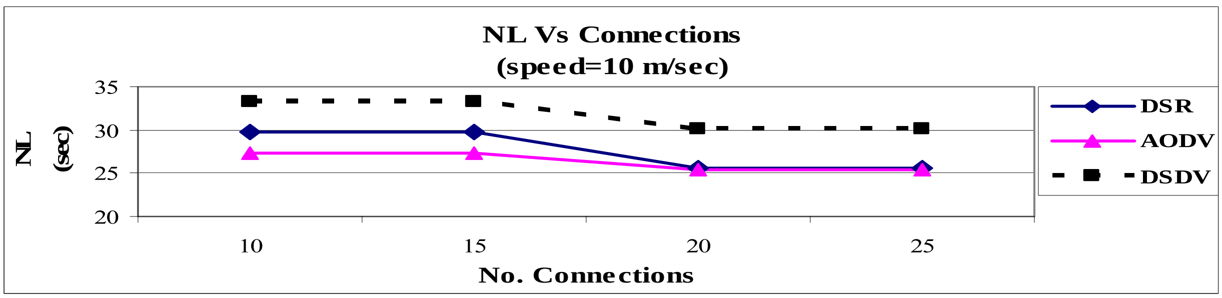


Figure 4.12: Network lifetime of AODV, DSR and DSDV for Motorcycle

This scenario represents the mobility of nodes for motorcycle. The speed of this scenario is faster than the previous two scenarios. Figure 4.10 shows that DSR and AODV outperform DSDV in PDF. By high mobility, DSDV acts very badly. Because of stale routing table entries, packets are sent or forwarded over broken links and PDF fails at high speed. PDF of DSR (maximum 99% and minimum=66%) is better than AODV (maximum=98% and minimum=42%) because DSR has access to a significantly greater amount of routing information than AODV in single cycle of route discovery. By virtue of source routing in DSR, using a single request-reply cycle, the source can learn routes to each intermediate node on the route in addition to the intended destination. Promiscuous listening on data packet transmissions can also give DSR access to a significant amount of routing information. In the absence of source routing and promiscuous listening, AODV can gather only a very limited amount of routing information. So AODV uses too many routing packets for accessing number of routing information as much as DSR.

As shown in the figure 4.11, DSR uses less ECSDD than AODV and DSDV. DSDV doesn't have up to date route entry to send the data packets in dynamic network. The node sends a packet on staled out routes. The packet is transmitted successfully after number of attempts. Number of attempts leads to much energy consumption. In addition, DSDV requires periodic transmission of reach ability information; this also leads to much higher energy consumption of DSDV. AODV consumes much more energy than DSDV. High mobility increases incidence of link and connection failures. Since AODV does not cache multiple routes, the failure of a link requires all sessions currently using that path to issue new RREQs. It causes high flooding, which drain the battery energy of the nodes. The energy consumption of the three routing protocols increases as the numbers of connections increase. Mainly, ECSDD of DSR increases dramatically (from 1.54J to 2.07J per packet) as the numbers of connections increases. This is due to the fact that DSR caches large number of routes for large numbers of connections. But these routes are not valid longer due to high mobility.

The network lifetime of the three MANETs routing protocol is demonstrated in figure 4.12. DSDV shows longer network life time than AODV and DSR as shown in the previous two scenarios. DSR prolongs the network lifetime better than AODV. The link breakage due to high mobility is more serious to AODV than DSR because AODV is aggressive to maintain broken link. Hence, the network lifetime of AODV is shorter than DSR. This indicates that ECSDD is dominant in the network lifetime of AODV and DSR for this case. NL of DSDV still outperforms DSR and AODV due to it's properly load balancing. Since the VRBE pattern of this and rest scenarios are similar to in the above two scenarios, we omit to sketch out.

Scenario-4 results and discussions

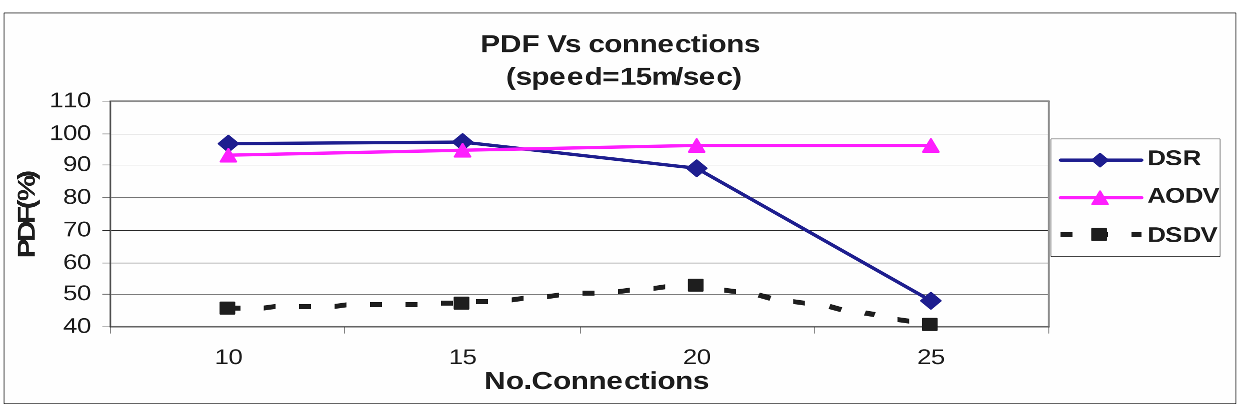


Figure 4.13: Packet Delivery Fraction of AODV, DSR and DSDV for Car

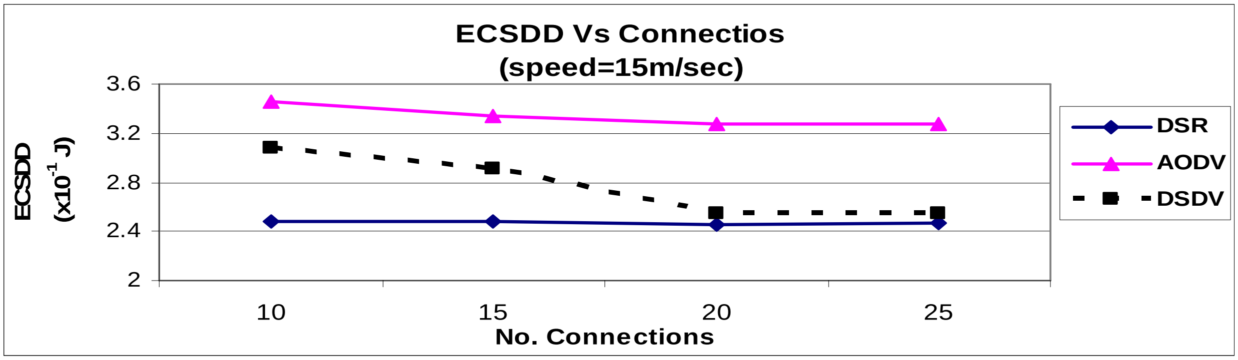


Figure 4.14: Energy per Packet of AODV, DSR and DSDV for Motorcycle

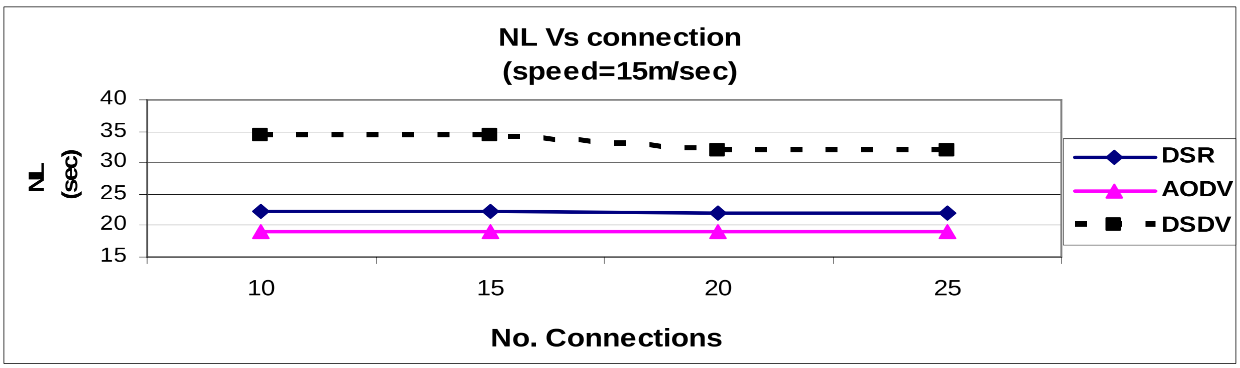


Figure 4.15: Network lifetime of AODV, DSR and DSDV for Car

This scenario represents the highest mobility. As shown in figure 4.13, PDF of DSR is better than AODV and DSDV. DSDV acts very badly for high mobility as discussed in scenario-3. DSR has access to a significantly greater amount of routing information than AODV. By virtue of source routing in DSR, using a single request-reply cycle, the source can learn routes to each intermediate node on the route in addition to the intended destination. Promiscuous listening on data packet transmissions can also give DSR access to a significant amount of routing information. But DSR is not benefited from this feature for all traffics. When the number of connections increases, DSR is highly susceptible to staled route. Hence AODV scores better PDF for greater than 15 number of connections. In the absence of source routing and promiscuous listening, AODV can gather only a very limited amount of routing information. So AODV uses too many routing packets for accessing number of routing information.

Figure 4.14 shows that DSR consumes lower energy per packet than AODV and DSDV. This is due to the fact that DSR is advantageous from the cached route even though cached routes are not valid for long in high mobility. Usage of cached route minimizes broadcast storm. Hence, the breakage of the route due to drain out of battery energy is minimized. Hence, the retransmission attempts are less for the case of DSR. So, DSR utilizes less energy for successful transmission. AODV consumes minimum of 3.3 J/packet which is much greater than the maximum ECSDD of DSR (2.5 J/packet). AODV uses too many routing packets for accessing number of routing information. Hence, AODV is suffered from the breakage of the routes due to drain out of battery energy by routing packets. The ECSDD of DSDV becomes less when the number of connections become large. This is due to the fact that high traffic increases utilization of the routes in route table entry before the routes are staled out in this scenario.

Figure 4.15 shows the network life time. DSDV does better than AODV and DSR due to the fact that DSDV is advantageous from its load balancing of routing overhead. DSR makes longer the network life time than AODV. Here, ECSDD of DSR dominates in the network life compare with load balancing of AODV.

In general, energy consumption of successful data packet includes energy consumption to routing overhead. High ECSDD causes early die of a node. It leads to link breakage (network partition). This adds routing overhead on the networks. Hence, staled out routes due to mobility raise the rate of energy consumption, which amplifies the frequent of the staled route due to battery energy drained out. In addition, the conventional routing protocols AODV, DSR and DSDV use maximum transmission power for packet transmission (covers 250m). Hence, the sender emits maximum power whether the receiver node is too close or distant. This leads to battery energy to be drained out early. This is due to the fact that the sender node emits too much energy to transmit the packet to the receiver node close to it. This also sacrifices link breakage due to lack of battery energy of the node in the route. This is not stopped here but it continues for further energy scarification for route maintenance. All the scenarios are at risk to this problem. When the number of connections increases, it becomes more severe.

4.5 Protocol selection to improve the Active Communication Energy Efficiency

The existing familiar routing protocols of MANETs have not been designed to provide energy efficient route. They have been designed to offer best efforts of less delay. Even if their design objectives are not to offer energy efficient route, they have shown significant differences in energy conservation. A single routing protocol of MANETs is not qualified to all metrics of energy efficient routing. The route discovery and maintenance of each routing protocol outperform for different energy efficient metrics. DSR outperforms others by consuming less energy per packet. Similarly, DSDV makes longer the network lifetime than the others. But DSDV consumes larger amount of energy per packet and less PDF for high speed scenarios. AODV also outshines for special scenarios. Therefore, the routing protocol selection has to consider other issues in addition to the simulation results. These issues must strength the protocol selections. The issues are the performance evaluations of the previous works and existing structure of the routing protocols for designing of energy efficient routing protocol.

PDF is one of the principal metrics which show the performance of the networks. ECSDD is also one of the fundamental metrics to show the energy consumption of the networks. Regarded these two metrics, DSR offers its best of PDF and ECSDD simultaneously. DSR has best features those are used to design energy efficient routing protocol. DSR has the feature called cached route reply. Cached route reply is used to reduce the broadcast storms. A single cycle of route discovery can provide multiple routes incase of DSR. This feature reduces the energy consumption to route discoveries. Numbers of performance evaluations have been taken on AODV, DSR and DSDV. Broch et al. [27] found out that DSR has quite stable packet delivery ratio with low and high mobility values. Perkins et al. [12] pointed out that the normalized routing load of DSR seems to be quite good and it stays quite stable with respect to node mobility even on high traffic loads. Due to the above reasons, DSR is selected to implement the Active Communication Energy Efficient routing of MANETs.

CHAPTER 5: DESIGN and IMPLEMENTATION of EEDSR

5.1 Energy Efficient DSR (EEDSR)

The main objective of this thesis is to improve the active communication energy efficiency of the routing protocols. The energy efficient routing protocols must be designed on the view point of the nodes and the network. The network lifetime is directly influenced by the nodes' lifetime in the network because the nodes act in the network as router and host. The energy consumption can be reduced by designing routing protocols those select routes with less energy consumption for end-to-end packet transmission. Even if such type routing protocols save significant amount energy, they don't guarantee to prolong the network lifetime. Sometimes these protocols may shorten the network lifetime since they use specific routes repeatedly by considering of the end-to-end energy consumption. Based on the simulation result on the previous chapter, DSR consumes the least energy per packet but the network lifetime of DSR is shorter than DSDV. This indicates that the network lifetime is not only depending on the minimum energy consumption for packet but also energy aware load balance. We design energy efficient routing protocol of MANETs is called EEDSR. It discovers the route based on energy aware metrics. It implements transmit power control hop-to-hop. EEDSR includes minimum transmit power and load distribution approaches. EEDSR bypasses energy-poor and highly queued nodes and at the same time pick a route that will consume less energy. Since EEDSR is extended from DSR, the basic operations are the same as DSR. The design of this protocol incorporates many features of energy efficient routing into DSR.

5.2 Design of EEDSR

Existing version of DSR does not posses most required features of an energy efficient routing protocol described in section 3.3. In EEDSR, all nodes except the source calculate their link cost, route cost, minimum transmit power; and add route cost and minimum transmit power to the header of RREQ packet. This section describes a design of the energy efficient routing protocols features on DSR to be extended to EEDSR.

5.2.1 Design of Transmit power control

DSR uses fixed transmit power which covers a maximum range of 250m. Hence DSR uses the same power to send the packet to nearest node and distant node from sender. This leads to unnecessary energy consumption to send the packet to near nodes. This work implements hop to hop power control at the network layer. The power required between the hops is used as part of link cost function parameter in the route discovery and selection. The aim of suitable transmit power level is to reduce the energy consumption and increase the overall network performance. This method requires that each node can record in suitable packet format field the power level, P_{tx}, used to transmit that packet. In addition, it requires that radio transceiver can estimate received power, P_{rx}, (many drivers of products based on the IEEE 802.11 standard provide this information)

With the knowledge of P_{tx} and P_{rx}, the generic node is able estimate the link attenuation. In particular, when a node receives a packet from a neighbor, the channel attenuation is simply computed as the difference (in dB) of the transmitted power P_{tx} and the received power P_{rx}. For the simple case of a symmetric channel, where neglect possible channel time fluctuation and we assume the same interference power level, the attenuation affecting the transmission of that node towards that neighbor would be the same as measured. The minimum power required for the transmission of the packet so that it is successfully received by the receiver (P_t) can be calculated by receiving node as[35]

$$P_t = P_{tx} + P_r - p_{rx} + M \qquad (5.1)$$

Where P_r is the minimum power level required for correct packet reception and M is a power margin introduced to take into account channel and interference power level fluctuations, i.e, to make the transmission more reliable in view of the fact that the channel is not symmetric. We assumed that M is the same for each terminal and its value should be properly set as a function of network density, terminal speed and channel conditions.

5.2.2 Link cost computation

DSR are designed to select route based minimum hop-count metrics. Hence the DSR assigns one for each link. The DSR has not a mechanism of link cost computation which is related with energy efficient route selection. As we have seen on chapter 2, link cost was computed by considering transmission power or/and the residual battery energy. EEDSR implements route selection metric. The new route selection metric needs the link cost computation. The link cost computation includes the parameters those are used to minimize the energy per packet and balance the load among the nodes. The link and route cost of EEDSR is derived from [12, 28 and 34]. The load is distributed based on the residual battery energy and queue length. Hence, the link cost is calculated as.

$$Lc_k = \beta\left(\frac{P_t}{E_{rk}} + \frac{PRX}{E_{r(k+1)}}\right) + \alpha \log(1 + QL_k) \quad (5.2)$$

Where P_t is minimum transmit power between node k(sender) and node k+1(receiver),

Lc_k is the link cost between node k and k+1

E_{rk} is residual battery energy of node k

$E_{r(K+1)}$ is residual battery energy of node k+1

PRX is a power to receive packet

QL_k is queue length of node k, and

β and α are weight factors for energy and load aware cost computation respectively. Current queue length is important parameter to determine the delay of the link and predict energy consumption of the sender node. If there are more packets in the queues, the sender node will spent more energy to send queued packets than the node with fewer packets in the queues. A large link cost usually indicates that the link has less remaining energy, more energy consumption due to transmitting and receiving, and more packets those are paid out the energy of the sender node.

$$L_\Pi = \underset{k \in \Pi}{Max}\{Lc_k\} \quad (5.3)$$

Where L_Π is the route cost of route π

The link with large link cost on the route is considered as the cost of the route. The worst link along the route determines the cost of the route. We need to modify the RREQ packet header to include the route cost. This value is attached in the route request packet. This protocol favors the path with minimum value of the route cost. We represent our objective function as follows:

$$R = \underset{\Pi}{Min}\{L_{\Pi}\} \tag{5.4}$$

Where R is Energy Efficient route selected by EEDSR A smaller route cost indicates that the selected route is suffered not as much of the others nominated routes. The destination node receives the route RREQs and replies the route (R) with least route cost value to destination.

5.2.3 Delay forwarding

Reconsidering the example in Figure 3.6, it is clear that, in order to solve the broadcast storm problem, Node X has to delay for a certain period before rebroadcast the best available request it received. With similar reasoning, it is apparent that each node in the network has to apply its own delay before forwarding the route request in order to suppress the redundant packets. In EEDSR, the nodes calculate the delay time when they receive the first RREQs. Receiving nodes record these RREQs ids (which include the packet source node id and RREQ sequence number) and delay time δ in request_table and rebroadcast them immediately. The waiting time δ is calculated for each first arrived RREQ as follow [43].

$$\delta = \mu \frac{P_t}{E_{rk}} \tag{5.5}$$

Where μ is a factor to adjust delay time. Small value of μ provides route with less energy efficient and hop-count than large value of μ. P_t is the minimum transmit power between sender node k and receiver node k+1. E_{rk} is the residual battery energy of the sender node k.

If the value of δ is small, the possibility of replacing RREQ in the request_table is rare. Because small value of δ indicates small minimum transmit power, large amount of residual battery energy or small minimum transmit power with large amount of residual battery energy, it is not necessary to wait for a long time to get another route with better cost.

EEDSR's intermediate and destination nodes receive copies of RREQs more than once to achieve energy efficient routing. The nodes receive other copies of RREQs with the best route, replace the copies stored in request_table (update the route cost of the stored RREQs) if their δ is not elapsed. EEDSR rebroadcasts or replies to RREQs in request_table at the end of waiting time. To minimize the latency and converges time of the routing, the EEDSR rebroadcasts or replies to the first arrived RREQs without delayed them. EEDSR changes the routes constructed by the first arrived RREQs if there are other better routes in later.

5.2.4 EEDSR Route Discovery of Energy Efficient Route

Energy Efficient Route Discovery is the mechanism by which a source node S wishing to send a packet to a destination node D. EEDSR obtains an energy efficient source route with a list of minimum transmit powers to D. Energy Efficient Route Discovery is initiated only when the "initiator" node S attempts to send a packet to "target" node D and does not already know a route to D. The process of Energy Efficient Route Discovery is entirely on demand.

The Energy Efficient Route Discovery procedure utilizes two types of messages, a Route Request (RREQ) and a Route Reply (RREP), to actively search the Ad Hoc network for a route to the desired destination.

When some source node originates a new packet addressed to some destination node, the source node places in the header of the packet a source route giving the sequence of hops along with the minimum transmit powers at which the packet is transmitted for each hop and the cost of the route. The node will look up in its cache to select the Energy Efficient route to the destination. If no route is found in the cache, it will initiate route discovery similar to the route request flooding process carried out in the DSR protocol.

5.2.4.1 Processing Route Request

To discover an Energy Efficient route, a route request packet is broadcasted over the medium at the maximum power of the interface. This is to maximize the connectivity of the route request packet in the network. The route request packet contains a source route, the link energy information for each link in the source route, and the power that the route request packet will be transmitted.

Nodes receive RREQs, compute the minimum power and the link cost using equations 5.1 and 5.2 respectively. In addition, these nodes compute δ for the new arrived RREQ using equation 5.5 and route cost for all RREQs. The route cost is the maximum cost of the link in the route. The RREQ can be processed by either the destination node of the request or intermediate node.

- *The target (destination) node processes RREQ as follows:*

Step -1: The node checks whether RREQ is first arrived by looking up the sequence number and source node id in EErequest_table.

Step-2: If RREQ is first arrived, the destination node sends a "Route Reply" to the initiator of the route request packet in which it includes the entire source route from the initiator to the destination and the minimum transmit powers for each hop, computes the RREQ waiting time (δ) and store it in EErequest_table with its waiting time till it is expired.

Step-3: If RREQ is not the first, then the node checks its waiting time δ **.**

Step-4: If RREQ is not expired, then EEDSR compares the route cost of this RREQ and route cost of its copy in EErequest_table.

Step-5: If the route cost of the coming RREQ is better than its copy in the EErequest_table, then the destination node replaces the EErequest_table entry for existing RREQ by the coming copies of RREQ. The coming RREQ with the better route cost is not replied to the destination immediately rather it is delayed for δ. If the node receives another copy of RREQ with better route cost, it replaces again.

Step-6: EEDSR timer checks the expiration time of RREQs based on the δ in EErequest_table and takes the actions stated on section 5.3.3.3

Step -7: If the route cost of coming RREQs is not better than their copies route costs in EErequest_table, then the coming RREQs is discarded.

The route reply route is found by reversing the source route in the route request and sending the packet with this source route. Each node on the route forwards the packet to the next node and transmits at the minimum power computed for the link during the route request. In this way the source learns a source route.

- *The intermediate nodes process the RREQ as follows:*

Step-1: It checks whether RREQ is new by looking up the sequence number and source node id in EErequest_table as like in target nodes.

Step-2: If RREQ is arrived, the node computes the RREQ waiting time (δ), the link cost, the minimum transmit power and updates route cost. The minimum transmit power is included in source route header.

Step-3: if RREQ is the first, the RREQ is rebroadcasted and saved in EErequest_table with its waiting time.

Step-4: If RREQ is not the first, then the node checks its waiting time δ and its expiration.

Step 5: If RREQ is not expired, then EEDSR compares the route cost of this RREQ and route cost of its copy in EErequest_table.

Step-6: If the route cost of the coming RREQ is better than its copy in the EErequest_table, then the intermediate node replaces the EErequest_table entry for existing RREQ by the coming copies of RREQ. The coming RREQ with the better route cost is not rebroadcasted to the destination immediately rather it is delayed for δ that is calculated at the first copy of RREQ. If the node receives another copy of RREQ with better route cost, it replaces again.

Step-7: EEDSR checks the route in its cache. If there is no route in cache, the RREQ must be processed based on the procedure from step-1 to step-6.

Step-8 If there is a route in cache, EEDSR unicasts the RREQ to destination for checking the route. The unicasted routes are treated as just like the others RREQs by each node.

Step-9: EEDSR timer takes the actions as stated on section 5.3.3.3 to rebroadcaste or unicast the updates periodically.

Step -10: If the route costs of coming RREQs are not better than their copies route costs in EErequest_table, then the coming RREQs is discarded.

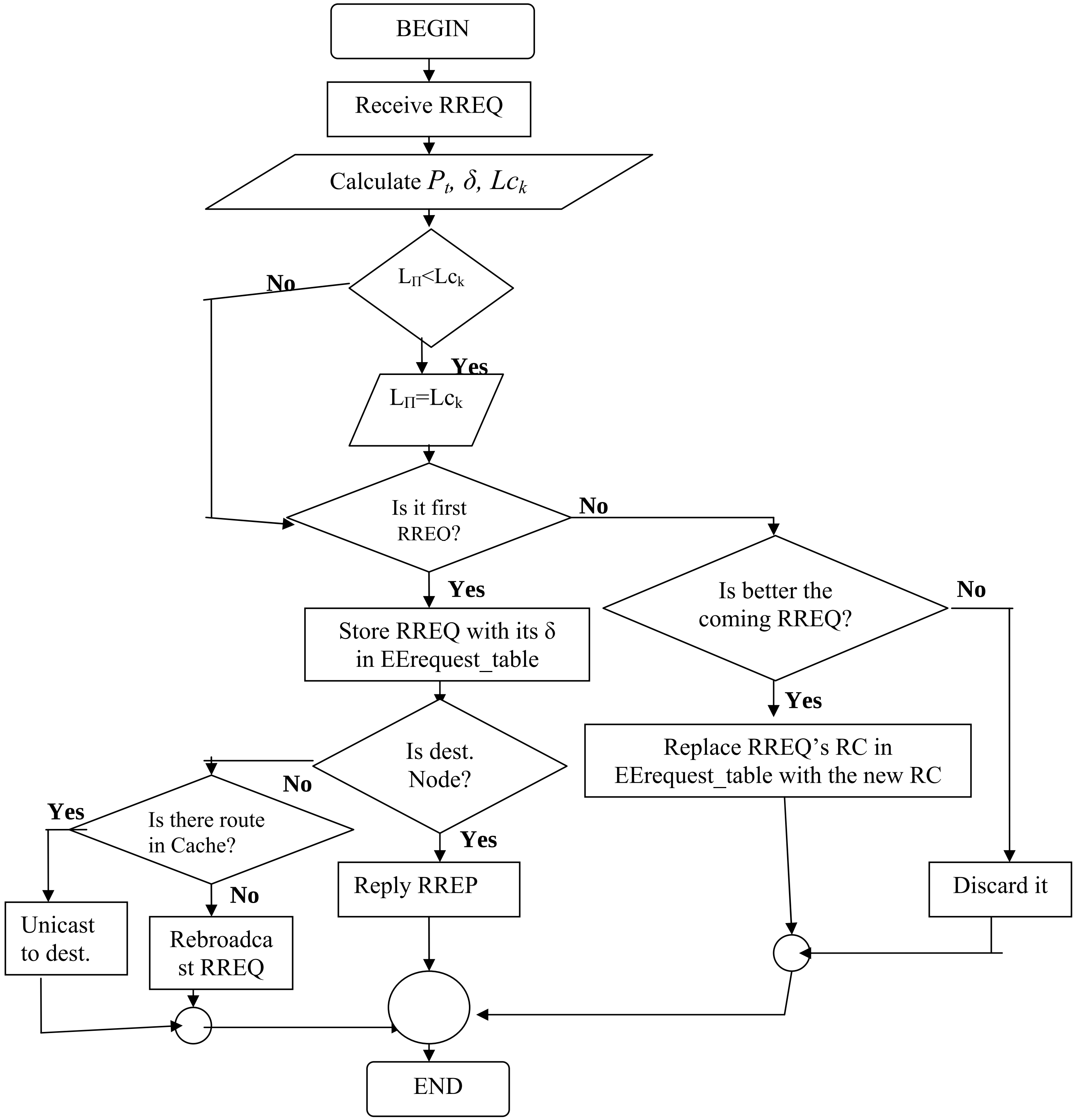


Figure 5.1: EEDSR route request packet processing flow chart

Figure 5.1 shows the RREQ processing of EEDSR by intermediate and destination nodes. EEDSR timer checks the EErequest_table periodically. This timer accesses the RREQs in EErequest_table. If there are RREQs whose lifetime are expired, it broadcasts or replies automatically and delete from the table.

5.2.4.2 Additional route discovery mechanisms

EEDSR includes additional route discovery mechanisms. These mechanisms are inherited from promiscuous mode and route-cache reply of DSR. Each node listens to the unicast route replies using the "***promiscuous***" mode and estimates the link cost between itself and the transmitting node using equation 5.2. It then looks up its cache to check if there exists a route from itself to the next hop of the route reply packet whose route cost is less than the cost at which the packet is currently being transmitted by the transmitting node. If such a route exists, the node unicasts to destination. The destination node replies a route with less cost to the initiator of the route discovery.

DSR optionally allows non-destination nodes to generate Route Replies from cached values (***route-cache reply***). Any on-demand routing protocol must utilize some type of routing cache in order to avoid the need to re-discover each routing decision for each individual packet. However, the cache itself may contain out-of-date information indicating that links exist between nodes that are no longer within wireless transmission range of each other. This stale data represents a liability that may degrade performance -rather than improve it [17]. EEDSR requires fresh routes in the network to be optimal energy efficient routing protocol. In EEDSR, the route from the cache is unicasted to the destination, instead of replaying to initiator of the request. This mechanism minimizes the broadcast storm and provides a route with updated information. DSR provides each node with a route cache to be used aggressively to reduce the number of control messages that must be sent. Even if route reply from cache saves energy; the link information may be staled out because mobility and drain out of the node battery energy. So, we use unicast propagating of the RREQ to destination for all routes from the cache. Hence, EEDSR minimizes the broadcast storm and discovers the route with updated information. The destination node replies gratuitous to initiator of the node.

5.2.4.3 Processing Route Reply

The Route Reply packet (RREP) is processed by the three functional types of the nodes. These are source node, destination node and intermediate node of the request. The destination node of the request originates RREP as follows

- The node creates an RREP source route header based on the Route Reply packet format of the table 5.2.
- The ***MTP*** fields are copied from the Route Request packet to RREP source route header
- The ***MTP[n]*** field is set to the minimum transmit power computed from the last hop.
- The packet should be sent at the power represented by the ***MTP[n].***

The condition of bi-directional links should exist for Energy Aware Route Replies. The node should send a unicast Route Reply to every Route Request packet it receives for which it is a target node.

If the node is on the source route specified on the route reply, it should check that the computed minimum transmit power that it would transmit at on the route is achievable. If the node forwards the RREP, it should transmit the packet at the minimum transmit power listed in the EEDSR header. The source node of the request receives RREP. This node caches the route then creates the source route for packet waiting this route. The source node should send the packet with the transmit power in ***MTP [1]*** field.

5.2.4.4 Design of the timer

To minimize rebroadcast storm, EEDSR keeps RREQs in the table called EErequest_table. As mentioned in design of route request processing, another copy of RREQs with better route cost may be received by the intermediate or destination nodes. The nodes do not rebroadcast or reply these RREQs immediately. Instead, the nodes save these RREQs in the table by replacing the existing copies of them. The RREQs are valid in the table till their waiting time (δ) is expired. So, there must be a timer which checks and perform appropriate action on the expired RREQs in the table.

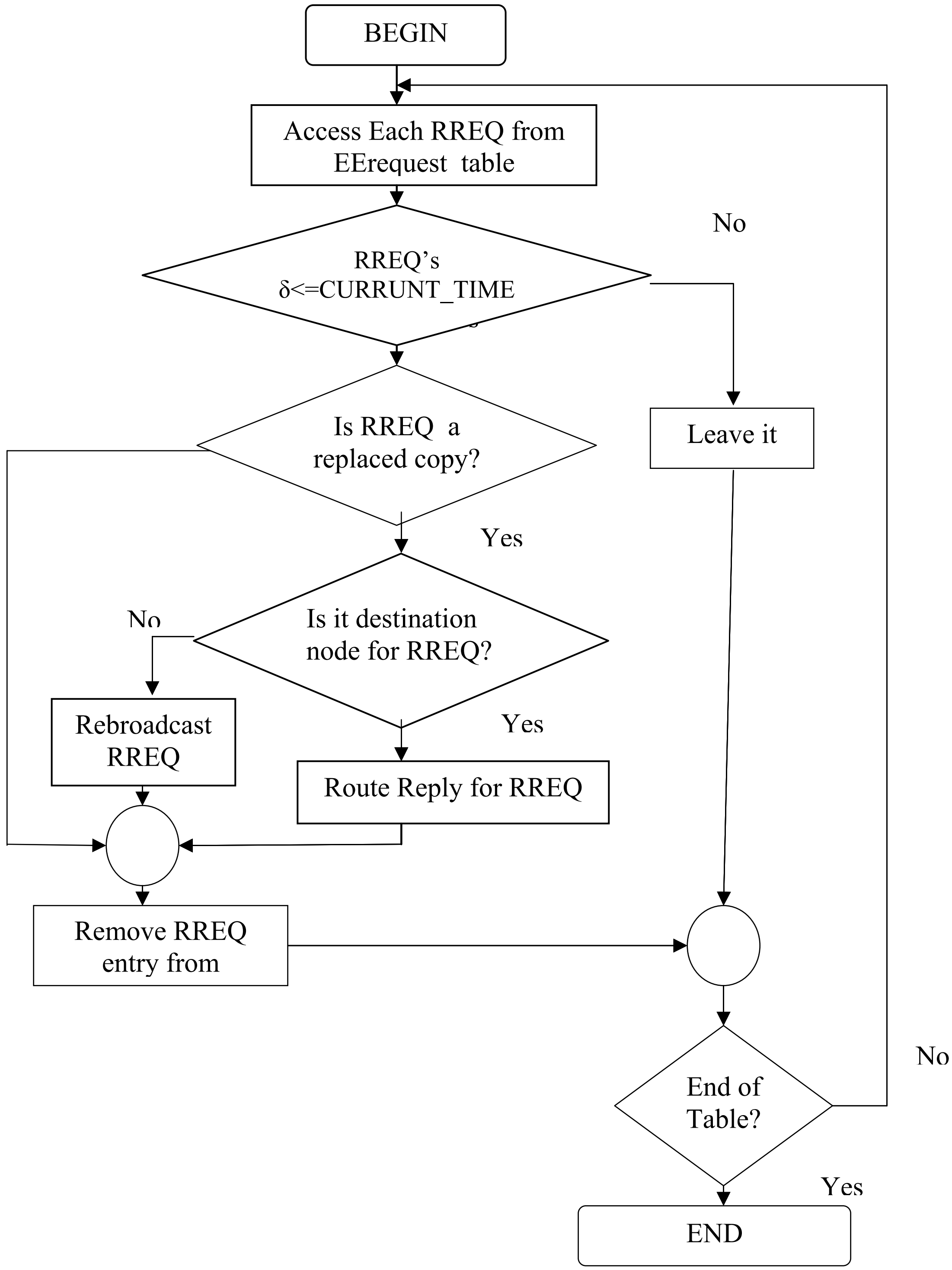


Figure 5.2: Flow chart for EEDSR timer

As shown the figure 5.2, the timer checks each RREQ till the end of EErequest_table. Each RREQ's δ is compared with the current time. If its δ is less than the current time, the RREQ is considered as expired. Therefore, it must be removed from the table. Before removing it, the timer checks whether this is the first RREQ not updated yet, or not. If this is the first RREQs, this RREQ was rebroadcasted or replied before so that it is removed from the table with out doing anything. It may be an update of the previous RREQ. This RREQ replaced the previous copy of itself because its route cost better than the previous copy. So it must be rebroadcasted or replied by the timer at the end of its lifetime in the table. Finally the timer must remove this RREQ's entry from the table.

5.2.5 EEDSR Route Maintenance

In Energy efficient routing, Route maintenance is carried out in case the links in the routes being used break due to the following reasons:

• Mobility and channel fluctuation: Connections between some nodes on the path are lost because the received power falls below the receiver sensitivity threshold.

• Energy Depletion: The energy resources of some nodes on the path may be depleting too quickly. Hence, the node is automatically out of the network.

In EEDSR, the source route header includes the list of intermediate nodes and the minimum transmit power for each link. The data packet is now transmitted by each node in the route at the power level specified by the minimum transmit power value in the header. On each forwarding link, the transmitting node expects a Link-Layer Acknowledgement in return. In case the ACK is not received within a certain time interval, the node removes that link from the cache. As in DSR, if it is not the source of the packet, it generates a route error message specifying the link that is broken and sends the route error packet to the source of the data packet.

Energy Aware Route maintenance additionally involves tracking the minimum transmit power of the links on the route. At every link in the route of a data packet, the receiving nodes compute the new estimate of minimum transmit power for the link (P_{cmp}) and compares the value to the value specified in the header (P_{hdr}). Each node along a source route should check the difference between the P_{cmp} and P_{hdr} for this hop. If the following equation holds, the ***Link Flag*** should be set and the advertised minimum transmit power should be overwritten by the new estimated value of the minimum transmit power.

$$|P_{hdr} - P_{cmp}| > M_{thresh} \quad (5.6)$$

Where P_{hdr} is the power the packet was transmitted as listed in the EEDSR option, and P_{cmp} is the computed minimum transmit power for the received packet. If the destination node receives the Data packet, it should check the ***Link Flag*** in the Source Route header. If the flag is set, it should create a gratuitous reply to the source node. This reply is used to update cached route in the source node

5.2.6 Design of Packet Structure for EEDSR

EEDSR is source route on demand routing. So EEDSR consists of small packet header and the actual packet data. The header holds the route for the packet. i.e. the complete route sequence and corresponding minimum transmit power are included within the source rout of the packet. Each node extracts the source route header to decide the next hop and transmit power for data, error and route reply packet. The route request packet either broadcasted or unicasted with maximum power of range to 250m.During route discovery, the optimal route are selected based on the route cost in the source route header. The EEDSR packet formats are adopted from [19, 45] with some modifications. The EEDSR protocol uses all the options that are used by the DSR protocol in addition to a special option denoted the EEDSR option. This optional header consists of the fields that carry energy aware information. The special headers of the EEDSR are written in bold format (Table 5.1, 5.2, 5.3 and 5.4).Minimum Transmission power (**MTP**) field is one of the fields added for EEDSR It is a variable length field whose length is varied based on the number of hops on the route. The ***MTP*** field may have different definitions in different packets and its position on the format of the packet For example; the ***MTP*** fields are shown on the table 5.3 twice. Its meaning is different on the two positions. In the source route field, ***MTP [1]*** corresponds to the source to first node link in the source route. ***MTP [2]*** corresponds to the first nodes to second node link, etc. ***MTP[n]*** in every packet correspond to the link to the destination. Route Cost ***(L_{Π})*** is another important field in the EEDSR option. It is a single float value of the route based equation 5.3. We describe the packet structures for EEDSR and discuss the changes in each packet option below.

Data packet: The P_t value must be the power that the packet is actually transmitted on the link. If for any reason a node chooses to change the transmit power for hop i, then it must set the P_t value in ***MTP[i]*** to the actual transmit power. If the new power differs by more than $\boldsymbol{M_{thresh}}$, then the ***Link Flag*** is set. Table 5.1 shows the data packet format for EEDSR. The packet includes the DSR fields besides the special fields of EEDSR.

IP Header	DSR fixed Header	DSR source header	DSR source Route Address [1……..N]	**EEDSR Source route MTP [1……..N]**	**Link Flag**	DATA

Table 5.1: Data Packet Format in EEDSR

Route Request (RREQ) Packet: The receiving node of RREQ must compute the P_t for this hop according to equation 5.4 and replace ***MTP[i]*** with this computed P_t. In addition, the receiving node must compute the route cost because the current hop may change the value of route cost. If there is a change, ***RC*** must be replaced by the changed value. Table 5.2 shows the RREQ packet format in EEDSR.

IP Header	DSR fixed Header	DSR Route Request Header	Request Addresses [1…….N]	**EEDSR Source Route Powers (MTP) [1………N]**	**EEDSR Route Cost (L_{Π})**

Table 5.2: Route Request Packet Format in EEDSR

Route Reply Packet: The reply path powers and the source path powers are included in the new route reply packet format. As discussed in section 5.3.3.2, the RREPs are forwarded to the next hop defined on the source route addresses with minimum transmit powers given by the EEDSR Source Route Powers MTP [1…N]. The source route for RREP is the reverse of source route of the RREQ. Hence, the destination node reverses the source route of RREQ and assign to source route of RREP. Reply addresses and powers of RREP are copied directly from the RREQ source route. These fields decide the next hop and minimum transmit power for the data packet to be transmitted using the route defined in RREP. The source node copies the Reply Addresses and Powers ***MTP*** of the RREP to source route of the data packet waiting in send buffer. The table 5.3 shows the format of RREP packet that includes the energy aware information for implementation of EEDSR.

IP Header	DSR Fixed Header	DSR Route Reply Header	Reply Addresses [Src,1…N,dest]	**EEDSR Reply Powers MTP [1…N,dest]**	DSR source Route Header	DSR source Route Addresses [1……..N**]**	**EEDSR Source Route Powers MTP [1….N]**

Table 5.3: Route Reply Packet format in EEDSR

Route Error packet: These packets are generated at a node in case the link-layer reports a broken link during a data-packet transmission. When a node is unable to verify reach ability of a next-hop node after reaching a maximum number of retransmission attempts, it should send a Route Error to the source node of the packet. A node transmitting a Route Error must create an IP packet. Set the Source Address field in this packet's IP header to the address of this node and copy the source address field of the packet triggering the route error into the destination address field in new packet's IP header. The source route of the new packets are field with the reverse source route of the data packet from the source node to the node triggers the route error. Hence, MTP [1] is the minimum transmit power from the node triggers route error to the next hop whose address in addresses [1] of table 5.4.

IP Header	DSR Fixed Header	DSR Route Error Header	Unreachable Node Address	DSR Source Route Header	DSR Source Route adresses [1…N]	**EEDSR Source Route powers [1…..N]**

Table 5.4 Route Error Packet format in EEDSR

When a node receives a packet containing a Route Error option, that node must remove from its Route Cache the link from the node identified by the Error Source Address field to the node identified by the Unreachable Node Address field (if this link is present in its Route Cache). After processing the Route, the node MAY initiate a new Route Discovery for any destination node for which it then has no route in its Route Cache as a result of processing this Route Error.

5.3 Implementations

This section presents the specific implementation of EEDSR designed for the proposed solutions. The proposed solutions are expected to extend the lifetime of the network and nodes. The DSR, MAC, COMMON and QUEUE folders of NS-2 have been modified to implement EEDSR. Majority of the works have been done on DSR program files' folder

5.3.1 Changes made to DSR's to implement EEDSR in NS-2

DSR is already implemented in NS-2. Details of the implementations of DSR in NS-2 can be found in the documentation [38]. This section presents the changes made on existing DSR [22] protocol implementation in order to have EEDSR. More C++ program files of DSR are modified to implement the desired objectives of EEDSR in the NS-2 simulator. In addition to the DSR program files folder, the other supportive files folders are also modified like MAC, COMMON and QEUEU. Here are the modified program files of DSR protocol:

dsragent.cc and dsragent.h implement and define the DSR routing protocol in NS-2. ***dsragent.cc*** is organized in to functions. The functions are designed based on their task on routing activity. These thesis starts implementation by incorporating the computation of the P_t, LC_k, and δ (equations 5.1, 5.2 and 5.3) in **`handleCost(SRPacket &p)`** function in ***dsragent.cc***. ***HandlePacketReceipt*** and ***handleRouteRequest*** functions are modified to implement energy aware route reply (in section 5.3.3.2) and route request (in section 5.3.3.1) respectively. Existing

ignoreRouteRequestp function of DSR discards the copy of RREQ. In EEDSR, this function is modified to receive more than one copy of RREQs**.** ***HandleRouteRequest*** and ***handlePacketReceipt*** functions decide to whether discard or replace the existing copy based on the ***RC*** value extracted from the RREQ packet. ***replyFromRouteCache*** is substituted by ***EEreplyFromCache***. This function unicasts the route request to the destination rather than reply the route from cache to initiator of the request. EEDSR includes delay forwarding mechanism to minimize broadcast storm. Delay forwarding is handled by the timer driven function. This function is included in ***dsragent.c*** file with function name of ***rreq_purge***. The route is maintained during data communication by computing the actual minimum transmit power of the data packet with the minimum transmit power in source route of the data packet using equation 5.6. The destination node of the data must reply a gratitude reply to the source node if the data Link Flag is set. The gratitude reply is implemented with the function called ***gratituedReply(SRPacket &p)***. ***hdr_sr.h*** file defines the source route header of DSR. The DSR source route format is modified to handle power aware information of EEDSR (section 5.3.5). In addition to the above source files, other source files are also modified.

5.3.2 Changes made to other common folders to implement EEDSR

COMMON is a folder which includes a number of source files. ***packet-stamp.h*** is one of the source file in COMMON folder. It defines the information which is stamped with the packet. The sender node must stamp vital information for EEDSR on the packet. This information includes its residual battery energy, queue length and the power packet sent with. The receiver node must extract this information from the packet for further processes. The packet structure is defined in ***packet.h*** file. The packet structure contains headers and information (data). Common header (***struct hdr_cmn***) is one of the headers on the packet structure. This header is accessed by all the layers. So, it is used to exchange information between the layers. In EEDSR, the residual battery energy of receiver node is used for link cost computation on the network layer. The physical layer must send the residual energy of the node to the network layer using ***hdr_cmn***. These are mains of many modifications made to implement EEDSR in NS-2 simulator.

CHAPTER -6: SIMULATION RESULTs and DISCUSSIONs of EEDSR and DSR

6.1 Simulation of EEDSR and DSR

This chapter is concerning the testing of EEDSR in simulation. The simulation results are taken based on the four scenarios defined in section 4.3. These scenarios have been used for evaluation of the three well-known MANETs routing protocols. The simulation results have to address the evaluation metrics defined at section 4.2. We consider one additional scenario called traffic based scenario. The objective of this scenario is to analysis the effectiveness of the EEDSR for different traffic rates. As shown on table 6.1, traffic based scenario considers average speed of 10 m/sec. The traffic rate varies from 2 packet /sec to 10 packet/sec in 2 packets/sec interval. The simulation results and discussions are used to analyze the energy efficiency and performance of EEDSR and DSR.

Parameters	Values
Types of node	Motorcycle
Node speed	10m/sec
Traffic Rate	2-10 packet/sec with two interval
Number of connections	10-25 with 5 interval

Table 6.1: traffic rate based Scenario's parameters and values

6.2 Simulation results of EEDSR and DSR

Scenario-1 results:

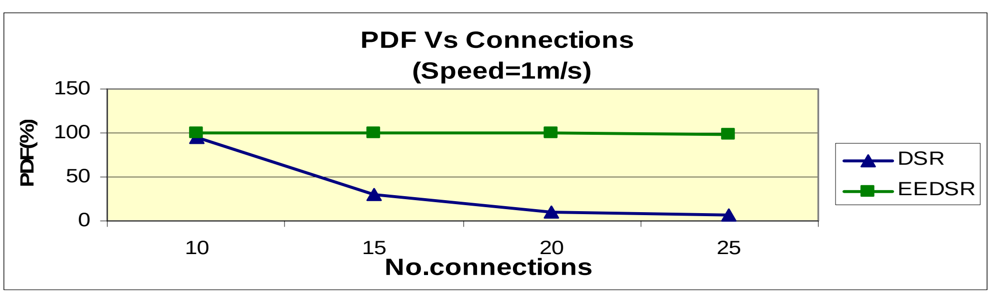


Figure 6.1: PDF Vs No. connections for scenario-1

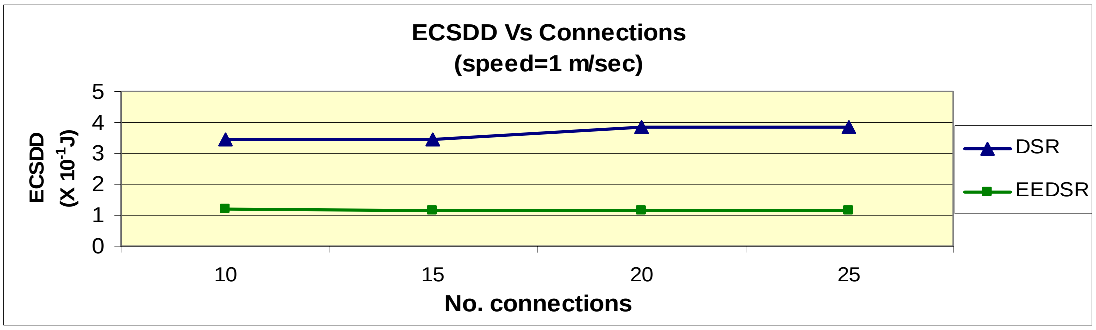


Figure 6.2: ECSDD Vs No. connections for scenario-1

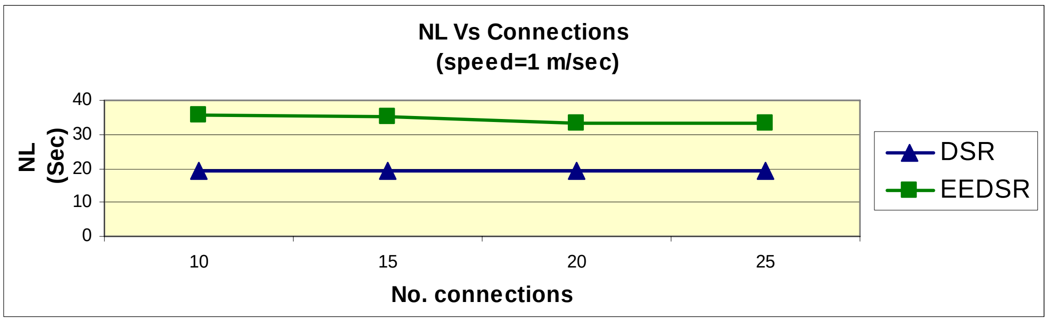


Figure 6.3: NL Vs No. connections for scenario-1

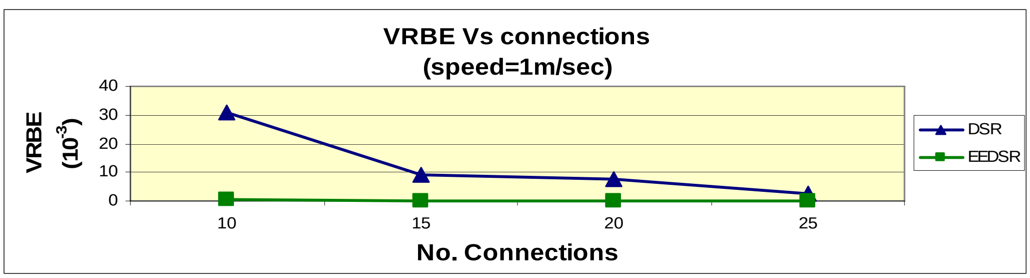


Figure 6.4: VRBE Vs No. connections for scenario-1

Scenario-2 results:

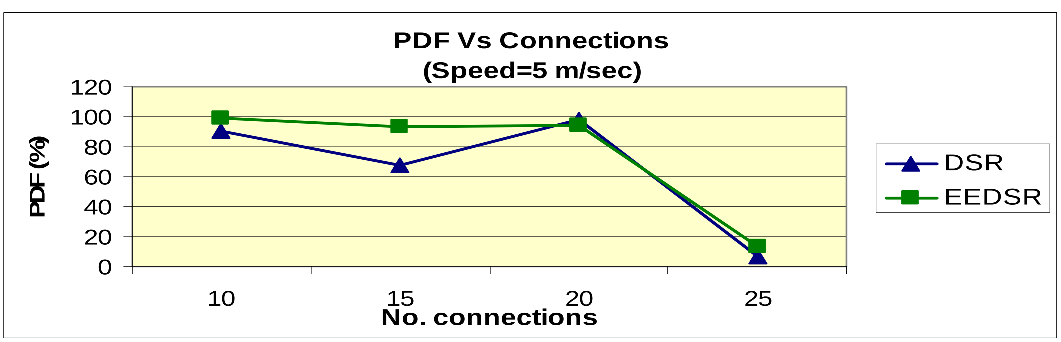


Figure 6.5: PDF Vs No. connections for scenario-2

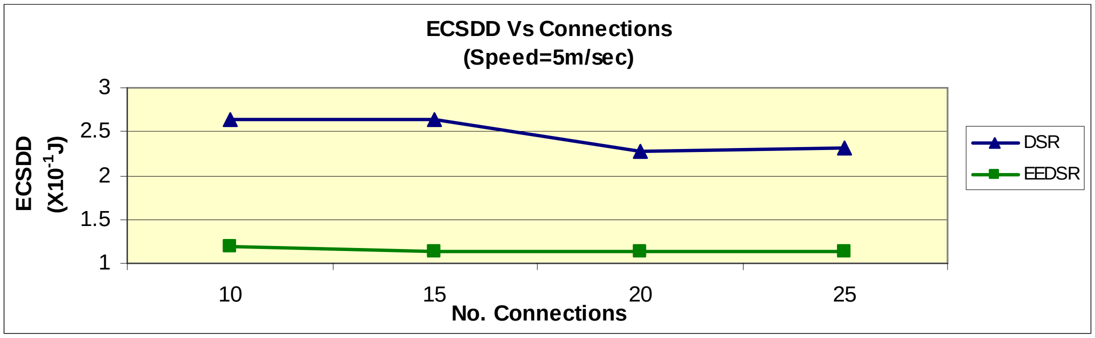


Figure 6.6: ECSDD Vs No. connections for scenario-2

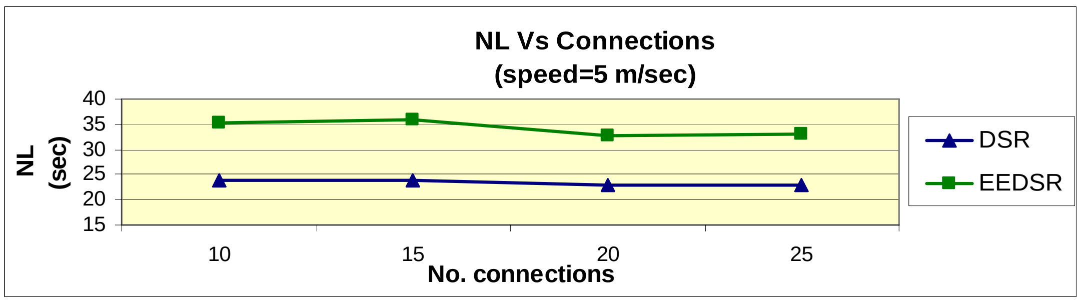


Figure 6.7: NL Vs No. connections for scenario-2

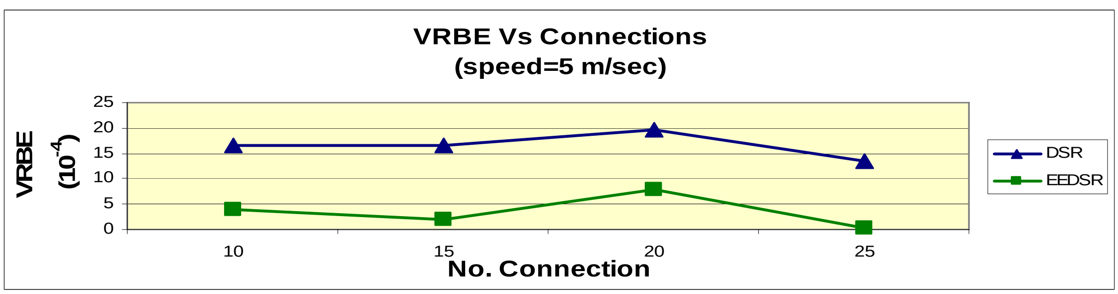


Figure 6.8: VRBE Vs No. connections for scenario-2

Scenario-3 results:

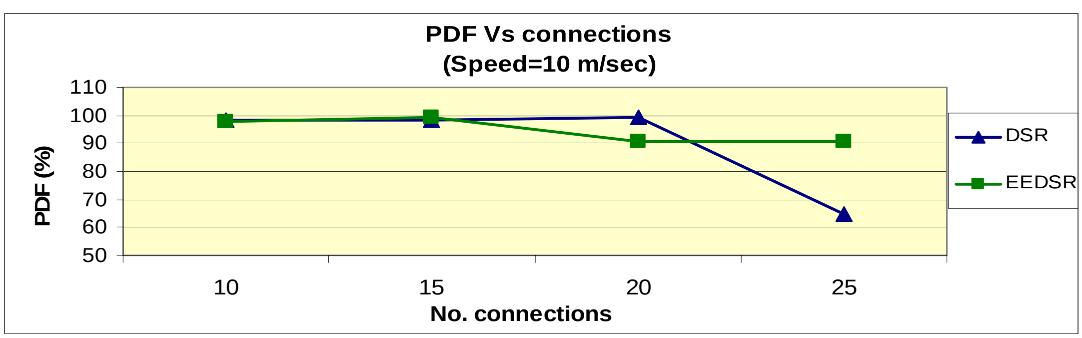


Figure 6.9: PDF Vs No. connections for scenario-3

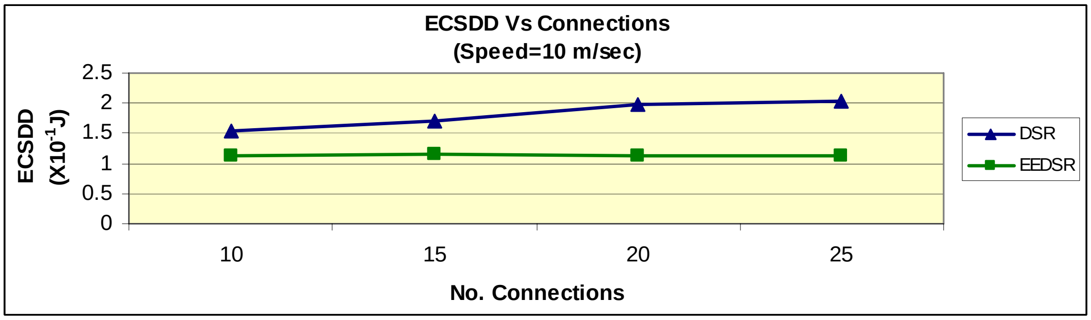


Figure 6.10: ECSDD Vs No. connections for scenario-3

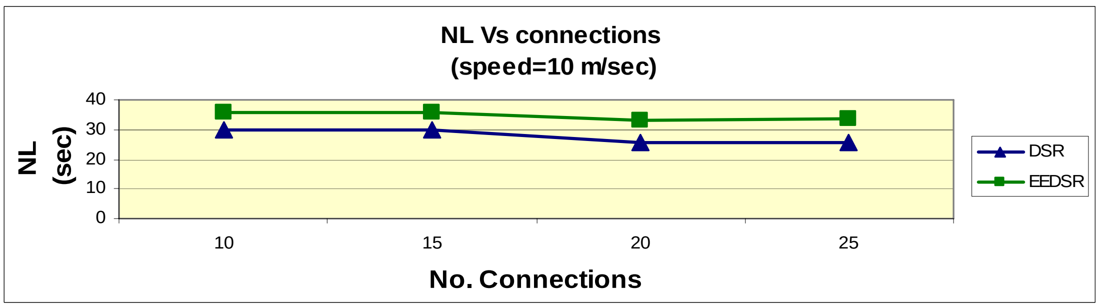


Figure 6.11: NL Vs No. connections for scenario-3

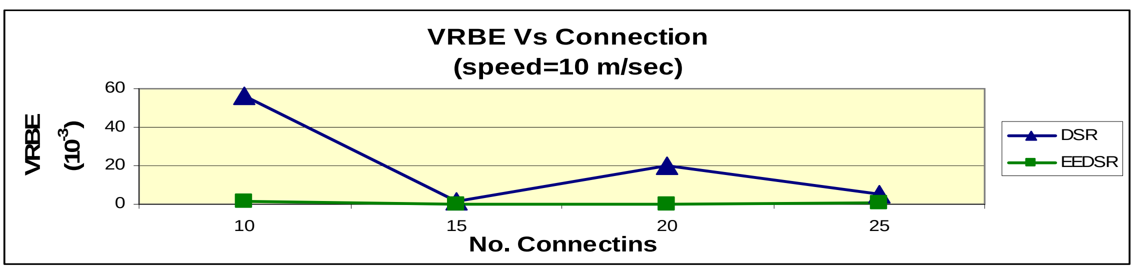


Figure 6.12: VRBE Vs No. connections for scenario-3

Scenario-4 results:

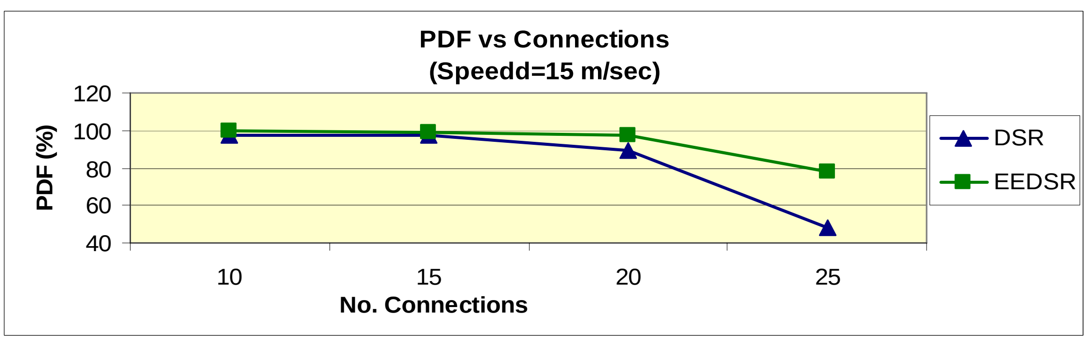


Figure 6.13: PDF Vs No. connections for scenario-4

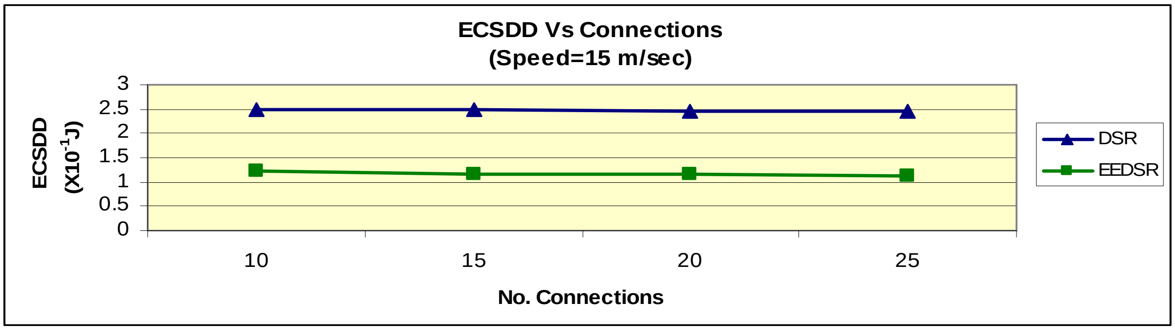


Figure 6.14: ECSDD Vs No. connections for scenario-4

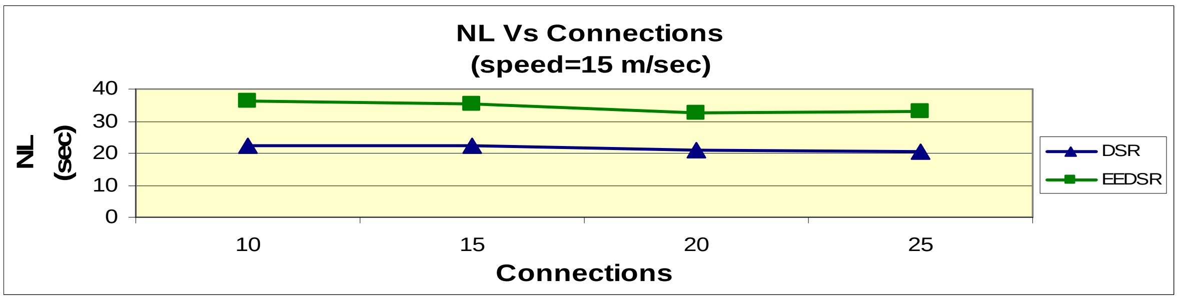


Figure 6.15: NL Vs No. connections for scenario-4

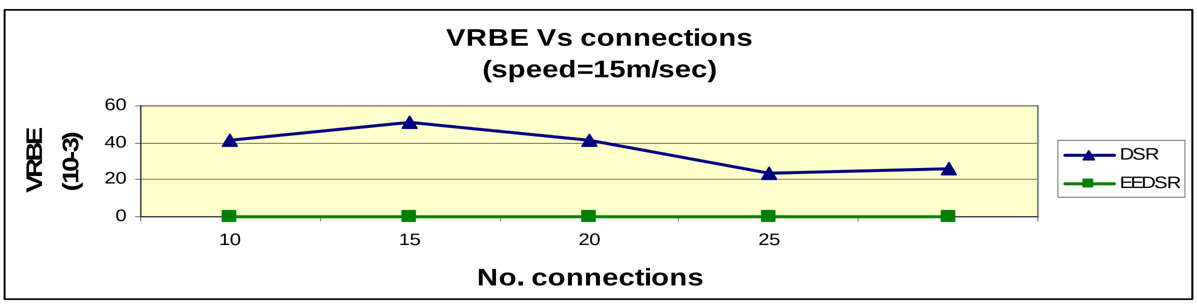


Figure 6.16: VRBE Vs No. connections for scenario-4

Traffic based scenario results:

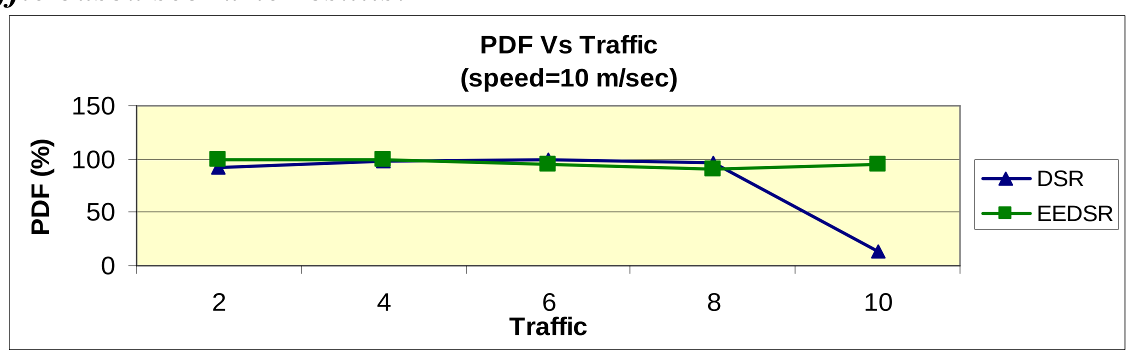


Figure 6.17: PDF Vs No. connections for traffic based scenario

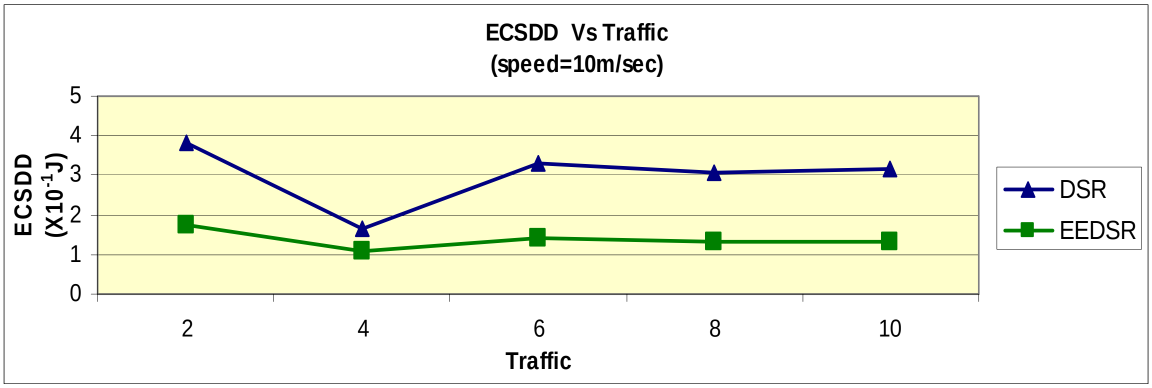


Figure 6.18: ECSDD Vs No. connections for traffic based scenario

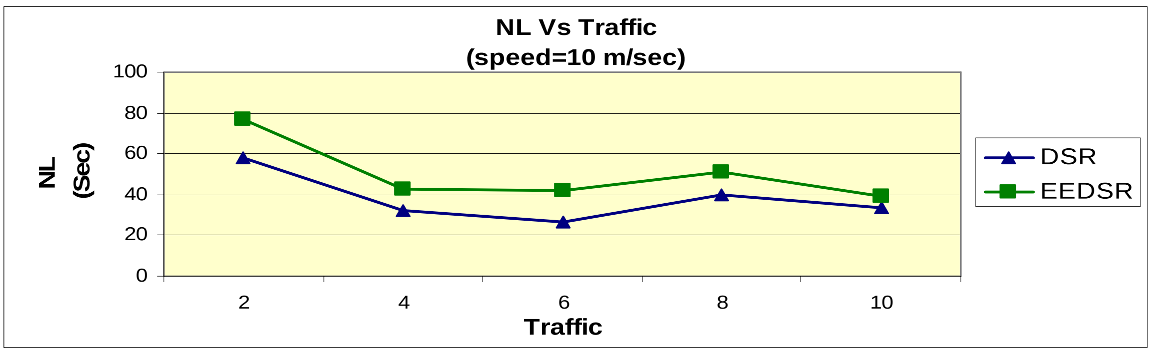


Figure 6.19: NL Vs No. connections for traffic based scenario

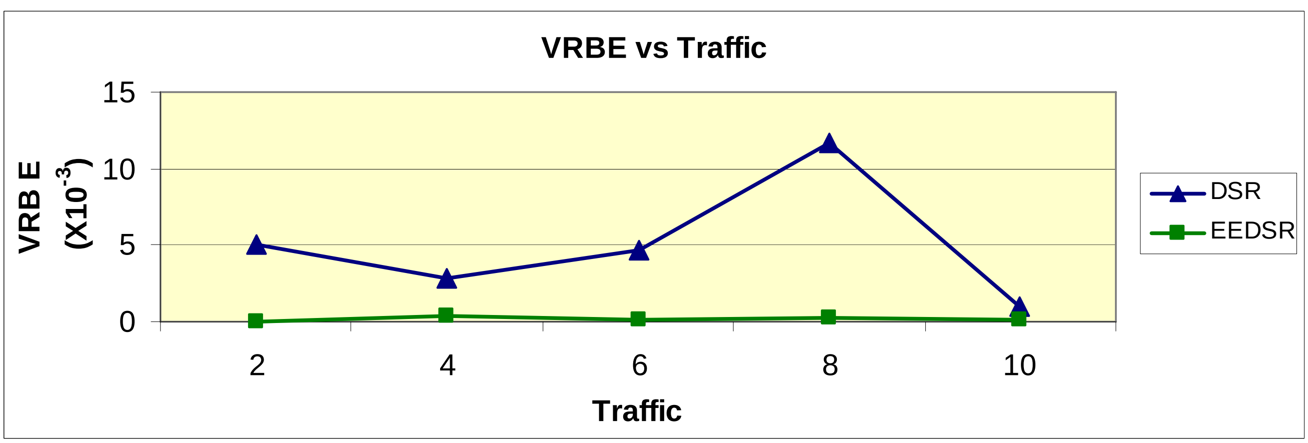


Figure 6.20: VRBE Vs No. connections for traffic based scenario

6.3 Summary of EEDSR and DSR Results

The result sections show the performance and energy efficiency of EEDSR and DSR with line graphs. This section copes with the analysis of the results for five different scenarios. The discussions are divided into four sections based on the performance and energy efficiency metrics. These metrics are PDF, ECSDD, VRBE and NL.

Packet Delivery Fractions: The objective of this metric is to analyze one of the network performance metrics called PDF. The enhanced protocol provides better performance than the original. PDFs of EEDSR and DSR are shown on the figures (6.1, 6.5, 6.9, 5.13 and 6.17). EEDSR provides considerable improvement of PDF in all scenarios. This indicates that EEDSR is more resistive in stressful situation than DSR. This is due to the following reasons. The first is that it uses transmit power control. The transmit power control reduce the collision rate of the packets. Even the stress (number connections and traffics) is high; every data packet must be transmitted with appropriate power level. The second, minimum transmit power and residual battery energy level based load distribution secure the nodes from early die due to their energy draw off. Hence, the packet drop rate is less due to the network partition. DSR uses maximum transmit power that leads to more collision and unnecessary energy dissipation to closed destination. The third, EEDSR never reply the cached routes immediately. Instead of directly reply the cached route, EEDSR has to unicaste the cached route to destination of the RREQ. This reduces the opportunity of utilization of the staled out routes which add to the packet drop rates. EEDSR also outperforms by providing sustainable PDFs all over different stresses for all scenarios.

Energy Consumption per Successful Delivered data: This is one of the metrics that used to analyze the energy consumption. This metric addresses mainly the end-to-end energy consumptions to deliver the data packets. The figures (6.2, 6.6, 6.10, 6.14 and 6.18) show ECSDD of EEDSR and DSR for different scenarios. The ECSDD results show that EEDSR consumes less energy than DSR to deliver the packet. EEDSR saves 25.97%-70.5% of the energy when it compares with DSR. This is due to number of improvements applied in EEDSR. The first is, implementation of the transmit power control. The transmit power control assigns the minimum transmit power to deliver the packet to the next hop. This mechanism saves unnecessary energy consumption due to maximum power level of transmission in DSR. Besides, transmit power control reduces the collision rates which leads to number of retransmissions and routing overhead to deliver the packet to next hop. Retransmissions of the packet and routing overhead increase the energy consumption. The second is implementation of energy aware route selection. The link cost computation comprises the hop-to-hop transmission power. Hence, EEDSR selects the route which takes less power to transmit the packets from source to destination. The third is unicast the cached route to destination. This avoids reply of staled routes which cause retransmissions to deliver a packet. The ECSDDs of EEDSR are constant with different number of connections and traffics. This indicates that the impact of the routing overhead is insignificant on energy consumption of EEDSR. This also due to transmit power control to deliver data packets.

Variance of Residual Battery Energy: The objective of this thesis is to prolong the network life time by implementing minimum transmit power control and load balance on base of residual battery energy of the nodes. Accordingly, VRBE is used to analyze the load balance of the routing protocol to extend the network lifetime. The VRBE of EEDSR and DSR are analyzed for different scenarios with different number of connections and traffics. The VRBE of EEDSR and DSR are shown on the figures (6.4, 6.8, 6.12, 6.16 and 6.20) for five scenarios with varying number of connections and traffics. The VRBE results of the two routing protocols show that EEDSR provides better variances (fewer figures of values) than DSR. These values are comparable with the variance of AODV for similar scenarios. This is due the fact that EEDSR routes have to be selected not only to deliver packet with minimum energy consumption but also to distribute the load based on the residual energy levels and queue lengths of the nodes.

Network lifetime: this metric used to analyze the network partitions (network lifetime). The figures (6.3, 6.7, 6.11, 6.15 and 6.19) show that the network lifetime of EEDSR and DSR for five scenarios by varying number of connections and traffics. As shown on the figures, EEDSR prolongs the network lifetime of DSR from 15.74%-84.71%. This is the over all results of many energy efficiency issues incorporated on EEDSR. The network life time of EEDSR is better than DSR due to the following main reasons. First, EEDSR implements the transmission power control which saves energy consumption. Transmission power control reduces the number of retransmissions. Second, EEDSR selects the routes which consume less energy with suitable load balance. The minimum transmit power route reduces the over all energy consumption of the network. Third, the load balance routing of EEDSR used to secure a node from early die. The route selection avoids a node with less residual battery energy. When the rate of traffics and number of connections are increased, the NL of EEDSR is degraded in small number. This is because of the innate features of EEDSR from DSR.

CHAPTER 7: CONCLUSION and FUTURE WORKS

7.1 Conclusion

Reducing power consumption in Ad Hoc networks has received increased attention among researchers in recent years. Since a node is used as a host and router, design of Energy efficient routing protocols must address reducing of power consumption from the viewpoint of the node and network. In this thesis, we evaluate the energy efficiency of the existing well known MANETs routing protocols. Even if energy efficiency is not the design goals of these routing protocols, each routing protocol reacted in a different way with energy aware metrics. This is due to the route discovery and maintenance mechanisms of the routing protocols. The simulation results showed that DSR outperforms AODV and DSDV in energy per packet consumption. However, the network lifetime of DSDV is better than DSR and AODV. This indicates that less energy consumption does not prolong the network lifetime by itself. So, it is a clue that energy efficient routing protocols must include battery energy level aware load balancing. Each routing protocol showed better performance in specific scenarios and metrics. In general DSR outperforms in majority of scenarios and metrics. Hence we conclude that DSR is more energy efficient than DSDV and AODV with better performance.

We propose a mechanism which improves the active communication energy efficiency of MANETs routing protocols. The mechanism started from computation of link and route cost. The link cost takes account of the transmission power, the battery energy level of the sender and receiver nodes, and the queue length of the sender node. The link cost used to balance the load among the nodes and to select minimum transmission route between the source and destination successfully. The route discovery searches an energy efficient route based on cost of the links in the routes. This energy efficient routing mechanism is incorporated into DSR and we provide EEDSR. Transmission power control and energy efficient route discovery together extended the network lifetime. In addition, the proposed mechanism included delay forward techniques to reduce broadcast storms. Hence, delay forwarding of RREQ minimized the energy consumption for successful data delivery because the energy consumption due to routing overhead is reduced. The simulation results show that EEDSR consumes less energy per packet and prolongs the network life simultaneously. EEDSR saves the energy consumption per packet from 25.97% to 70.5% of DSR. The network lifetime is extended by EEDSR from 15.74% to 84.71% of DSR. EEDSR improves the performance of packet delivery of DSR due to the fact that it minimizes the collision rate as a result of transmission power control.

7.2 Future Works

The richness of the treated themes makes us elaborate a certain number of future research directions, some are short terms and others aim to provide more wide investigations. We propose the following perspectives as a means of providing more investigations in the area of energy efficient routing protocols design and evaluation:

- Evaluating the routing performance and energy efficiency using different mobility models; mainly, under group and community based mobility models.
- Studying the effect of different applications and transport protocols on the routing energy efficiency.
- Considering the effects of interference, shadowing, and multipath fading in energy efficient routing protocol design and evaluation.
- Studying the energy efficiency of routing protocols from quality of service provisioning.

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Appendix A: Scripts for Metrics Calculations

A.1. Packet Delivery Fraction

```
BEGIN {

       sends=0;
       recvs=0;

       }
       {

 # CALCULATE PACKET DELIVERY FRACTION
if (( $1 == "s") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {
      sends++; }

if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" ))   {
      recvs++; }

END {

     PDF = (recvs/sends)*100;  #packet delivery ratio[fraction]
     printf("PDF = %.2f\n",PDF);
    }
```

A.2. Energy Consumption per Successful Data Delivery Script

```
BEGIN {             recvs=0;
                    EnergyConsume=0.0
      }
      {
        packet_id = $41;
        NodeId=$9;
        NodeEnergy=$17;

        if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" ))   {
            cvs++; }
            if($16=="-Ne")
            {
            EnergyRemain[NodeId]=NodeEnergy;
            }
            }

        END {

        for(i in EnergyRemain)
          {
           EnergyConsume+=1-EnergyRemain[i];
          }
          averageEnergyPacket=EnergyConsume/recvs;
          printf("ECSDD=%f\n", averageEnergyPacket);
          }
```

A.3. Network lifetime script

```
BEGIN {
              flag=0;
             firsttime=0.0;
       }
            {
            time = $3;
            NodeEnergy=$17;
                  #Energy level
                  if($16=="-Ne")
                  {
                  if( NodeEnergy<=0.2)
                  {
                  if(flag==0){
                  firsttime=time;
                  flag=1;
                  }}}
            }

        END {
     printf(" Died first node=%e\n",firsttime);
            }
```

A.4. Variance of Residual Battery Energy script

```
BEGIN {
             summean=0.0;
             count=0;
             variance=0.0;
              }
         {
        time = $3;
        NodeId=$9;
        NodeEnergy=$17;
            #Energy level
            if($16=="-Ne")
            {
            EnergyRemain[NodeId]=NodeEnergy;
             }
        }
            END {
                  for(i in EnergyRemain)
                  {
                   summean+=EnergyRemain[i];
                   count++;
                  }
                  mean=summean/count;
                         for(i in EnergyRemain)
                        {
                   variance+=(EnergyRemain[i]-mean)*(EnergyRemain[i]-mean)
                        }
                        variance=variance/count;
                   printf("Variance=%f\n",variance);
                 }
```

Appendix B: TCL Scripts

B.1. DSR and EEDSR Simulation TCL Scripts

```
# February 1, 2008, Alemneh Adane

# ======================================================================
# Define options
# ======================================================================

set val(chan)       Channel/WirelessChannel
set val(prop)       Propagation/TwoRayGround
set val(netif)      Phy/WirelessPhy
set val(mac)        Mac/802_11
set val(ifq)        CMUPriQueue
set val(ll)         LL
set val(ant)        Antenna/OmniAntenna
set val(x)              670;# X dimension of the topography
set val(y)              670;# Y dimension of the topography
set val(ifqlen)         20       ;# max packet in ifq
set val(seed)           1.0
set val(adhocRouting)   DSR
set val(nn)             50 ;# how many nodes are simulated
set val(cp)             "alemnew2/alemcbrnew2"
set val(sc)             "alemnew2/alemsce-1"
set val(stop)           500.0         ;# simulation time

# =====================================================================
# Main Program
# ======================================================================

#
# Initialize Global Variables
#

# create simulator instance

set ns_           [new Simulator]

# setup topography object

set topo    [new Topography]
$ns_   use-newtrace

# create trace object for ns and nam

set tracefd [open wireless1-out.tr w]
set namtrace    [open wireless1-out.nam w]

$ns_ trace-all $tracefd
$ns_ namtrace-all-wireless $namtrace $val(x) $val(y)

# define topology
$topo load_flatgrid $val(x) $val(y)
```

```
# Create God
set god_ [create-god $val(nn)]

# define how node should be created
#global node setting

$ns_ node-config -adhocRouting $val(adhocRouting) \
                 -llType $val(ll) \
                 -macType $val(mac) \
                 -ifqType $val(ifq) \
                 -ifqLen $val(ifqlen) \
                 -antType $val(ant) \
                 -propType $val(prop) \
                 -phyType $val(netif) \
                 -channelType $val(chan) \
             -topoInstance $topo \
             -agentTrace ON \
                 -routerTrace ON \
                 -macTrace OFF \
                -energyModel "EnergyModel" \
                -initialEnergy 1

#  Create the specified number of nodes [$val(nn)] and "attach" them
#  to the channel.

for {set i 0} {$i < $val(nn) } {incr i} {
      set node_($i) [$ns_ node]
      $node_($i) random-motion 0          ;# disable random motion
}


# Define node movement model

puts "Loading connection pattern..."
source $val(cp)

# Define traffic model

puts "Loading scenario file..."
source $val(sc)

# Define node initial position in nam

for {set i 0} {$i < $val(nn)} {incr i} {

    # 20 defines the node size in nam, must adjust it according to your
scenario
    # The function must be called after mobility model is defined

    $ns_ initial_node_pos $node_($i) 20
}
```

```
# Tell nodes when the simulation ends
for {set i 0} {$i < $val(nn) } {incr i} {
    $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

puts $tracefd "M 0.0 nn $val(nn) x $val(x) y $val(y) rp $val(adhocRouting)"
puts $tracefd "M 0.0 sc $val(sc) cp $val(cp) seed $val(seed)"
puts $tracefd "M 0.0 prop $val(prop) ant $val(ant)"

puts "Starting Simulation..."
$ns_ run
```

B.2. AODV and DSDV Simulation TCL Scripts

```
# ======================================================================
# Define options
# ======================================================================

set val(chan)       Channel/WirelessChannel
set val(prop)       Propagation/TwoRayGround
set val(netif)      Phy/WirelessPhy
set val(mac)        Mac/802_11
set val(ifq)        Queue/DropTail/PriQueue
set val(ll)         LL
set val(ant)        Antenna/OmniAntenna
set val(x)              670;# X dimension of the topography
set val(y)              670;# Y dimension of the topography
set val(ifqlen)         20       ;# max packet in ifq
set val(seed)           1.0
set val(adhocRouting)   AODV    # Replace AODV by DSDV for DSDV script
set val(nn)             50 ;  # how many nodes are simulated
set val(cp)             "alemnew2/alemcbrnew2"
set val(sc)             "alemnew2/alemsce-1"
set val(stop)           500.0         ;# simulation time

# =====================================================================
# Main Program
# ======================================================================

#
# Initialize Global Variables
#

# create simulator instance

set ns_          [new Simulator]

# setup topography object

set topo    [new Topography]
$ns_   use-newtrace

# create trace object for ns and nam
```

```
set tracefd [open wireless1-out.tr w]
set namtrace    [open wireless1-out.nam w]

$ns_ trace-all $tracefd
$ns_ namtrace-all-wireless $namtrace $val(x) $val(y)

# define topology
$topo load_flatgrid $val(x) $val(y)

#
# Create God
#
set god_ [create-god $val(nn)]

#
# define how node should be created
#

#global node setting

$ns_ node-config -adhocRouting $val(adhocRouting) \
                 -llType $val(ll) \
                 -macType $val(mac) \
                 -ifqType $val(ifq) \
                 -ifqLen $val(ifqlen) \
                 -antType $val(ant) \
                 -propType $val(prop) \
                 -phyType $val(netif) \
                 -channelType $val(chan) \
             -topoInstance $topo \
             -agentTrace ON \
                 -routerTrace ON \
                 -macTrace OFF \
                -energyModel "EnergyModel" \
                -initialEnergy 1

#
#  Create the specified number of nodes [$val(nn)] and "attach" them
#  to the channel.

for {set i 0} {$i < $val(nn) } {incr i} {
      set node_($i) [$ns_ node]
      $node_($i) random-motion 0          ;# disable random motion
}


#
# Define node movement model
#
puts "Loading connection pattern..."
source $val(cp)

#
```

```
# Define traffic model
#
puts "Loading scenario file..."
source $val(sc)

# Define node initial position in nam

for {set i 0} {$i < $val(nn)} {incr i} {

    # 20 defines the node size in nam, must adjust it according to your
scenario
    # The function must be called after mobility model is defined

    $ns_ initial_node_pos $node_($i) 20
}


#
# Tell nodes when the simulation ends
#
for {set i 0} {$i < $val(nn) } {incr i} {
    $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

puts $tracefd "M 0.0 nn $val(nn) x $val(x) y $val(y) rp $val(adhocRouting)"
puts $tracefd "M 0.0 sc $val(sc) cp $val(cp) seed $val(seed)"
puts $tracefd "M 0.0 prop $val(prop) ant $val(ant)"

puts "Starting Simulation..."
$ns_ run
```