PERFORMANCE EVALUATION OF ENERGY CONSUMPTION IN MANET

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Ashish Kumar

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **“Performance Evaluation of Energy Consumption in MANET”** by **Ashish Kumar** in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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ABSTRACT

The mobile ad hoc network (MANET) is a self-configuring infrastructure-free network of mobile devices connected by wireless links; it is essentially a temporary wireless network which users who are willing to communicate form and who subsequently use multi-hop peer-to-peer routing to provide the network connectivity. MANETs have applications in rapidly deployed and dynamically changing environment such as military systems. The nodes in MANET being mobile may result in dynamic topology with a high rate of link breakages and network partitions leading to an interruption in the ongoing communication. Further, the nodes in MANET are dependent upon the exhaustible power supply; and because of shared nature of medium, the transmitted packets may cause an energy loss in the surroundings nodes due to overhearing. There is increased possibility of packet loss and congestion in MANET compared to wired networks, resulting in considerable energy consumption. While the problem of network partitioning due to the movement of nodes cannot be handled by routing protocol, the partitioning due to the outage of battery can be solved by routing decisions. The routing techniques help in the path establishment for communication. The traditional routing protocols may not be suitable for MANET due to its dynamic nature. The MANET group of internet engineering task force (IETF) has specified the routing techniques for MANET. These routing techniques consist of different types of overheads such as the routing overhead; and the overhead caused in managing the link failure is a significant contributor of energy consumption. This is because the start node of the broken link has to wait/retry for a time-out interval before deciding that the link has failed and cannot be used further and has to inform through a route error (RERR) packet to all other nodes using the failed link in their path. Also, the packets following this path experience large delays and the source node has to find a new route to destination. In this thesis is proposed a technique to measure the stability of the link. The measured value reflects the present stability of the link, that is, it gets updated with the time. The technique was implemented on dynamic source routing (DSR), the chosen candidate routing protocol is selected due to the absence of local recovery mechanism in its ns2 implementation. The energy aware QoS routing protocol (EAEDSR) with link stability prediction for MANETs is proposed. The link stability helps to predict the likely link break time. In order to select a stable and reliable path, in route discovery, the nodes consider the received power strength and traffic levels of the nodes on the path. The destination selects the node disjoint multiple paths. The nodes over the path keep on monitoring the node's stability and the link lifetime. The link lifetime is measured by the received signal power strengths at different time intervals. The node's stability is measured by considering the available energy of the nodes. These two measures help to compute the link stability metric which is used as a preemptive criterion. The technique reduces the communication overhead exponentially. The simulation results show that the proposed technique outperforms DSR.

Keywords: MANET, link breaks, overhead, link stability, preemptive, routing protocol.

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CHAPTER 1 INTRODUCTION

1.1 OVERVIEW

Traditional wireless networks have an infrastructure such as the access point in order to handle the communication among nodes. This type of network is a single-hop network. A mobile ad hoc network (MANET) is a self organized network of mobile nodes connected by wireless links and requires no infrastructure for communication. The nodes can move freely and in arbitrary manner. All nodes within the range of each other can communicate without the need of a central access point. Each node can act as both a router and as a host for multi-hop messages. The nodes in the network forward messages on behalf of other nodes which are not in the transmission range of each other. Hence separate schemes are required for such dynamically changing network. It is anytime, anywhere type of network. Because of this, such a network can be quickly deployed in emergence services such as disaster recovery like fire and search and rescue operation, and, further, the ease of data acquisition in inhospitable terrains makes it suitable for military operations. It is also applicable in meetings, conferences, classrooms, and vehicular networks, etc.

1.2 MOTIVATION

An accelerating energy crisis in the oil and gas industry is driving the development and investment in MANET technologies in the oil and gas industry. The importance of MANET in oil and gas industry can be understood from the following. The crude oil is available in the remote area of seas where it is very difficult to implement *infrastructure* oriented network for communication. As such the working staff sometimes faces catastrophic situations in such remote areas and it is very difficult for them to communicate with each other without any infrastructure. This calls for the infrastructure less network, namely, MANET for such a sector to be implemented.

MANET was designed such that a certain number of nodes should be able to communicate with each other in situations where these nodes come together, i.e., come within the transmission range of each other. Since MANET nodes need not cater to a fixed network for long time use, suffice it to equip them with low power and computing facility with routing capabilities. Because, in MANET, topology frequently changes, and nodes have got limited power so its routing is challenged by these factors. So the conventional routing protocols employed for wired networks cannot be used. This has been the motivation behind taking up the design of a suitable protocol for MANET in the present work. Initial routing protocol considered the minimum number of hops as metric, but the problem of overuse of nodes on a path may result in the disruption in communication. It becomes a serious problem considering the rescue operation where all nodes need to be connected. Also, it may lead to delay in communication and looking at the demand of real time applications this may be a serious concern and motivated us to investigate into this field.

1.3 PROBLEM FORMULATION

The nodes in MANET are mobile, which may result in dynamic topology with high rate of link breakage and network partitions interrupting the ongoing communication or transmission. The nodes in MANET are dependable upon the exhaustible power supply. Also, because of shared nature of medium, the transmitted packets may also cause energy loss in the surrounding nodes due to overhearing. Further, compared to wired network there is increased possibility of packet loss and congestion in MANET resulting in energy consumption. Energy consumption can also be due to receiving of the data, transmitting of the data, traffic, mobility and size of the network. While the problem of network partitioning due to the movement of nodes cannot be handled by routing protocol, partitioning due to outage of battery can be solved by routing decisions. Routing techniques helps in path establishment for communication.

MANET consists of different types of overheads such as Routing overhead (Route request, route reply and route error packets). The overhead caused in managing the link failure is a significant contributor of energy consumption. As the start node of the broken link has to wait/ retry for a time out interval before deciding that the link is failed and can not be used further and has to inform through RERR packet to all other nodes using the failed link as one of the hop in their paths. Also the packets following this path experience large delays and the source node has to find a new route to destination. This problem occurs rather more frequently in wireless networks. Hence the problem of energy consumption due to overheads in routing protocols requires special attention and further study.

1.4 OBJECTIVES

In view of the above issues (Sections 1.1-1.4), in the present work, the following objectives have been set:

- To carry out energy consumption analysis due to overheads in MANET under various routing techniques.
- To investigate into the different issues that affect communication.
- To make efforts with a view to reducing the energy consumption in managing the link failure.
- To put efforts for providing QOS (quality of service) in the routing technique.

1.5 RESEARCH METHODOLOGY

The research methodology adopted in the present work comprises the following phases (Fig. 1.1).

(a) Reviewing previous work and relevant literature

A literature survey has been carried out with a view to reviewing and revisiting the previous work related to the problems (Section 1.3) and the objectives (Section 1.4). The knowledge gained during this phase has been subsequently used during the implementation/ development phase of the work. The energy management schemes and different layer protocols reported in the literature have been studied in detail for acquiring the knowledge that has been used in designing the new protocol in the present work. The review of the previous work has also included the simulation tool that has helped the present work in the analysis and implementation phase.

(b) Identifying related problems

In the existing literature mainly energy consumption analyses of routing protocols have been studied. Their emphasis was in reducing the energy consumption in route finding through various approaches such as the transmission power control or the sending of the data through multiple paths to improve network lifetime by uniform utilization of nodes. However, as far as the author is aware, none studied the amount of energy consumed in managing the link failures in different routing techniques so that efforts could be put to improve the performance of routing techniques. Thus, the problem has been identified as of to design an energy aware routing technique avoiding route breaks and complying with congestion (interface queue length) over the path.

(c) Simulation study and analysis

The existing routing protocols have been analyzed in order to gain the insight and ensure the correctness of the existing results. Different scenarios are developed as per the requirement and also an energy model is considered needed for evaluating the energy consumption of different protocols.

(d) Design and Implementation of the technique

After analyzing the existing protocols, a better performing protocol has been extended to propose its energy efficient version. The proposed protocols has been designed and implemented over the simulator. In order to verify its implementation and correctness of the protocol, the testing has been done.

(e) Analysis/ evaluation

The implemented technique has been analyzed and the results evaluated and compared with the objectives.

(f) Modification/ improvement

The design under (e) above has been put iterative modifications until the results converge to the desired objectives.

(g) Write up of the report to on the work

The work has been reported in journals (see Section 1.6). Also, the complete work has been reported in the form of a thesis (Section 1.7).

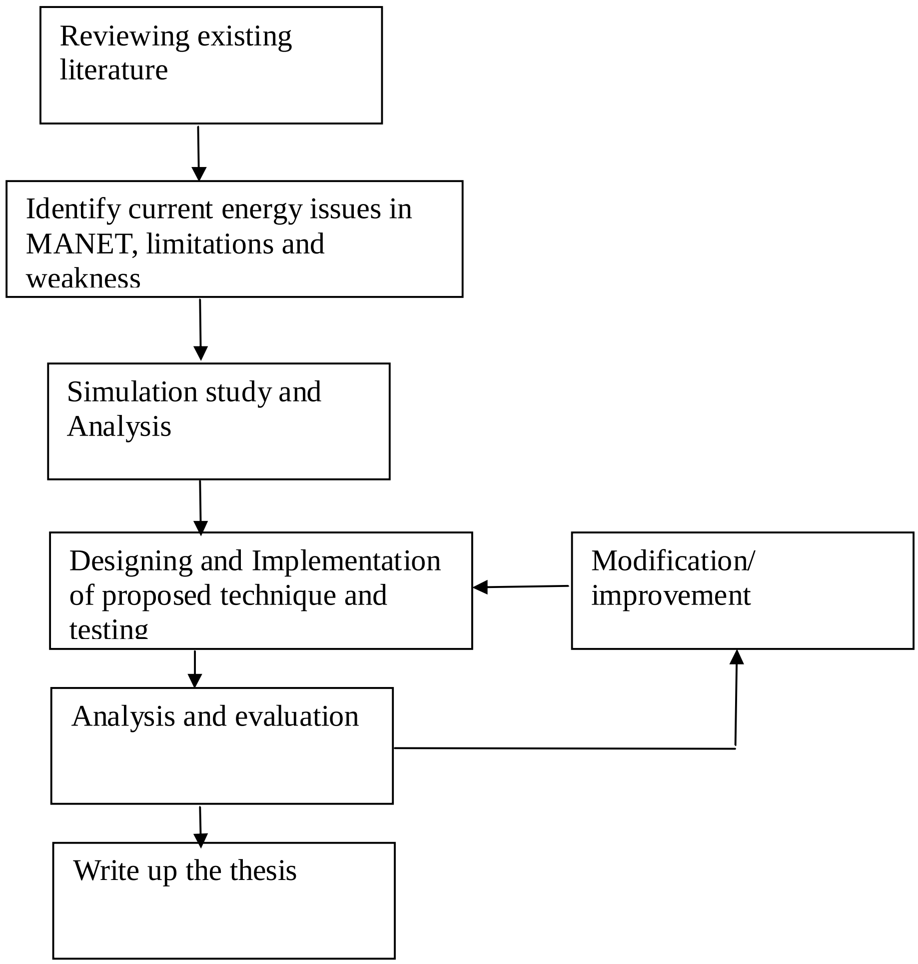

Fig. 1.1: Flow chart for adopted research methodology

1.6 CONTRIBUTIONS

The main contributions of our research are listed below; these have been elaborated further in the thesis (Chapter 4-6).

- **Performance evaluation has been carried out on various MANET routing protocols based on energy consumption, network lifetime, throughput and number of link breaks.**
- **A technique to predict the link stability is proposed. The technique considers the node stability and the link lifetime in order to measure link stability.**

- **The proposed technique performance has been evaluated on Dynamic Source routing protocol.**
- **The reduction in the cost incurred in managing the link breaks by the proposed technique of predicting the link stability has been established.**

<u>Publications from the Thesis</u>

a. A. Kumar, M. Q. Rafiq and Kamal Bansal, “A Survey of Link Failure Mechanism and Overhead of Routing Protocols in MANET”, International Journal of Computer Science and Information Technologies, Vol.2 (5), pp. 2421-2425, 2011.

b. A. Kumar, M. Q. Rafiq and Kamal Bansal, “Performance Evaluation of Energy Consumption in MANET”, International Journal of Computer Applications, Vol .42 (2), pp. 7-12, 2012.

c. A. Kumar, M. Q. Rafiq and Kamal Bansal, “Energy Efficient Routing Protocol Avoiding Route Breaks Based on DSR”, International Journal of Computer Applications, Vol. 44 (4), pp. 39-44, 2012.

1.7 THESIS OUTLINE AND PLAN AND SCOPE

The first three chapters, including the present chapter, introduce the subject; present the literature survey, explain the objective of the work discussing in what way the present work is different from and an improvement over the previously reported work; state the problem undertaken providing the plan and scope of the work, and revisit all the necessary concepts which are necessary to execute the work. The next three chapters embody the core work carried out highlighting the results and their interpretation.

Chapter 2 presents the work done on energy management at different layers for MANET and as well as the related work on energy efficient routing protocols. Chapter 3 describes the basic concepts needed to understand the thesis.

Chapters 4-6 embody a report on the work done within the purview of the plan and scope of the present work.

Chapter 4 describes the performance analysis carried out on various routing protocols and also on the selection of appropriate routing protocols as per the present work.

Chapter 5 presents the proposed technique to derive the link stability and the design of EAEDSR routing protocol.

Chapter 6 presents the implementation detail and results analysis of the EAEDSR routing protocol.

Chapter 7 concludes the work summarizing it and highlighting the major findings and their interpretation as well as pointing out the limitation of the present work and the scope for further work.

CHAPTER 2 LITERATURE SURVEY

In this chapter we discuss the existing techniques and approaches which are relevant to our work. We have put them into two categories: one that may be used at either of the layers (mac layer, network layer etc.) and are non-preemptive in nature (Section 2.1 and section 2.2). And the other (Section 2.3) is preemptive and are related to the present work and have been proposed at network layer, i.e., energy efficient routing protocols. The section on related work emphasizes the energy minimization techniques using preemptive routing techniques and overhead reduction approaches.

2.1 ENERGY MANAGEMENT

The energy efficiency of a node is defined as the ratio of amount of data delivered by the node to the total energy expended. Therefore, a node with more energy reserve can deliver more data. The main reasons for energy management in ad hoc wireless networks are listed below [1]:

i. Limited energy reserve
ii. Difficulties in replacing the batteries
iii. Lack of central coordination
iv. Constraints on the battery source
v. Selection of optimal transmission power
vi. Channel utilization

Hence the energy management has to be adopted by the protocols at all layers in the protocol stack and should be considered as one of the main design parameter of such protocols. The energy management can be done using the following techniques [1]:

i. Battery management schemes
ii. Transmission power management schemes
iii. System power management schemes
    a. Device management schemes
    b. Processor power management schemes

A classification of energy management schemes is shown in Fig. 2.1.

2.1.1 Battery management schemes

The battery driven systems are designed considering the battery and its internal characteristics. These schemes try to maximize the amount of energy provided by battery sources by exploiting their internal property to recover their charge when kept idle. Researches in this area have proved that a significant improvement in energy drawn can be gained by varying the manner in which the energy is drawn. The different battery management schemes have been divided into the following categories:

i. Device dependent schemes
ii. Data link layer schemes
iii. Network layer schemes

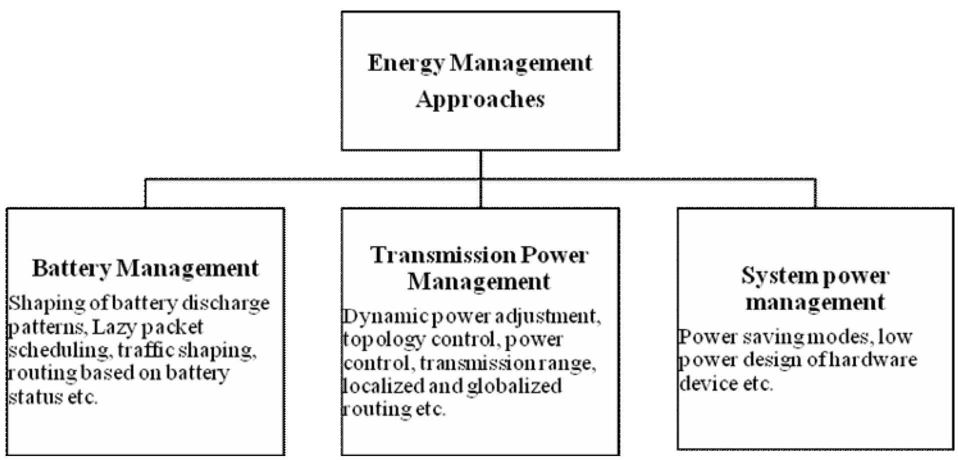

Fig 2.1: Classification of energy management schemes [1]

2.1.1.A Device dependent schemes

In this section, some of the recent approaches to increase the battery lifetime have been discussed.

(i) Modeling and shaping of battery discharge patterns

The stochastic model of discharge pattern of batteries deals with two important aspects: the rate capacity effect and the recovery effects. The rate capacity effect depends on the actual capacity of the cell and the discharge current. The recovery effect is concerned with the recovery of charges under idle conditions. Therefore, by increasing the idle time of battery its lifetime can be increased. The techniques exist suggesting that the application of pulsed current discharge for bursty stochastic transmission improves battery lifetime. A model for battery pulsed discharge with recovery was proposed. The model consists of a battery with a theoretical capacity of A charge units and initial battery capacity of N charge units. The battery behavior is considered as discrete-time Markov process with initial value N and fully discharged state 0. The time is divided into slots. A node takes one time slot to transmit one packet and battery enters previous state by losing a charge unit. If the battery remains idle then it regains one charge unit and enters next state. The results of this model suggest that at most A packets can be transmitted if the enough idle time is given for the recovery of charges. Different pulsed charge methods have been proposed, namely, the binary pulsed discharge and generalized pulsed discharge methods.

(ii) Battery scheduling

Researchers have proposed the battery scheduling techniques to improve the battery lifetime. A battery package containing a number of cells can be scheduled for transmitting a given packet, keeping the other cells idle to recover their charge. Different approaches have been proposed to select the subset of cells: the delay free and the no-delay-free approaches. In the delay-free approaches, as soon as the job arrives, the battery charge for processing the job is provided from the cells without any delay. The different cells are scheduled according to the different techniques such as joint technique, the round robin technique and the random techniques. On the contrary, in no-delay-free approaches, the cells coordinate among themselves to provide enough charge.

2.1.1.B Data link layer schemes

The data link layer protocols consider the battery characteristics as the main design criterion. Two different types of schemes have been proposed: the Lazy packet scheduling scheme and the battery aware medium access control (BAMAC) scheme. The Lazy packet scheduling technique is based on the principle that the energy required to transmit a packet can be reduced by minimizing the transmission power and increasing the transmission duration in channel coding schemes. But this scheme may not suit practical requirements. Hence a transmission schedule was designed and energy optimal offline and online algorithms were proposed. The BAMAC protocol is a contention based node scheduling algorithm that tries to increase lifetime of nodes by exploiting the recovery capacity of the battery. Each node maintains a battery table which contains the information about the remaining battery charge of each of its one-hop neighbor nodes. The request to send (RTS), clear to send (CTS), data and acknowledgements (ACK) packets carry the remaining battery charge of the node from where the packets originated. The listening nodes make entry in their battery table. In this protocols, whenever a node gains access to the channel, it is allowed to transmit only one packet resulting in the idle time of $(N-1)\times m$, where N is the total number of nodes contending for common channel and m is the average time taken by a node for transmission of a packet.

2.1.1.C Network layer schemes

The network layer protocols try to maximize the network lifetime. The routing protocols developed use various metrics such as the low energy cost and the remaining battery charge. The traffic shaping schemes based on battery discharge characteristics have been defined. They assume that the most of the network traffic is bursty. Therefore, a proper analysis of the network traffic may help in increasing the battery lifetime. The battery energy- efficient (BEE) routing protocol combines the lazy packet scheduling and traffic shaping techniques. The BEE protocol finds a balance of energy consumption among all the nodes using the metric energy cost. So from all available routes the one with lowest cost is selected. The energy conserving routing based on battery status maximizes the lifetime by routing the traffic such that energy consumption is balanced instead of reducing power consumption.

2.1.2 Transmission power management schemes

Transmission power management schemes deals with finding the tradeoff between two contradictory issues that is increasing the coverage of a node and decreasing its battery consumption. The different schemes have been proposed at different layers.

a. Data link layer solutions
b. Network layer solutions
c. Higher layer solutions

2.1.2.A Data link layer solutions

The solutions proposed at this layer suggest that a proper power level for nodes is required to save the power. Some of the solutions to calculate the optimum transmission range are as follows:

i. Dynamic power adjustment policies
ii. Distributed topology control algorithms
iii. Constructing distributed power control loop
iv. Centralized topology control algorithms

(i) Dynamic power adjustment based on link affinity

The link failure problem in ad hoc network is more frequent and result in reduced throughput. Hence, the algorithms considering link stability (affinity) have been defined. The node *m* samples a set of signals from the node *n* and calculates the affinity (a_{nm}) as follows:

$$a_{nm} = \begin{Bmatrix} high & if\, \delta S_{nm} > 0 \\ S_{thresh} - S_{nm(current)} / \delta S_{nm(ave)} & otherwise \end{Bmatrix}$$

Therefore, the link is supposed to be disconnected if the signal strength $S_{nm(current)}$ is below S_{thresh}. $\delta S_{nm(ave)}$ is the average of the rate of change of signal strength over the last few samples.

(ii) Distributed topology control mechanism

This approach runs a localized algorithm on each node of the network to decide the appropriate power used by the node. A node can go on increasing the power until it finds a node in any direction. Then, the algorithm attempts to increase the lifetime of the nodes by reducing transmission power but maintaining the same connectivity as when the nodes were maximally powered. Therefore, the topology of the network gets influenced by power levels of nodes and results in poor network utilization if not chosen appropriately. The model used in the algorithm uses a cone-based topology on a two-dimensional surface and works in two phases. The first phase is concerned with the discovery of the neighbor. In the second phase, the redundant edges are removed without affecting the network connectivity of nodes and without removing the minimum power path.

(iii) Constructing distributed power control loop

These algorithms reduce the energy cost of communication between nodes and thereby increase the battery lifetime and effective bandwidth. Each node uses different power levels for transmission but retains the connectivity of the network. The different power levels help in interference reduction vis-a-vis common power (higher power) for all the nodes.

(iv) Centralized topology control algorithm

The algorithm suggested is a centralized algorithm which adjusts the power levels of the nodes to create the desired topology. This is tackled as an optimization problem with power level as the optimization objective and constraints as connectivity and bi-connectivity.

2.1.2.B Network layer solutions

The networks layer solutions are concerned with the power consumption used in communication and computation. The communication power consumption occurs in two states, namely, the transmit and the receive states. Even when the node is in in-active state, i.e., in the listening mode the power keeps discharging. The computation power refers to the power that takes place in routing and power adjustments. Hence a protocol with small tables and less number of calculations is desired. Since, the data compression may reduce communication but increases computation, a balance is called for. Accordingly, the following different approaches become relevant:

i. Common power protocol

ii. Globalized power aware routing techniques
iii. Localized power aware routing techniques
iv. Energy efficient ad hoc wireless design technique (ANDA)
v. Critical transmission range determination

2.1.2.C System power management schemes

System power management can reduce significant power consumption if designed properly. This can be done at two levels:

i. Processor power management
ii. Device power management

(i) Processor power management

The nodes consumes the power even when in idle mode because it has to continuously check for the arrival of the request packet. Therefore in order to avoid this, the nodes are switched off in idle state. Also, the battery is kept idle during idle time so that it may recover its charge. One solution to this is based on the quality of service (QoS) requirements. One approach is to remotely switch on the battery using RF tags. Another approach is based on the traffic delay pattern and remaining charges of batteries to determine the sleep duration. Power aware multi-access signaling (PAMAS) approach suggests the addition of a separate channel in Multi Access Collision Avoidance (MACA) protocol to determine the time off duration of a node.

(ii) Device power management schemes

The major sources of power consumption in wireless networks are the transmitters and receivers. Therefore, it is suggested that they be switched off while not in use or in idle state. Further, instead of switching a system as a whole, one may even go for switching off some relevant from time to time depending on the requirements. The main components of a mobile node are the display unit, the CPU, the RAM, the CD/ DVD Drive, the wireless interface and the I/O sub systems. These components consumes different amount of power. The various approaches for device power management are in vogue such as CPU idle time scheduling, the spin-down, etc.

2.2 ENERGY EFFICIENT ROUTING PROTOCOLS

The routing protocols helps one to find the correct and efficient route between a pair of nodes, but the discovered route may not be live long. Thus, in addition to finding the route, an important goal is to keep the network functioning as long as possible. Further, this goal can be improved by minimizing the energy consumption of nodes not only during the active communication but also in their inactive state. The transmission power control and the load distribution approaches have been proposed in the literature to reduce energy consumption during active communication and the sleep power-down approach for inactive state. Table 2.1 shows the taxonomy of the energy efficient routing protocols [2]. Numerous energy metrics have been defined to determine energy efficient path instead of the shortest path as the metric. These are

1. Energy consumed/ packet
2. Time to network partition
3. Variance in node power levels
4. Cost/packet
5. Maximum node cost

In the first metric, the cost of every link over the path is determined and is summed up to calculate the path cost. This metric does not use nodes energy evenly if an overburdened node may exhaust early and may compromise the life of the overall network. Hence a more fundamental goal is to improve the network lifetime (second metric). Given the alternative paths, one may choose the one that will result in longest lifetime. Since the network lifetime is practically hard to estimate, other metrics have been defined. The variance in node power levels determines the energy balance of nodes and can be used to improve the network lifetime. The cost/ packet metric takes residual battery power of the nodes and transmission power into consideration for determining the path. It selects the path with the minimum transmission power but avoids the node with lower residual power. The last metric define the path cost as the cost of the minimum residual power node among all other nodes over the path and select the path with the maximum cost so that the path containing the nodes with less power can be avoided.

Table 2.1: Taxonomy of the energy efficient routing protocols [2]

Approach		Protocols	Goal
Minimization of active communication energy	Transmission power control	⅄ Flow argumentation routing ⅄ Online Max- Min ⅄ Power aware localized routing ⅄ Minimum energy routing	Minimization of the total transmission energy but avoidance of low energy nodes.
		⅄ Retransmission energy aware routing ⅄ Smallest common power	Minimization of the total transmission energy while considering retransmission overhead or bi-directionality requirements.
	Load Distribution	⅄ Localized energy aware routing ⅄ Conditional max-min battery capacity routing	Distribution of load to energy rich nodes
Minimization of inactive communication energy	Sleep/ Power-down mode	⅄ SPAN ⅄ Geographic adaptive fidelity ⅄ Prototype embedded network	Minimization of energy consumption during inactivity

2.2.1 Transmission Power Control

The transmission power based routing protocols find the best route that minimizes the total transmission power between the source and the destination. Numerous energy efficient routing protocols based on transmission power optimization have been defined like flow augmentation routing (FAR), online max-min routing (OMM), and power aware localized routing (PLR). The FAR finds the path that minimizes the sum of link costs along the path. The OMM protocol finds the path in two phases. First it finds optimal path by using Dijkstras algorithm (Minimum power consumption path). In the second phase it includes other paths (Multiple) which are near (Transmission power consumption) to optimal paths and selects the path which optimizes the max-min metric. In PLR protocol, the source node has information of link costs from itself to its neighbors and to the destination. It uses this information to select the next hop through which overall transmission power to destination is minimized. The goal of minimum energy routing (MER) protocol is not to provide energy efficient paths but to make the given path energy efficient by adjusting transmission power just enough to reach the next hop. The reason is that that the path with many short range links may perform worse than that with a few long range links because more hops are likely to introduce more errors and may result in retransmission and, may consequently, cause more energy consumption. Therefore, the retransmission energy aware routing protocol (RAR) modifies the optimization path definition by considering the effect of transmission link errors. In wireless network, for the communication to work correctly at the link level, bidirectional links are a must. As whenever a node receives a packet it replies with ACK, and, if ACK is received then the sender automatically retransmits. But in the approaches followed by various transmission power control protocols, the nodes use different power levels and as such no bidirectional transmission is possible.

2.2.2 Load Distribution Approach

The goal of the load distribution approach is to balance energy utilization among all nodes by selecting a route containing underutilized nodes rather than shortest route. The Localized energy aware routing (LEAR) and the conditional max-min battery capacity routing (CMMBCR) protocols are based on load distribution. During the route discovery in the DSR protocol, intermediate nodes forward the route-requests soon after their receipt, after appending their identity in the header of the packet. However, in LEAR, a node may or may not forward the route-request depending on its residual battery power. If the residual battery power is above a threshold value then the node forwards the packet; otherwise it drops the packet. As the time passes, the residual battery power decreases and consequently the threshold also decreases in proportion. To maximize the lifetime of nodes and to use the battery fairly, CMMBCR protocol uses the concept of threshold. Of the routes discovered between a source and destination pair, the protocol selects the minimum power route and in which the nodes battery reserve is higher than the threshold. If the nodes energy over all the routes is lower than the threshold value then the max-min route is selected. The threshold value is fixed and does not change as in the LEAR protocol.

2.2.3 Sleep/ Power-down mode approach

This approach focuses on inactive time of communication. Most radio hardware supports a number of power states. Therefore, in order to save energy, the radio subsystem should be either turned off or be made to go into sleep state. *Lucents WaveLAN-II* network interface card based on IEEE 802.11 standard uses different amount of power in different states. For instance, in the transmit state it uses *300 mA*; in the receive state *250 mA*; in the idle state *230 mA*; and in sleep state *9 mA*. However, in order to deliver packets all nodes cannot be in sleep state. So to make communication possible a special node called master is elected that coordinates the communication on behalf of its neighboring slave nodes. The slave nodes can safely sleep and wake up whenever required (when informed by the master node). However, in multihop MANET one master node can not cover the entire network. Hence, two types of MANET architectures have been defined- one is symmetric, in which the master nodes have the same transmission range as the slave node, and the other is asymmetric, in which master nodes have a longer transmission range. The SPAN protocol and the geographic adaptive fidelity (GAF) protocols employ the master-slave architecture and put the slave nodes in low power states to save energy, whereas prototype embedded network (PEN) protocol practices the sleep period operation in an asynchronous way without involving master nodes.

2.3 PREEMPTIVE AND OVERHEAD REDUCTION TECHNIQUES

A technique to improve delay caused due to link failure resulting in route rediscovery is discussed in [3]. The technique computes the battery power levels of the nodes. During transmission, whenever the power level of the node N (likely to cause link failure) goes below a certain acceptable threshold, it sends a warning message to predecessor of N for determining an alternative path so that remaining packets can be transmitted through alternative path. In case predecessor is unable to determine alternative path, all upstream neighbors using this link as part of their path are also informed about likely link break so that routing table updates can be done. And the source starts new route discovery and send remaining packets. The approach is based on prediction. The approach of [4] is based on preemptive routing scheme. The approach has considered DSR protocol for evaluation. To generate warning message required to find alternative path for transmission, the approach finds the threshold of signal strength considering the concept of preemptive region width as in [5] and also the age of the path. The value of the threshold parameter used in the algorithm determines the efficiency of the approach. If the threshold value is too small then there will not be the sufficient time to discover a new path before the disconnection of the existing path. Conversely, if the threshold value is too large then unnecessary route discovery will take place and will increase the network control traffic. Therefore, a tradeoff has to be made to determine an optimal threshold value. A preemptive region is assumed around every node and as soon as a node enters in its preemptive region, a warning message is sent to the sender node. Then the sender node initiates a route discovery process. With the establishment of a new route, data transmission is continued along this new route. The time required to discover a new path is called recovery time and is denoted by T_{rec}. Therefore, the time required between the warning message and the disconnection should be at least as large as the recovery time. In order to determine the optimal range, it is necessary to exchange the location and velocity information of the nodes amongst all the nodes depending on the received signal power. The received signal power is given by $P_r = P_0 / r^n$ at a distance r from the transmitter, where P_0 is the transmitted power and path loss exponent is n and it is typically in ranges from *2* and *4*. The minimum power received at the node is the power which is received at the maximum transmission range and is defined as $P_d = P_0 / d^4$. Based on same concept, the preemptive signal power threshold is the power received at the boundary of the preemptive region. The signal power threshold for a preemptive region of width w is define as

$P_{safe} = P_0/d^4_{safe}$ where d_{safe} is defined as *(d- w)* and *w=relative speed*$*T_{warn}$. The preemptive ratio (α) is given as $\alpha = P_{safe} / P_d$ = *range/ (range- w)*. In real time networks, the received signal may experience fluctuations caused due to fading and multipath effects thereby may result in unnecessary warning messages being sent. This may result in lower quality routes being initiated and add to routing overheads. In cellular networks, an exponential average of the signal power is used to verify that the signal power drop was not due to the fading. However, if the traffic is bursty, the preemptive region may be crossed by the time the enough packets are received and to drop the average power below the threshold. To trim down the effect of bursty traffic, frequent power estimates can be done by sending the warning messages whenever the power drops below the threshold and in turn the source checks the power of the received warning message. If the power of the received warning message is lower than the threshold than there is a chance of warning being the real. The warning may be issued based on the life of the path. The continuous traffic supply over a path may result in intermediate node's energy exhausted fully. Therefore alternate route discoveries are required before the occurrence of the failure. The nodes store a record of their most recent encounter times with all other nodes. The source node sets the time at the instant the path is discovered. The life of the path is defined as the time difference between the two consecutive route discoveries among the same source and destination pair. A threshold value is determined for the life of the path. If the life is less than the determined threshold value, the data transmission can be continued otherwise a warning message is generated leading to new route discovery. However, the new path may or may not be the shortest path to the destination. The value of the threshold depends on the density of the network and if the network is sparse then its value is kept large due to availability of lesser number of paths. The approaches discussed in [3, 4, 5] do not consider both the metric simultaneously, i.e., the node life and link life time, in determining the link stability metric which is needed to better reflect the current status of nodes over the path.

In the Enhanced Power based Multipath Routing Protocol (EPAOMDV) [6] if the received signal strength falls below certain threshold, it triggers warning message being sent to source node. Source node has multiple paths to destination being found during initial route discovery phase. During initial route discovery phase the repeated RREQ packets received by intermediate nodes are not discarded, instead they help in determining short path. Hence, destination after receiving RREQ through multiple paths sends back RREP on all the paths helping in finding multiple paths. So after warning message is received by source node it uses alternative path for transmission. Every node waits for the acknowledgment of the packet it has sent, and thus can compute the diminishing received power used for predicting likely link failure. In EPAOMDV, source node uses alternative path whereas in [3] predecessor of *N* does this and if predecessor fails then source does the job of finding the new path. The protocol preemptive multipath ad hoc on demand distance vector routing (PMAODV) [7] is based on the concept of AODV with multipath and preemptive routing. The source node finds multiple paths to destination during route discovery phase. When the source node sends a route request (RREQ) to destination, and the received power of RREQ packets falls below preemptive signal threshold at an intermediate node, then a route warning message (RWRN) is sent to source node by the intermediate node indicating likely link break. Also the routing table is modified to include the status of likely link break so that all the upstream nodes can change in their routing tables about link failure indication this is done by adding a flag field in the routing table. The source node after receiving the RWRN message, finds an alternative path from its routing table if exist and uses this path for sending the data. If the alternative route does not exist then a new route discovery mechanism is started to find the path to destination. PMAODV performs better than AODV and preemptive protocol routing techniques. The predictive preemptive AODV routing protocol (PPAODV) [8] is designed by adding the concept of preemptive routing to the AODV routing protocol. In PPAODV protocol, when a node moves to its preemptive region, its signal strength falls below the threshold value. So to predict the power value required to send warning message, three consecutive signal strengths of the packets received from predecessor node are used in Lagrange's interpolation formula i.e. it measures P_0, P_1 and P_2 power values at time t_0, t_1 and t_2 respectively and put the values in the formula to compute received signal strength *P*. When *P* falls below a threshold value, a warning message is sent to predecessor node to start local route repair by finding alternative path to the destination. The protocol's performance is evaluated on Glomosim simulator. The Cache-enabled Preemptive Dynamic Source Routing (CPDSR) routing protocol [9] suggests the solution to the problem of stale routes available in nodes caches. The preemptive routing produces early warning so route error (RERR) packets are not being broadcast, hence, nodes are still with that stale route information in their cache. The warning node sends warning message to source node. The source node in turn refreshes its local route cache and finds new available route to destination in its cache. If the route exists then uses the route and if the route does not exist then broadcast RREQ packets with unstable link (likely to break soon) information to find the new route. Unstable link information is kept in RREQ packet so that all the nodes on the path may refresh their cache with the unstable link information and any new replied route does not contain such unstable links. The source node sends RERR message to warning node so that all the nodes on this path may refresh their route cache and warning node may know that route has changed. The author has also given a method to determine reaction time i.e. the time to determine when a link is regarded as unstable. The EPAOMDV [6], PMAODV [7], PPAODV [8] and CPDSR [9] routing protocols remain silent for node stability and QoS.

A technique to hand-off the router in case of weak link is proposed in [10]. The hand-off is determined by considering the power difference table and neighbor power list which are kept by every node. Based on tables values warning node determines the neighbor node which is reachable from both i.e. the source and destination node (switches to a new path), so that the data can be diverted through new path and warning node broadcast a hand-off packet containing the address of predecessor and successor to make the path. If the neighbor node with sufficient link stability can not be determined then technique allows the link fail to occur and later route repair is done as per AODV protocol's standard mechanism. In Minimum Energy Dynamic Source Routing (MEDSR) [11] approach has introduced the concept of minimum power transmission required to reach neighbor's node by adjusting the power link by link in route reply packets during route discovery phase. MEDSR is built on DSR by adding the concept of power adjustment which is just enough to reach the neighbor. The approach uses two different power levels (Say P_1 and P_2) to find the path to destination. If the source finds the path using power level P_1 then during route reply cycle when the destination node sends the reply packet with its transmit power information, the predecessor of destination receives the reply packet and calculates minimum transmit power to reach the destination by subtracting the received power from the transmit power and add a threshold power (receiver's sensitivity) to the subtracted value. The calculated power value is stored in power table kept by each node. Also, during forward/ backward cycle of route request/ reply packets, each node keeps it's transmit power information in the packet header. If the source node can find the path to destination using low power (P_1) then it tries three times before trying to find the path using high power (P_2) and if the source can't find the path in high power mode then also it tries three times before failing to find the path. The protocol's hierarchical version i.e. minimum energy hierarchical DSR (MEHDSR) to reduce energy consumption by reducing the energy incurred in overheads (MAC and Routing packets) per data packet is also proposed. In the MEHDSR, a node can be in two states i.e. either in mobile or in forwarding state. Mobile node can be either source or destination. Because a node in forwarding state can forward the packets may reduce the overhead. A node in forwarding state can be either a gateway node or a cluster head. The HDSR being with less overhead is combined with MEDSR to evolve HMEDSR. There are the disadvantages of minimum power transmission approach, as the increased number of hops may result in delay. Also this may result in network partitioning problem and leading to increased overhead.

The Common Power Protocol [12] selects the minimum power required to maintain the connectivity of the network. Every node in the protocol maintain routing table which include power level information. By exchanging routing table, node may know about the minimum power require which is just enough to maintain the connectivity of the network. The protocol uses six different power levels during route discovery phase. The quantitative measurement of the inaccuracy of state information of nodes in OLSR routing protocol is done in [13]. State information may be such as residual energy level, queue length and link attributes. The link attributes are delay, bandwidth, and error rate. This study reveals the inaccuracy present in the information such as a node may likely to have outdated information about residual energy of other nodes and the inaccuracy keeps on increasing with the time. So the work mentioned measured the inaccuracy and also proposed two approaches to reduce the inaccuracy present in the information namely prediction and smart prediction. In prediction approach, last two values are taken to determine the consumption rate of other nodes at a particular instant of time. The smart prediction is applicable in case information about other nodes is absent. So the residual energy value is predicted by taking the average consumption rate of other nodes (if present) or itself. The approaches discussed in [10, 11, 12, 13] do not take account of the node stability. A new cost function for determining the cost of the route from source to destination is proposed in [14]. The cost function includes the variables *unstable_nodes_count* (*a*), *number_of_neighbors* (*b*) and *buffered_packets* (*c*). The variables are added to route request packet in addition to amount of data source node wants to send. During route discovery intermediate nodes adds their values of the variables to the already existing values in the received route request packet. Over the path, nodes may have different number of neighbors, buffered packets and different number of unstable nodes. So, a node is called stable if its certain number of neighbors does not change during a fixed time interval. The destination receives the route request with cost function value calculated for the traveled path and stores the value in the buffer for the fixed time. If in the mean time another route request comes with smaller cost function value then the previous route request is discarded. Otherwise, the destination waits for the fixed time to expire and retrieve stored route request and sends the route reply. In the approach, the nodes with more number of neighbors are discouraged as they will do more overhearing and will loss energy soon. Similarly path with stable nodes is encouraged otherwise path breaks are likely to occur and cause maintenance phase to start will result in energy loss. The nodes with long buffer queues cause timer expiring causing retransmissions result in energy loss. In the approach a node forwards the route request if the node's remaining lifetime is more than the needed to send the packet. Otherwise the node drops the request packet. The node's lifetime is calculated by its residual energy and drain rate. The path stability is measured by considering the stability of neighbors. Also the approach is not adoptable to the type of data sent.

The method to minimize the broadcast overhead is discussed in [15]. Three techniques namely flooding, probability based flooding and clustering is used to minimize the overhead. The flooding is used to find the location information of nodes and clustering (using K Mean algorithm) is used to minimize overhead which in turn may result in energy efficiency. The impact of path stability on energy consumption is studied in [16]. The study reveals the fact that minimum hop routing gives least energy consumption in absence of power control mechanism. Also, in dynamic topology, stable paths help in reducing energy consumption due to fewer path discoveries and the argument become stronger if the overhearing can be reduce or avoided. An example arguing the energy efficiency of stable path and minimum hops path i.e. the packet sending rate or the offered traffic load is the determining factor while keeping the energy consumed per route discovery and energy consumed per hop is fixed, is also given. The effect of mobility on the performance of routing protocols considering the metrics energy consumption, overhead and average data packet transfer delay is studied in [17]. The analysis concluded that the mobility has negative effect on routing. It results in more energy consumption, more packet loss and more congestion due to increased overhead to retain the transmissions. The approach of [15] discusses the energy saving by minimizing the broadcast overhead. But both the approaches of energy minimization i.e. by measuring link stability and overhead reduction have not been taken together in [15, 16, 17].

A modified AODV by including the concept of speed of energy consumption in nodes is proposed in [18]. The generic AODV uses the number of hops as metric in route establishment. But to improve the network lifetime, this parameter alone is not sufficient. If the cost computation is based on the speed of energy consumption then the nodes which participate in communication for longer duration can be avoided and other nodes can be chosen. An algorithm to choose an energy efficient path and mitigates the effect of delay in data packets is proposed in [19]. The cost function given is based on two parameters the residual energy and queue length at every node. Because the residual energy is an indication of the capability of the node and queue length may help in avoiding congested path otherwise which may result in delay and energy dissipation at faster rate. The proposed protocol does not talk about link stability as well as overhead reduction.

The energy overhead performance of three routing protocols i.e. AOMDV, TORA and OLSR under three different energy models, namely Bansal model, Vaddina model and Chandrakasan model is studied in [20]. The study concluded that TORA has highest energy overhead among all three studied protocols. During the study some contrasting results were also seen such as the energy consumption increased up to certain transmission range and after that it decreases up to a certain value and thereafter remained same across all the transmission ranges. The study remains silent for any proposal. The routing protocols to improve the network lifetime are categorized into two categories [21]. The protocols which are based on transmission power, residual energy, battery drain rate, local routing, expected energy consumption and battery sensitivity routing have been put into energy aware routing protocols. And the protocols which improve the performance by spreading the traffic over multiple paths have been put into load balancing category. The study concluded that by employing either of the approach the full potential of extending lifetime cannot achieved.

A gossip-based routing protocol supporting probabilistic broadcast to reduce communication overhead in route discovery is proposed in [22]. In the protocol, every node forwards a RREQ with a uniform probability. The protocol does not require the knowledge of topology. Each node [23] store one or two hop neighbor information and decides whether or not to re-transmit a received packet further on behalf of its own information about neighbor information and might be uncovered (neighbors) in the flooding operation. So the approach reduces the retransmissions up to certain extent. The construction and maintenance of the dominating set in the network is also an approach for reducing the broadcast overhead. But it is NP- hard problem. The minimum-energy broadcasting with adjustable transmission power capability of nodes, centralized [24] and hop-by-hop heuristics [25] have been studied. The approaches require either global state information to work or certain localized topology controlling algorithm. The approaches of [22, 23, 24] discuss the energy minimization by reducing the overhead.

The design of several on-demand energy-aware routing protocols is given in [26]. The protocols keep the overhead to minimum and finds energy efficient routes. In the protocol, nodes do not use topological information. The performance of multipath routing techniques on DSR and AODV is analyzed in [27]. In the single path scheme the same path is being used all the time, may result in early depletion compromising the network lifetime. The study concluded that by employing load balancing technique lifetime can be increased up to *22* minutes. The different proportion of energy is consumed on different types of packets such as control packets, data packets and routing packets. Also *89*% of the network interface card energy is consumed in receiving while *11*% in sending the packets. The two new power aware metrics that can be implemented on any routing protocol are defined in [28]. The defined metrics consider both i.e. the power required on links and nodes battery status. The technique is analogous to round robin policy used by operating system schedulers to schedule different jobs. Similarly the traffic is scheduled among multiple paths prioritized by considering the optimality metric. The metrics performance is tested on DSR protocol. The flooding phenomenon of ad hoc network is studied in [29]. It is most frequent operation of most of the routing protocols for broadcasting. But it is also a costly operation in terms resource usage (energy consumption) and introduces large number of duplicate messages and may result in broadcast storm problem. An approach to reduce broadcast redundancy is proposed in [29]. It works in distributed manner and uses local topological information along with the statistical information of duplicate messages, to avoid unnecessary broadcast of control packets. The broadcast storm is avoided by not allowing a node to rebroadcast a message if all the neighbors have been explored by the past transmissions. The algorithm works in two parts i.e. one is local neighborhood discovery and the other is data broadcasting. The local neighborhood discovery is simple. The issue of long and short hop has been investigated in [30]. In the literature it has been suggested that transmission range of node should be small, but not too small that may result in network partitioning. Also many important issues related to the performance of MANET has been cited such as generation of overhead control packets, energy conservation, packet loss, end to end delay, nodes mobility, efficient access control mechanism and shadowing effects etc. The quality of the link is an important design issue of MANET. It is measured by signal to interference ratio. However it varies with time since the signal travels through wireless medium which varies with the time. These signal variations results in shadowing effects and the cause of signal strength going below threshold can be very well explained by the shadowing effect. The signal variations results in packets loss. So, careful selection of transmission range is required to cope with the shadowing effect. Analysis of the shadowing effect on different topologies is also studied. The conclusion drawn favors that the transmission range should be kept as high as possible to reduce the packet loss. In mission critical and industrial applications packet loss should be kept at minimum so favoring the long hop routing. Packets are lost due to route breakages. So the nodes of a particular region (neighbors) are of significant importance. The analysis suggests more number of neighbors is needed to improve connectivity. Also, concluded that long hop routing is better under mobility conditions. The routing overhead analysis revealed that long-hop routing reduces routing overhead control packets. The approaches proposed in [26, 27, 28, 29, 30] do not consider load balancing and energy efficiency simultaneously.

The energy efficient multipath routing protocols have been discussed in [31]. The multipath on-demand routing protocols have their origin in DSR with the modified maintenance phase. The protocol works in two phases. When a source is not with the route information to the destination node, it starts a route discovery procedure which floods the network with route request messages containing the source id, destination id and request id as part of the packet information. The size of the request message grows as it travels through the network. When the destination receives the route request message it replies to the neighbor from whom the destination received the request message. Both the request and reply messages contain the hop counter giving the number of hops traveled so far in the route discovery. This protocol conserve lot of energy as packet size does not grow with the path length otherwise which had grown as the packet had traveled. The energy and mobility aware geographical multipath routing proposed in [32] uses remaining battery capacity, mobility and the distance of the next hop towards destination to select the next hop during route discovery. According to the energy modes described in [33], the network interface can be in any of the states i.e. in transmit, sleep or idle. The typical power consumption values in different states for Lucent Silver Wavelan PC card are given in [33]. The preemptive routing technique with repaired backup approach is discussed in [34]. The techniques consider the node and link stability based on the probability. The technique of [35] proposed routing technique based on AODV to avoid link failures by predicting link status and also checks the status of signal strength by local route request packets. An approach to improve the network lifetime by minimizing the power consumption during the route discovery from source to the destination is given in [36]. And, a technique of pro-active route maintenance in DSR by monitoring signal strength is proposed in [37]. The improvement in routing protocol with the help of optimization is discussed in [38] and also, a power aware protocol has been proposed and analyzed. The overhead due to flooding has been studied in [39] and a position based selective flooding is used in the route discovery of AODV. A multipath reliable and energy aware routing protocol for MANET is discussed in [40]. An analytical expression has been given to estimate the link reliability. The link stability measure considering node stability and link duration is given in [41]. The technique's performance analysis is not given and also the work does not support real time traffic. The author has given the characteristic evaluation of the proposed technique.

2.4 SUMMARY

Most of reported research work in the present work domain either considers the transmission power in finding the stable paths or individual node's energy (node stability) [3, 4, 5, 10, 11, 12, 13, 34, 35, 36, 37]. Some have reported energy minimization by reducing the broadcast overhead [15, 22, 23, 24, 38]. But the energy efficient approach taking into account the link stability, node stability and the overhead reduction have not been discussed in [15, 16, 17, 18, 19]. The study in [26] reveals the fact that by employing the load balancing techniques network lifetime can be increased. The approaches proposed in [27, 28, 29, 30] do not consider load balancing and link stability together. Therefore, these approaches are not comparable to our approach. Few have reported researches addressing the multipath energy aware reliable QoS routing protocol [40]. And our presented technique minimizes the energy consumption by considering the energy ware, node and link stability, and by reducing the broadcast overhead. Our technique also complies with the QoS requirements i.e. congestion. The technique supports the transmission of both the data types i.e. the real time and the non real time data. The technique has been incorporated into DSR routing protocol and have shown significant reduction in link breaks leading to decrease in energy consumption and improved network lifetime.

CHAPTER 3 WIRELESS NETWORKS: IMPERATIVES AND CHALLENGES

3.1 INTRODUCTION

The communication between various devices in a network is a very powerful mechanism to realize the requirements of the users. However, the communication medium (wired) is a complex and clumsy way which limits its flexibility. The organizations setting up networks have to install cables walking through conduits going through walls, floors to reach the work desk. If there are chances of modifications in the requirements plan, then substantial efforts may be needed to put through. The wireless networks offer an escape from the problems of wired networks. The idea of ad hoc network, a wireless network, can be traced back to 500 B.C. The king of Persia used messengers to send messages from capital to different provinces of the country via shouting and messengers were positioned on tall buildings at a distance apart. Then later in 1970, Norman Abramson and fellow researchers implemented a single hop wireless network ALOHAnet. The success of ALOHAnet widespread the use of computer communication and lead to the development of Ethernet and packet radio networks (PRNET). The PRNET was developed for military operations. It uses ALOHA and carrier sense multiple access (CSMA) protocol to access the shared radio channel. During 1980s, the government realized the need to investigate the applications of wireless networks in military applications, and a working group called mobile ad hoc networks (MANET) within the Internet Engineering Task Force (IETF) was formed. The purpose of this group was to standardize the protocols and functional specifications of MANET. In the recent years, many wireless standards and technologies have emerged such as Bluetooth, Infrared Data Association (IrDA), HomeRF and Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. These technologies works best as per the application areas they were emerged for. Bluetooth is one of the first commercially available single hop, point to point ad hoc wireless networks [42] between heterogeneous device.

The MANET's are defined as the category of wireless networks which operates in multi-hop fashion without any infrastructure and are dynamic in nature. The relay of data packets is done via intermediate hops. The growth of MANET is attributed to its self organizing and configuring nature. All the nodes in the MANET can act as a router and participates in a routing protocol to decide and maintain the routes. Being the flexible, rapidly deployable and infrastructure less network, MANETs are suitable for applications involving outdoor events, emergencies, surveillance, natural disasters, mine sites, oil exploration sites and urgent meetings etc. In general, the routes among the nodes in the MANET may include multiple intermediate nodes (relay) therefore, are also termed as multi-hop wireless ad hoc networks. An ad hoc network differs from a cellular network in many ways. The presence of base station in a cellular network simplifies many of the tasks in contrast to an ad hoc network because the cellular network operates in a centralized manner. However, in ad hoc networks routing and other management tasks are performed in a distributed fashion. Hence nodes are capable of performing the job on behalf of the other nodes and are more complex and intelligent. An example of ad hoc wireless network of five nodes is shown in Fig. 3.1. The nodes within each other's range can communicate directly i.e. node *A* can communicate directly with the node *B* and *E*, *B* with the *C*, and *C* with the *D* but node *A* cannot communicate with the node *C* as it is not within the range of node *A*. Therefore, in order to communicate the node *A* with the node *D*, the node *A* has to use intermediate nodes *B* and *C*. The dashed line indicates communication, whereas solid lines indicate the willingness to communicate.

3.1.1 Characteristics

The attributes which are specific to MANET in addition to wireless networks are as follows:

a) The nodes in the MANET communicate in a wireless medium and share the same media i.e. the radio channel.

b) A temporary network is formed arbitrarily as per the application requirements.

c) It is an autonomous and infrastructure-less network

d) It operates in a distributed and peer to peer manner.

e) Every node in MANET can acts as a router.

f) Multi-hop routing: every node can act as a router and can forward data on behalf of the other nodes.

g) Mobility: Each node is free to move in any direction. Therefore, topology changes dynamically.

h) Accessibility: Information can be accessed irrespective of geographical location.

i) Deployment: Network can be setup at any place and time.

j) Infrastructure-less: It allows to work without any supporting infrastructure.

k) Dynamic: It can dynamically reconfigure and organize its network topology.

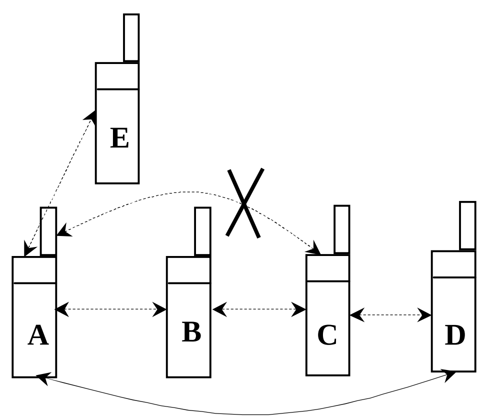

Fig. 3.1: An ad hoc wireless network

3.1.2 Applications

MANET is a flexible network and do not require any infrastructure for its establishment and even the administration tasks are nil. Therefore, the industry has realized its importance looking at the benefits MANET offers and it has become part of many commercial applications. This section describes some of the most ubiquitous applications of ad hoc network. The self-configuration and infrastructure less nature of this network makes it a suitable candidate for many commercial applications, and looking at the advantages it offers, the users are ready to have this network in place even they may have to compromise with its performance requirement. It is a extremely desirable for low cost applications. Therefore, owing to its economical viability and rapid deployment it has become an obvious choice for many commercial applications such as conferencing, home networking, emergency services, personal area network, embedded applications, sensor dust and automotive applications etc. Some of the important applications are described in brief in the following paragraphs.

(i) Military Applications

MANET is very useful for military operations. Because setting up the infrastructure in the battlefield is not a viable solution. It can help the group of soldiers to communicate with each other. There are the times when military operations require their vehicles to coordinate with each other. In such operations security and reliability are of primary concern. There are the times when the commander of a battalion wants to address a certain group of soldiers of his battalion requiring a multicast transmission. Therefore, the routing protocol design should concern the security, reliability and multicast requirements. Sometimes military operations need to be very secure and time bounded. In such situations real time traffic requirements are to be taken into account. The objects used in the battlefield like tanks can be mounted with high capacity battery to service high power transceivers and with the global positioning system (GPS). Then the battery life and the location information may not be the constraint for certain military operations.

(ii) Collaborative and Distributed Computing

The requisite of temporary network formation can be judge in the situations like conferences, lectures or group of researchers sitting together for some meeting and wants to demonstrate their work. In such situations, it is an ideal choice. The peoples may hold their personal digital assistance (PDAs) to share their ideas and may use their personal computers (PCs) if wants to demonstrate their findings. The multicast, battery life and reliability may be of prime concern for such situations.

(iii) Emergency Operations

MANET is very useful in emergency operations such as the fire and rescue operation. The self configuration, minimum overhead and flexibility characteristics make it a suitable candidate for emergency operations. Because there are sometimes the situations where basic infrastructure is destroyed due to war or natural calamities such as earthquakes and immediate establishment of the communication network is required. These scenarios may affect large populations; therefore their management is of utmost importance. The scalability, distributed and fault tolerance distributed are the important characteristics of such environment and need to be tackle by the established communication network.

(iv) Wireless Mesh Networks

Wireless mesh networks are formed to offer alternative communication infrastructure without spectrum reuse constraints for the involved mobile devices. The mesh topology offers alternate paths for data transmission in case of path failures. This service is the most economical support provided by the mesh network. The wireless mesh networks are quick, low deployment cost, easy extensibility, enhanced services, high data rate, high scalability and high availability. It operates in free license band i.e. ISM (2.4 GHz and 5 GHz) and offers data rates from 2 Mbps up to 60 Mbps.

(v) Wireless Sensor Networks

A wireless sensor network provides communication amongst the sensors, deployed in a specific area. The sensors are small devices capable of sensing physical properties and process the sensed data and send it to the monitoring station. The sensing of the phenomenon can be done either on periodic basis or on irregular as the application demands. Generally, the environmental properties such as the temperature, humidity etc. are sensed on periodic basis and the furnace temperature, structural stress etc. are sensed on demand basis. The characteristics of sensor networks which make it a distinct category of

MANET are the movement of nodes, size of the network, and density of deployment, power constraints and traffic distribution.

(vi) Hybrid Wireless Networks

Hybrid wireless architecture is an important application area of MANET. The multi-hop cellular networks and integrated cellular ad hoc relay networks are such type of networks. The growing demand of users in this application area has shrunken the cell size to pico-cell level. Many schemes have been defined to increase the capacity of cellular networks such as the cell sectoring and cell resizing. However, all of these schemes are costly. Therefore, the capacity of the network can be increased further by adopting the multi-hop relaying property within the existing setup. This type of networks offers many advantages such as higher capacity, reliability, increased flexibility, and connectivity and better coverage in untapped regions.

3.1.3 Design Issues and Challenges

MANET being the wireless network is with all the problems encountered in wireless communication such as the power control, transmission quality, and bandwidth optimization. The major issues that need to be tackled in the design are as follows: medium access scheme, multicasting, routing, and transport layer protocols, quality of service, security, scalability and energy management. The main function of the MAC layer protocols is the distribution arbitration of shared channel for transmission. In addition to distribution arbitration, the MAC protocol also tackles time synchronization, hidden terminal, exposed terminals, throughput, access delay, fairness and resource reservation etc. The main function of the routing protocols is to find a feasible path between a pair of nodes. The path selected should satisfy some criterion such as the hop length, least congested, lifetime of the links over the path and minimum power etc. The challenges, the routing protocols are faced with are the bandwidth constraints, mobility, error prone medium, and shared channel contention. The mobility of nodes causes randomness in the network and the links which were working till the present time may not be available for the next transmission. The limited resources also pose challenges to the protocols such as buffer storage, computing power, and battery power. The major design requirements to be faced by protocols are the delay, minimum overhead, security, privacy and scalability. The quality of service (QoS) is the performance measure of the services offered by network to the user. It is very much essential to maintain the communication successful in the network. The various QoS metrics are jitter, packet loss, throughput, congestion and error rate. The absence of central administration and limited resources exacerbate these challenges.

The neighbor discovery and topology organization activities are being taken care of by itself because of self organizing nature of the network. The neighbor discovery procedure collects the information about the neighbors. The procedure may require periodic transmission of short packets to perform this task. The topology organization phase requires information about the entire network to maintain the network topology. However, the limited battery power reserve poses energy constraints to the network. It becomes an issue to the functioning of the network, as each node has to act as an end system and a router at the same time thereby an additional energy is required to keep the node active.

Robustness and Reliability: The network connectivity in MANET is obtained by routing and forwarding the packets among the mobile nodes. Though this approach removes the constraints of fixed infrastructure connectivity, however, also brings certain challenges such as failed links, overloading, selfishness, and unwillingness to forward the packets. Such misbehaving nodes and unreliable links can impact the network performance severely. Further, this behavior can not be detected and isolated easily due to absence of centralized administration mechanism, further increase the design complexity.

Network Security: MANETs are more vulnerable to data and physical security threats contrary to fixed-wired networks. The nodes in MANET are with inadequate physical protection making them prone to security threats. The use of open and shared broadcast wireless channels also makes the nodes prone to security threats. Further, the MANET being a distributed and infrastructure-less network, it relies on individual node level security solution, as centralized security control is hard to implement.

3.2 ROUTING PROTOCOLS

The dynamic nature of MANET results in frequent and unpredictable changes in the network topology, making the routing activity among the mobile nodes, the difficult and complex. The challenges and complexities involved in the design and the importance in establishing communication among the nodes makes the routing protocol, the most active research area within the MANET community. Numerous routing protocols and algorithms have been proposed [43]. The performance of routing protocols in various network environments and different traffic conditions has been studied and compared. Several reports covering surveys and comparative performance evaluation of routing protocols have been published. The routing protocols can be classified on the basis of type-cast property also, namely are unicast, multicast, geocast or broadcast.

3.2.1 Classification of routing protocols

The standard link-state and distance-vector algorithms [43] do not scale well with the size of the networks. This is because of their periodic or frequent demand for route updates in large networks which result in significant part of the bandwidth being consumed, add to channel contention, and thereby, require each node to frequently recharge its battery. Because of the problems associated with the link-state and distance-vector algorithms, a number of routing protocols have been defined (Chapter 2). The protocols are classified into three categories namely the proactive, reactive, and the hybrid. In proactive routing protocols, the routes to all the destinations are determined at the start-up time. The discovered routes are maintained by a periodic route update process. In reactive protocols, routes are determined on demand using a route discovery process. The hybrid routing protocols combines the basic properties of both types of protocols into one. Therefore, they possess the advantages and disadvantages of both types of protocols i.e. the proactive and the reactive protocols. Each protocol category may employ a flat or a hierarchical routing strategy.

3.2.1.A Proactive routing protocols

The proactive routing protocols are also called "table-driven" routing protocols. The nodes using proactive protocols continuously keep on finding the routes to all the reachable nodes. The nodes with their continuous attempts maintain the routing information consistent and up-to-date. Therefore, a node can always get a routing path [43]. Whenever the changes in the network topology occur, the updates to maintain the topology must be propagated throughout the network. Most of the proactive routing protocols for MANET have inherited the properties from the routing protocols used in the wired networks. The necessary changes have been made on traditional wired network routing protocols to adapt to the dynamic environment of MANET. The mobile nodes using the proactive routing algorithms, proactively updates the network status and maintain the routes whether the data is being transmitted or not. The overhead to maintain the network topology up-to-date is high in such nodes. The routing information is kept in various routing tables and the tables are periodically updated if the network topology changes. There are numerous proactive routing protocols. The protocols differ in the way the routing tables are updated, the change detection and the information kept by each routing table. Some of the routing protocols with their basic characteristics and complexity information are listed in Table 3.1 [44].

Table 3.1 Characteristics of selected proactive routing protocols [44]

Protocol	No. of Tables	Frequeny of Updates	CT	MO	CO	Characteristics feature/ disadvantages
DSDV	2	Periodic and as required	O(D.I)	O(N)	O(N)	Loop free/ high overhead
WRP	4	Periodic	O(h)	$O(N^2)$	O(N)	Loop free/ memory overhead
FSR	3 and a list of available neighbors	Periodic and link stae is also periodically exchanged with neighboring nodes	O(D. I)	$O(N^2)$	O(N)	Reduces CO/ high memory overhead, reduced accuracy
OLSR	3 (Routing, neighbor and topology table)	Periodic	O(D.I)	$O(N^2)$	$O(N^2)$	Reduced CO and contention/ 2-hop neighbor knowledge required

CT= Convergence Time, MO= Memory Overhead, CO= Control Overhead N= Number of nodes in the network, D= diameter of the network, I= Average update interval, H= Height of the routing tree

3.2.1.B Reactive Routing Protocols

Reactive routing protocols for MANET are also known by the name "on-demand" routing protocols. In reactive routing protocols, routing paths are discovered on demand [43]. The route discovery procedure terminates when either a route has been found or the route does not exist after examining all possible routes. The scalability of reactive routing protocols is better than the proactive routing protocols but suffer with long delays before the source can start sending the data packets. The route discovery is done by flooding route request packets throughout the network [44]. During the route discovery, when an intermediate node with a route to the destination or the destination itself, is reached a route reply packet is sent back to the source node via same path if the route request has traveled through bi-directional links. If the links on the route were not bi-directional then the route is piggy-backed in the route reply packets and the packets are sent via flooding to the source node. Reactive protocols are of two types one is source routing and another is hop-by-hop routing protocol. In source routed on-demand protocols, each data packets carry the complete route from source to the destination. The main drawback with source routing protocols is that they do not scale well for large networks. In hop-by-hop routing each data packet carries only the destination address and the next hop address. Therefore, each intermediate node in the path to the destination uses its routing table to forward each data packet towards the destination. The advantage of the hop-by-hop routing is that routes are adaptable to the dynamic environment of MANET. However, the disadvantage is that each intermediate node on the route must store and maintain routing information for each active route. Also, each node may have to keep the information about their neighbors which is done by using the beaconing messages. Some of the reactive routing protocols with their basic characteristics and complexity information are listed in Table 3.2 [44].

3.2.1.C Hybrid routing Protocols

The hybrid routing protocols combines the advantages of both types of protocols i.e. the table driven and the on demand routing protocols and overcome their weaknesses [43]. These protocols are designed to overcome scalability problem. In this protocol, the nodes within each other's range work together to form a backbone network to reduce the route discovery overheads [44]. This is done by proactively maintaining the routes to the nodes in close proximity and the routes to the distant nodes are determined using a route discovery procedure. Most of the hybrid protocols proposed to date are based on zones that is the network is divided into different zones. Some protocols exist which formed trees or clusters among the nodes. Some of the routing protocols with their basic characteristics and complexity information are listed in Table 3.3 [44].

Table 3.2 Characteristics of selected reactive routing protocols [44]

Protocol	Multiple Routes/ Beacons	Route metric/ Route maintained in	Route recofnig uration strategy	TC[RD]	TC[RM]	Advantages/ Disadvantages
AODV	No/ Yes	Freshest and SP/ RT	Erase route then SN	O(2D)	O(2D)	Adaptability/ scalability problems and delays
DSR	Yes/No	SP or next available in RC/ RC	Erase route then SN	O(2D)	O(2D)	Multiple routes, promiscupous overhearing/ scalability problems and delays
TORA	Yes/No	SP or next available/ RT	Link reversal and route repair	O(2D)	O(2D)	Multiple routes/ temporary routing loops
LAR	Yes/No	SP/RC	Erase route then SN	O(2S)	O(2S)	Localised route discovery/ use of flooding if no local information

RT= Routing Table, RC= Routing Cache, SP=shortest Path, SN=Source notification, TC= Time Complexity, RD= Route Discovery, RM= Route Maintenance.

3.2.2 Description of Selected Routing Protocols [42]

3.2.2.A Destination Sequence Distance Vector Routing Protocol (DSDV)

The DSDV is based on the principal of Bellman-Ford routing algorithm [39]. The DSDV guarantees loop freedom by tagging each routing table entry with a sequence number to order the routing information. Every node in DSDV maintains a routing table. The routing table lists all the available destinations. It uses both the periodic and event driven updates to maintain the routing table consistency. Event driven updates are used whenever network topology changes and periodic update are done after a fixed interval of time. The update to maintain the consistency may introduce large so to alleviate this problem two types of updates have been defined. The first is full dump and second is incremental dump. The full dump carries all the available routing information whereas incremental update carries only the information updated since last update. Full dump are useful for fast changing networks, while incremental updates are for stable networks. Being equipped with all the routes to all destinations available all the time, route setup time is very small. The updates due to broken links in highly dynamic networks generate large amount of control overhead results scalability problem.

Table 3.3 Characteristics of selected hybrid routing protocols [44]

Protocol	Multiple routes	Route metric method	Route reconfig uration strategy	TC[RD]	TC[RM]	Advantages/ Disadvantages
ZRP	No	SP	Route repair at point of failure and SN	Intra: O(I)/ Inter: O(2D)	O(I)/ O(2D)	Reduce retransmission/ Overlapping zones
ZHLS	Yes, if more than one virtual link exist	SP or next available virtual link	Location request	Intra: O(I)/ Inter: O(D)	O(I)/ O(D)	Reduction of SPF, low CO/ Static zone mao required
DST	Yes, if available	Forwarding using the tree neighbours and the bridges using shutting	Holding time or shutting	Intra: $O(Z_D)$/ Inter: O(D)	$O(Z_D)$ / O(D)	Reduce retransmission/ Root node
DDR	Yes, if alternate gateway nodes are available	Stable routing	SN, then source initiates a new path discovery	Intra: O(I)/ Inter: O(2D)	O(I)/ O(2D)	No zone map ot zone coordinator/ Preferred neighbours may become bottlenecks

TC= time complexity, RD= route discovery, RM= route maintenance, I= periodic update interval, D= diameter of network, ZD = diameter of a zone, cluster or tree, SPF= single point of failure, CO= control overhead

In DSDV routing protocol, the routing table size and the bandwidth required to update them grows with the number of nodes and may introduce to communication overhead.

Example of DSDV in Operation

Consider the node *N1* in Fig. 3.2. Table 3.4 shows the possible structure of the forwarding table maintained at node *N1*. Suppose the sequence number are represented by the *SN_NodeID*, where *NodeID* is the identification number of the node generating the sequence i.e. the destination. The install field in the table helps to delete state entries. We have assumed that all information become available to node *N1* at the same time the other nodes in the network get, so most of the values are same. *Ptr_NodeID* entries of the table present the routes which are likely to compete with other routes to any particular destination. Therefore, points to the null structures.

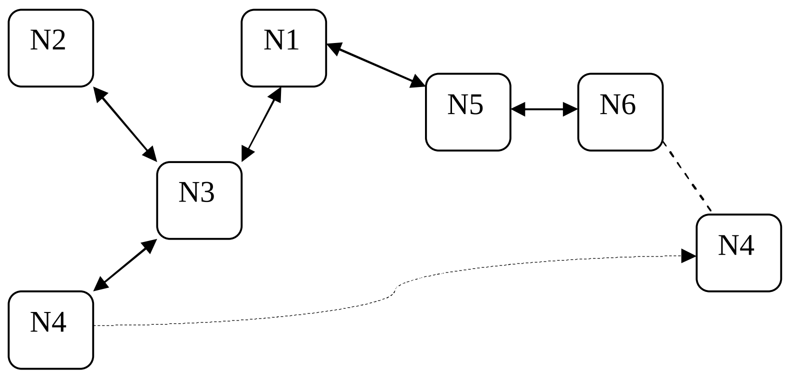

Fig 3.2: Example Network for DSDV

Table 3.4: Node *N1* internal forwarding table

Destination	Next Hop	Hops	Sequence Number	Install	Stable Data
N1	N1	0	730_N1	T001_N1	Ptr1_N1
N2	N2	2	574_N2	T001_N1	Ptr1_N2
N3	N3	1	148_N3	T001_N1	Ptr1_N3
N4	N3	2	426_N4	T001_N1	Ptr1_N4
N5	N5	1	096_N5	T001_N1	Ptr1_N5
N6	N5	2	148_N6	T002_N1	Ptr1_N6

Table 3.5 shows the structure of the advertised routing table of node N1.

Table 3.5: Node *N1* advertised routing table

Destination	Hops	Sequence Number
N1	0	730_N1
N2	2	574_N2
N3	1	148_N3
N4	2	426_N4
N5	1	096_N5
N6	2	148_N6

Suppose node *N4* moves near to the node *N6* and away from the node *N3*. The new internal forwarding table for node *N1* is as shown in Table 3.6. Only the entry for node *N1* is changed. But in the mean time node *N1* was moving, so new sequence numbers have been received and updated accordingly. Table 3.7 shows the node *N1* advertised table. The internal and advertised table structure is as given in [45].

Table 3.6: Updated forwarding table of node N1

Destination	Next Hops	Hops	Sequence Number	Install	Stable Data
N1	N1	0	840_N1	T001_N1	Ptr1_N1
N2	N3	2	684_N2	T001_N1	Ptr1_N2
N3	N3	1	258_N3	T001_N1	Ptr1_N3
N4	**N5**	**3**	**536_N4**	**T710_N1**	**Ptr1_N4**
N5	N5	1	206_N5	T001_N1	Ptr1_N5
N6	N5	2	258_N6	T002_N1	Ptr1_N6

Table 3.7: Node *N1* advertised table

Destination	Hops	Sequence Number
N1	0	840_N1
N2	2	684_N2
N3	1	258_N3
N4	3	536_N4
N5	1	206_N5
N6	2	258_N6

3.2.2.B Dynamic Source Routing Protocol (DSR)

DSR is the source routing on demand protocol. It is designed to restrict the bandwidth consumed by periodic routing table updates in table driven routing protocols. It is a beacon-less protocol i.e. does not require periodic hello packets to determine connectivity with the neighbors. During route construction process it floods the network with the route request packets. The destination node on receiving the route request packets sends back the route reply packets to the source either via following the bi-directional link method or by piggy-backing.

When a node has data packets to send, and the route to the destination is not available, it starts route discovery procedure by broadcasting route request packets to all its neighbors. The neighbors on receiving the packets, rebroadcast the same packet if it has not already broadcast the packet or the neighbor is not the destination itself, or the time to live (TTL) has not expired.

The route request (RREQ) packet carries the sequence number and the path traversed. The node forwards the packet if it has not already forwarded the packet bearing the same sequence number as of earlier one.

The sequence number prevents the loop formations and retransmission of the same packets by intermediate nodes. The destination after reception of the RREQ packet replies to the source node by reversing the path, the RREQ has traversed. This protocol uses route cache containing all the information needed to route the data packets. The route cache is also used during route construction phase i.e. during route discovery if an intermediate node has the route in its cache, then it replies with the information to destination from its cache. The route cache helps to reduce the control overhead. But sometimes stale routing information available in route cache may introduce inconsistency during route construction process. If during the transmission of data packets, a link is broken, the predecessor node of the broken link has to inform source node via sending route error packet so that the any other available route or a route construction process can be started in case the route does not exist. The protocol's maintenance mechanism is not equipped with function to locally repair the broken link. Being the source routing mechanism used by the protocol, routing overhead increases with the path length.

3.2.2.C Ad Hoc On-Demand Distance Vector Routing Protocol (AODV)

AODV is an on demand routing protocol i.e. the route between the source and destination is established on demand. It uses destination sequence numbers to identify the freshness of the paths. The DSR uses source routing while AODV uses the next hop information stored with the source and intermediate nodes for each transmission. The path information of a node is updated only when the received destination sequence number is greater than the already available sequence number with the node. The RREQ packet includes the following information: the source identifier, destination identifier, source sequence number, destination sequence number, the broadcast identifier and time to live information. When a source node is with the date packets to transmit but the route to the destination is not available, the source not broadcast the RREQ packets. When an intermediate node receives RREQ packet, it either replies with the valid route to the destination or forwards the request packet to its neighbors. The validity of the route is determined by comparing the sequence number of the route available with the intermediate node and the one in the received RREQ packet. The duplicates packets identified by comparing the sequence numbers are discarded by intermediate nodes. Sometimes intermediate nodes might be with the inconsistent route information. This situation can occur when the source sequence number is old and the intermediate nodes are with the higher but not fresh destination sequence number. The protocol might generate multiple replies in response to a single RREQ, which may result in control overhead and also periodic beaconing needed to determine the connectivity consumes a significant amount of bandwidth.

3.3 MOBILITY MODELS

The mobility models mimic the movement of mobile nodes in real environments so affects the directions and movement speed of the nodes and changes as per the adopted model. Since the movement of nodes cannot be assumed in a straight line. Therefore, following types of mobility models have been defined [46].

3.3.1 Random Waypoint Model

This is the simplest and widely used model. In this model, the nodes change their directions and speed both and also pause for a certain time period. The node start its movement from a particular location in the region and move towards the destination with the speed varying from min to max and after reaching the destination pause for a certain time and then randomly select the destination and repeat the process. The nodes trace can be generated with the setdest tool of NS-2 package [47].

3.3.2 Gauss Markov Model

The velocity of nodes is assumed to be correlated over time in this model and it is modeled as a Gauss-Markov stochastic process. It is a temporarily dependent mobility model. In the temporary dependent model the degree of dependency is determined by the memory level parameter α. The tuning of memory level parameter α results in various scenarios such as (i) if $\alpha = 0$ then the model is memory less, (ii) if $\alpha = 1$ then the model has strong memory and (iii) if $0 < \alpha < 1$ then the model has some memory. This model eliminates the possibility of sudden stops and sharp turns encountered in the random walk mobility model. This elimination occurs since the future velocities are influenced by the past velocities in the model.

3.3.3 Manhattan Grid Model

The movement pattern of mobile nodes in the streets is emulated by the maps. The model is useful for modeling the movement of nodes in an urban area. The model uses maps consisting of horizontal and vertical streets. The nodes in the model are allowed to move along the horizontal and vertical streets on the map. When the node reaches to an intersection it can take turn left, right or can go straight. The model supports temporal and spatial dependency of velocity. The model also imposes geographical restriction on the movement of mobile nodes.

3.3.4 Reference Point Group Mobility Model

In the MANET applications, there are a lot of scenarios where it becomes necessary to model the behavior of a group of mobile nodes such that they move together. The group mobility can be useful in military battlefield communication such as in rescue operations and for tracking the enemies etc. Each group has a logical center called group leader which determines the group’s movement behavior. At the beginning, every member of the group is uniformly distributed in the neighborhood of the group leader. Afterwards, at each instant of time, every node acquires a speed and direction which is derived by randomly deviating from the group leader. The movement of the group leader and the random motion of each node in the group is implemented via random way point mobility model. However, the individual nodes do not pause when the group is moving.

3.3.5 Pursue Mobility Model

It emulates the scenario where several nodes try to capture a single node which is ahead of them. The usefulness of this mobility model could be in the application areas where enforcement of law and target tracking is required. The target node moves according to the random way point mobility model. The next position of a node is determined by combining the current position, a random vector and an acceleration function. The pursuing nodes velocity is directed toward the target node so that they can catch the target node.

3.3.6 Column Mobility Model

In this model a group of nodes move in a certain fixed direction. The model can be used for the activities where, searching for an item and then performing some action on the found item has to be perform like finding the enemy places and destroying them in the military battlefields. The group of nodes moves in a forward direction around a given line. An initial reference grid is considered in the model. The nodes are placed in the reference grid in relation to their reference points; the nodes mover around their reference point as per the random way point or random walk model.

3.4 SUMMARY

In this chapter we reviewed the basic concepts, design issues and challenge of MANET. We also discussed the different types of routing protocols. We have pointed out the challenges, the protocols face in different situation along with their complexity analysis. Also, the nodes in MANET may follow the movement pattern according to the scenario and the model adopted. Our work considers the random way point mobility model, the most widely used model. We have chosen one representative protocol from proactive category and two representative protocols from reactive protocols category for performance analysis. The selection is done on the basic of their wide spread application and the studies being carried out by the researchers working in the present work area.

CHAPTER 4 PERFORMACE ANALYSIS OF SELECTED ROUTING PROTOCOLS

4.1 INTRODUCTION

It has become widespread fact among the MANET community that because of the high cost involved and lack of flexibility, experimentation in the MANET research area is done through simulations. There exist numerous simulation tools such as the Glomosim, Qualnet, NS2 and Opnet etc. The simulation tools are used for evaluating the ability of the chosen routing protocols i.e. DSDV, DSR and AODV and should be adaptable to different scenarios and modification. The tool should be extensible i.e. we should be able to extend or add a functionality. The tool should provide implementation of the selected routing protocols, also should have the scope to modify them. The presence of the desired features is not merely the criterion to choose a tool; but its results should be highly trusted among the community. We used NS2 simulation tool which is developed at the University of California at Berkeley. The monarch research group at CMU extended the ns-2 to include wireless scenarios for MANET. The MAC layer is defined by IEEE 802.22 standard for mobile nodes. We have used random way point mobility model, two ray ground reflection model and IEEE802.11 standard for our work.

4.1.1 Network Simulator 2

NS-2 is the discrete event simulator used for simulating any kind of internet communication. It provides implementation for *TCP*, *UDP* and variety of routing protocols and support QoS etc. The simulator is written in *C++* and *TCL*, and uses tcl interpreter for the user i.e. user writes the TCL script for the network to be simulated and then it is used by *ns* for simulation. The result of the simulation is the trace file containing various attributes concerning the protocol used. The trace file can be parsed with the scripts like *perl* and *awk* for determining the metrics such as the throughput and the delay etc. The simulation can be visualized with the help of network animator comes with the package. The use of *C+* and *TCL* increases the complexity of simulator.

However, being open source, its design is complex and makes any extension difficult. There have been the efforts going on to improve the structure and design of *NS-2*. However, the obtained results are most trusted by the research community.

4.1.2 Two Ray Ground Propagation Model

In wireless networks, the path loss is defined as the ratio of the transmitted power to the received power of the same signal on the path. The estimation of path loss is important for designing the wireless networks. It is dependent on many factors such as the radio frequency and the terrain. Since the terrain cannot be the same everywhere, so a single model cannot be sufficient. Therefore several models have been proposed in the literature for designing the wireless networks. The free space model is the simplest and most referred path loss model. In this model atmospheric attenuation is not assumed and a direct path signal exists between the sender and the receiver. In this model the relationship between the received power and transmitted power is given by Eqn. (4.1).

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2 \tag{4.1}$$

Where Gt and Gr are the gains of transmitter and receiver antennas, in the direction from transmitter to the receiver, d is the distance between transmitter and receiver, and λ is the wavelength of the signal.

Realistic path loss model considering propagation effects of the specific environment can be obtained by Maxwell's equation but it a complex process. Hence, simpler models have been proposed. The free space model assumes only single path from transmitter to receiver while in reality the signal is received through multiple paths. The two ray propagation model tries to capture real environment phenomenon and assumes that signal is received through two paths, one is the direct path and the other is via reflection or refraction. According to the two ray ground reflection model received power is given by Eqn. (4.2).

$$P_r = P_t G_t G_r \left(\frac{h_t h_r}{4\pi d} \right)^2 \quad (4.2)$$

Where Pt, Gt, Gr and d are the same as in Eqn. (4.1) and ht, hr are heights of the transmitter and receiver antennas respectively.

4.2 ENERGY CONSUMPTION MODEL

The energy consumption model used in the present work is of Carlos et. al. [48,49]. The energy consumption varies from 230mA to 330mA. The 230mA is used in receive mode and 330mA is used in transmit mode. We have assumed the energy supply of 5 V. The values used corresponds to 2,400 MHz WaveLAN implementation of IEEE802.11.

The networks interface of the node decrements the energy according to the following parameters:

a) the NIC characterstics
b) the size of the packet
c) the used bandwidth

Eqn. (4.3) and (4.4) gives the energy in Joule to transmit and receive a packet. In the model we have assumed that no energy is consumed while the node is in listening mode. But we have assumed energy consumption in idle and sleep mode as 1.0 W and 0.001 W respectively.

$$Energy_{Tx} = (330 * 5 * Packet\_Size) / 2 * 10^6 \quad (4.3)$$

$$Energy_{rx} = (230 * 5 * Packet\_Size) / 2 * 10^6 \quad (4.4)$$

We have assumed RF (radio frequency values) 281.8mW which is equivalent to the energy required to model a radio range of 250 meters.

4.3 SIMULATION TOOLS AND PARAMETERS

The performance evaluation of the selected routing protocols is done using the event driven ns2.34 simulator. The simulations are implemented using the random way point mobility models. The setup consists of 25 nodes in 500m X 500 m rectangular area. The initial energy of every node is 1000 J and the range is 250 m. We have used two ray ground reflection models being the realistic and the simulation time is 500 sec.

The traffic is generated using constant bit rate (CBR). The TCP sources are not being chosen because it adapts to the load of the network [50]. For the same data traffic and movement scenario, the time of sending the packet of a node will be different in case of TCP, hence will become difficult to compare the performance of different protocols. The packet size is 512 bytes and the sending rate is 4.0 packets/ second. The energy consumption analysis is done to find the behavior of selected routing protocols i.e. how the energy is consumed by different types of packets i.e. by the data packets, routing packets and MAC packets, by varying the various parameters such as the number of nodes, pause time, speed of nodes, sending rate of packets, number of sources and the area. The performance evaluation metrics used [51] are packet delivery fraction, energy consumed per successful data delivery, network lifetime and number of link breaks, and have been selected to determine the performance of chosen routing protocols. Some of these metrics might have been used in earlier simulation works also. Based on the performance of routing protocols we will choose the protocol to be modified for inclusion of our proposed technique. The number of link breaks is most significant and important metric from our present work point of view so we will analyze the modified routing protocol performance preferably based on this metric but the other metrics will also be analyzed.

Table 4.1: Simulation Parameters

Parameter	Values
Channel type	Wireless channel
Radio- propagation model	Two Ray Ground
Antenna type	Omni Antenna
Interface queue type	Drop Tail/ Pri Queue
Maximum packets in queue	50
Network interface type	Phy/ WirelessPhy
MAC type	802_11
Topological area	500 x 500 sq. m
txPower	1.65 W
rxPower	1.15 W
idlePower	1.0 W
sleepPowe	0.001 W
initial energy of a node	1000 Joules
Routing protocols	DSDV/ DSR/ AODV
Number of mobile nodes	25
Maximum speed	15 m/s
Rate	4 Packet/s

Pause time Simulation time	5, 10, 15, 20, 25 sec. 500 sec.

4.4 ENERGY CONSUMPTION ANALYSIS

Fig. 4.1 to 4.6 depicts the energy consumption of the network against the sources, pause time, number of nodes, area, rate and the mobility of the nodes respectively.

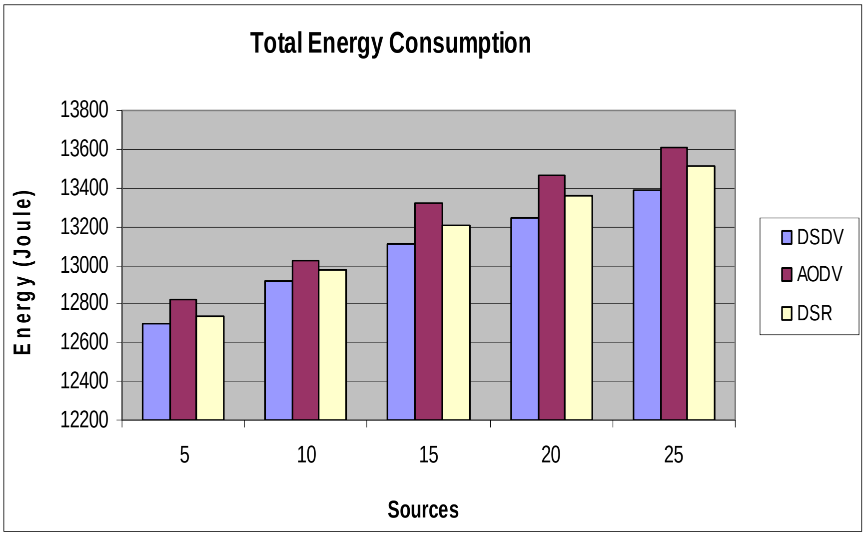

Fig. 4.1: Total Energy Consumption Vs Sources

The energy consumption is maximum for AODV and minimum for DSDV while varying the number of sources (Fig. 4.1). The increase in energy consumption due to the number of sources is consistent. If the nodes are static or are moving with the constant speed, then DSDV have shown minimum energy consumption because once it has established the routes to destination, further no more computation is required. While the reactive routing protocols have shown more energy consumption since establishes the route on demand.

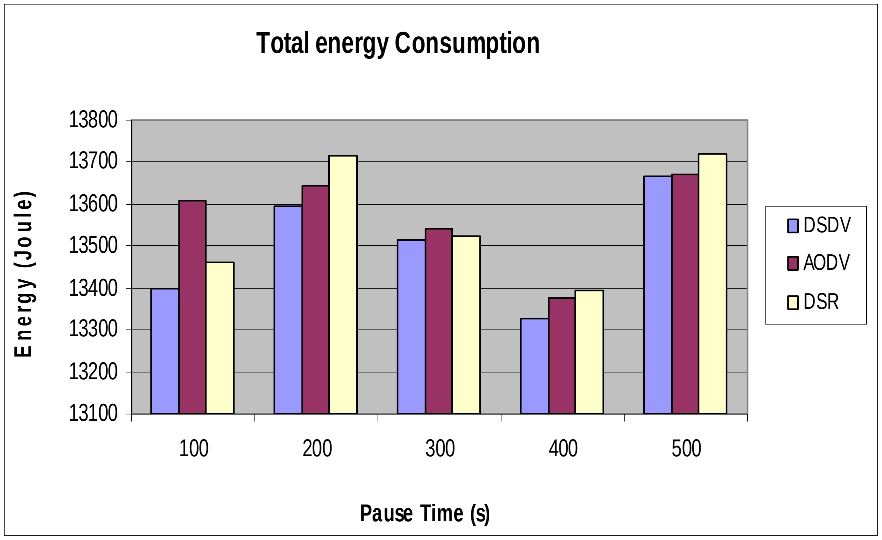

Fig. 4.2: Energy Consumption Vs Pause Time

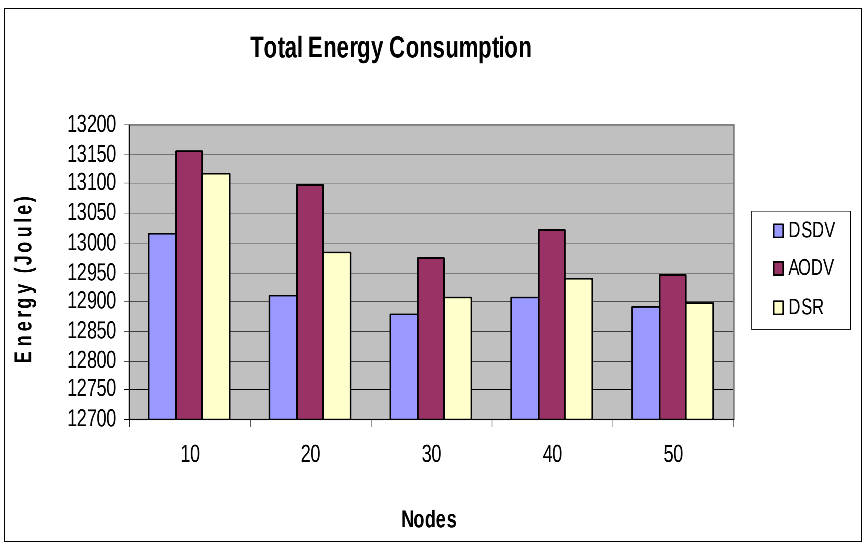

Fig. 4.3: Energy Consumption Vs Nodes

The DSR has shown less energy consumption in contrast to AODV in all the cases, and this might be due to the fact that the multiple paths are stored in the route caches of the nodes in the MANET using the DSR routing protocol, and which helps in future transmissions and reduces the route discovery overhead. The routing overhead for DSR is negligible compared to AODV (Fig. 4.7 (a), 4.7 (b), 4.8 (a) and 4.8 (b)).

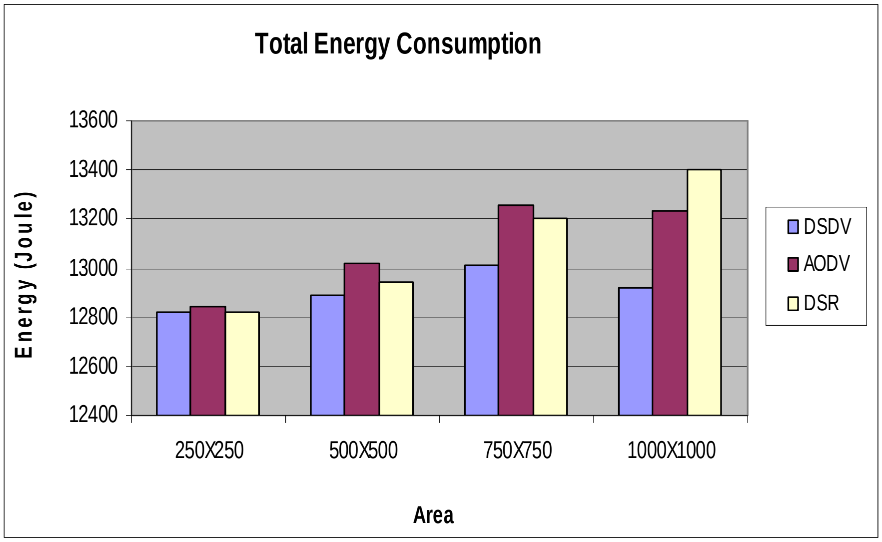

Fig. 4.4: Energy Consumption Vs Area

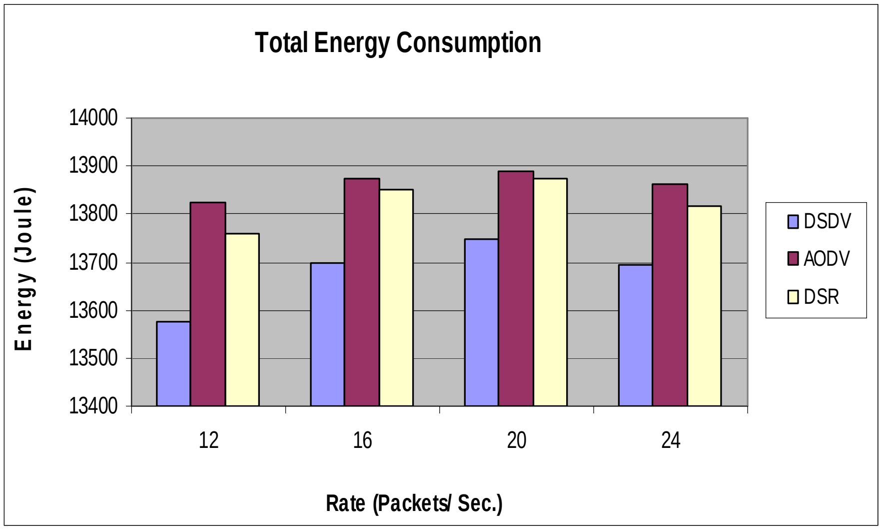

Fig. 4.5: Energy Consumption Vs Rate

The energy consumption against paused time has shown variable behavior. So accurate prediction is not possible but the routing overhead is minimal for DSR among all three protocols in this case.

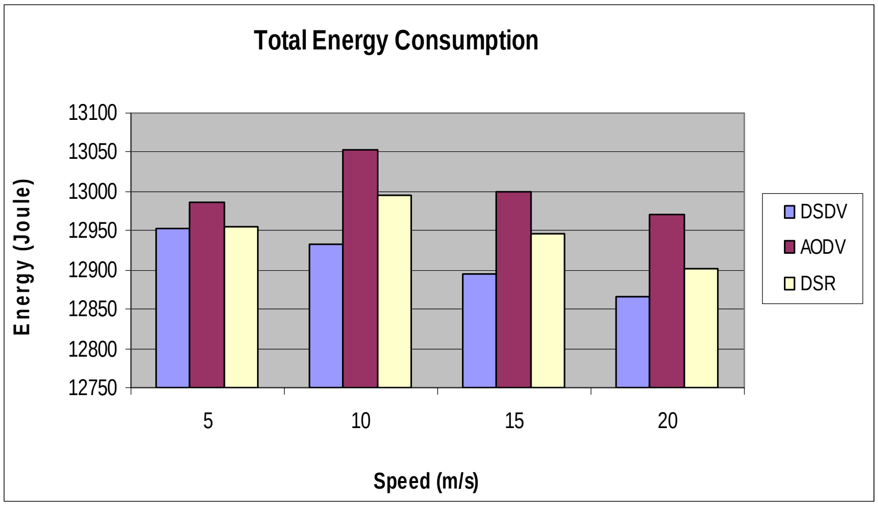

Fig. 4.6: Energy Consumption Vs Speed

We have varied all the parameters for sufficient range of values to evaluate the energy consumption of the selected protocols. But overall in most of the cases DSDV consumed minimum energy, and among reactive protocols DSR outperformed AODV. Based on the energy consumption behavior of routing protocols in all the cases, the performance analysis against the considered metrics (mentioned in section 4.3) was done by varying two parameters i.e. mobility and the number of nodes and these are the important and significant parameters from present study point of view.

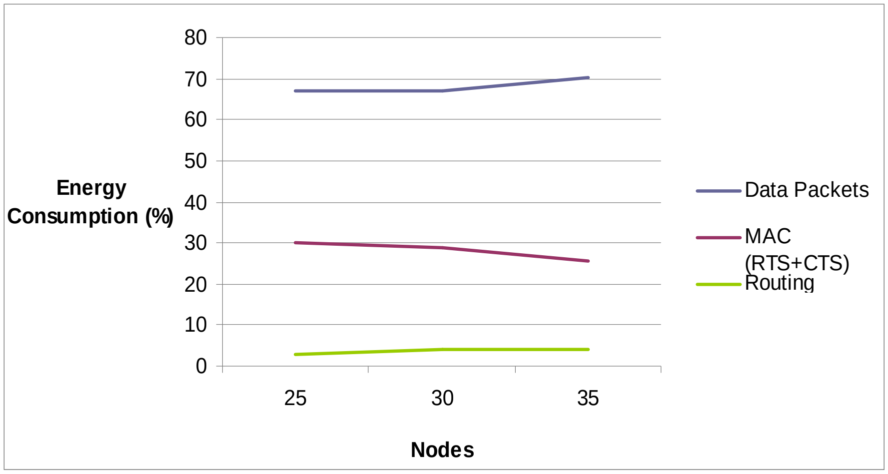

Fig. 4.7(a): Energy Consumption of AODV

Fig. 4.7, 4.8 and 4.9 shows the energy consumption of the selected routing protocols (AODV, DSR and DSV) by different types of packets (mac, routing and data packets). The routing energy consumption increases with the increase of either the nodes or the speed and it is minimum for DSR and maximum for DSDV. The mac layer energy consumption has shown decreasing behavior and it is minimum for DSDV. The DSR consumed less energy as compared to AODV because DSR uses cache mechanism for route maintenance whereas AODV starts a new route discovery for every link breakage.

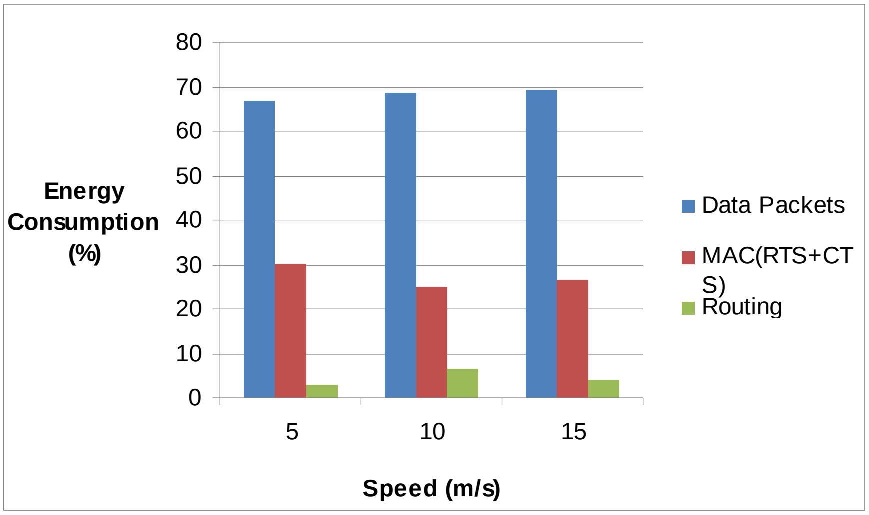

Fig. 4.7(b): Energy Consumption of AODV

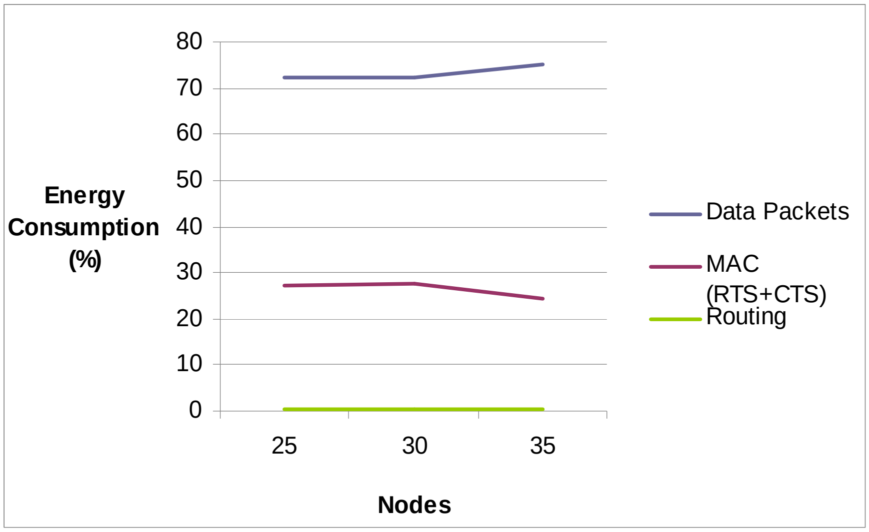

Fig. 4.8(a): Energy Consumption of DSR

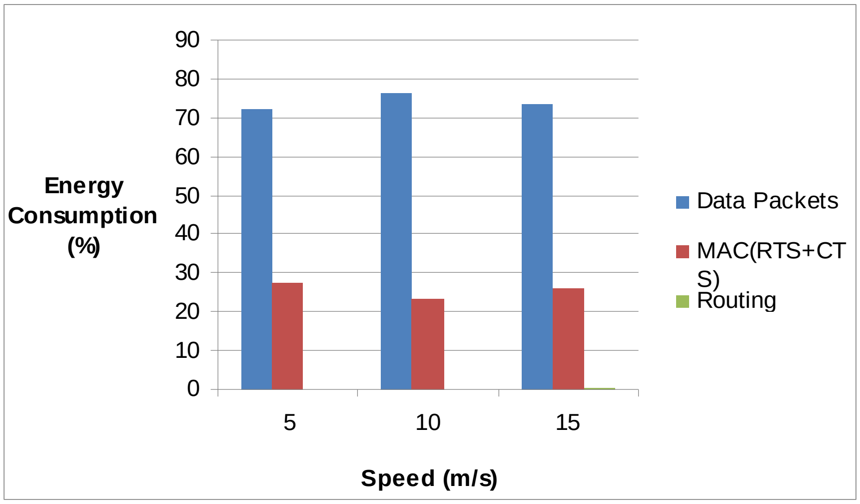

Fig. 4.8(b): Energy Consumption of DSR

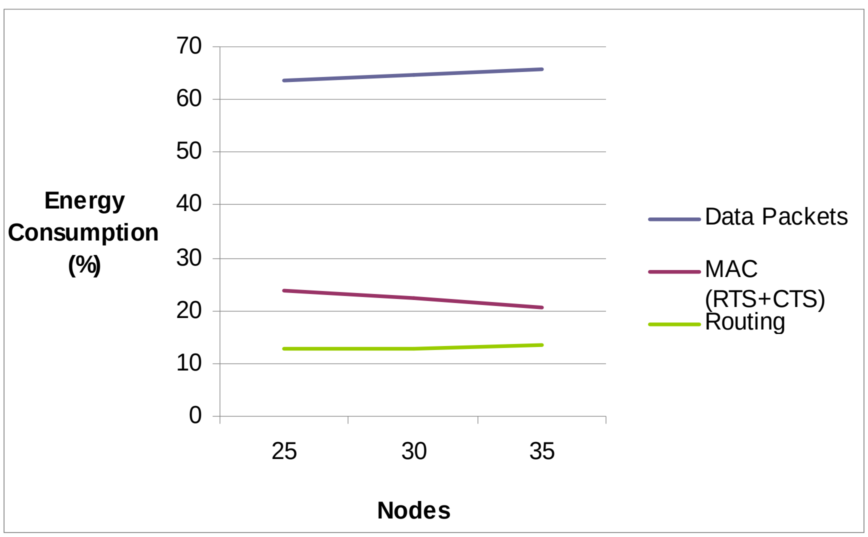

Fig. 4.9(a): Energy Consumption of DSDV

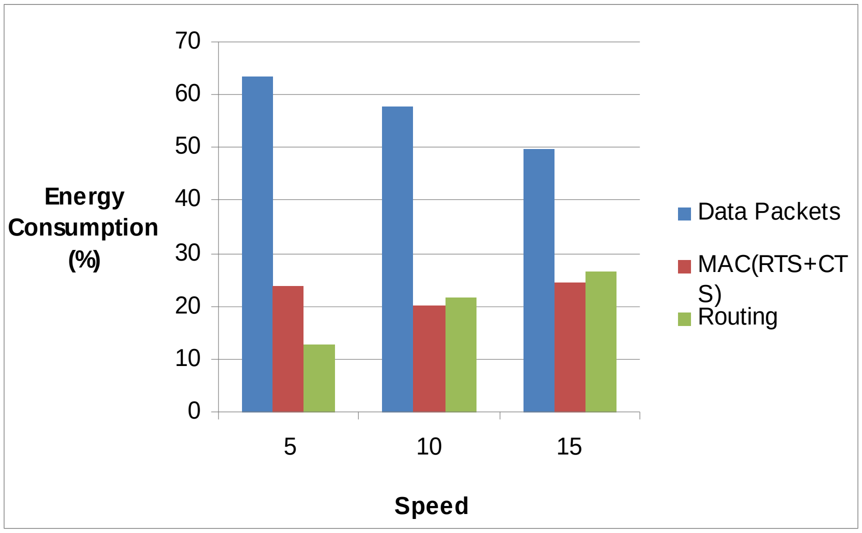

Fig. 4.9(b): Energy Consumption of DSDV

4.5 PERFORMANCE ANALYSIS BASED ON CHOSEN METRICS

Fig. 4.10 shows the packet delivery fraction (PDF) of DSDV, DSR and AODV routing protocols at different speed and nodes. The DSR and AODV outperformed DSDV. Their PDF is constant irrespective of the speed or the number of nodes. The performance of DSDV decreases with the increase of mobility (Fig. 4.10 (b)) because of the presence of stale routing table entries, thereby packets are sent or forwarded over broken links (happens due to stale routing table entries) and this behavior worsen at higher speeds. The throughput of DSR is better than AODV, because DSR has access to a significantly greater amount of routing information than AODV in a single cycle of route discovery. The DSR, being the source routing protocol, can learn routes to each intermediate node on the route to the destination in a single request- reply cycle. However, AODV uses too many routing packets to build the necessary routing tables.

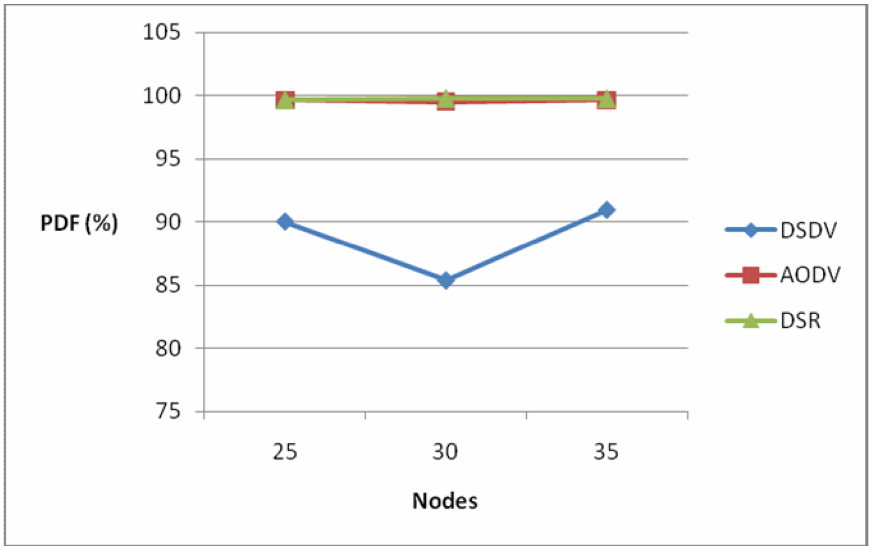

Fig. 4.10 (a): Packet Delivery Fraction Vs Nodes

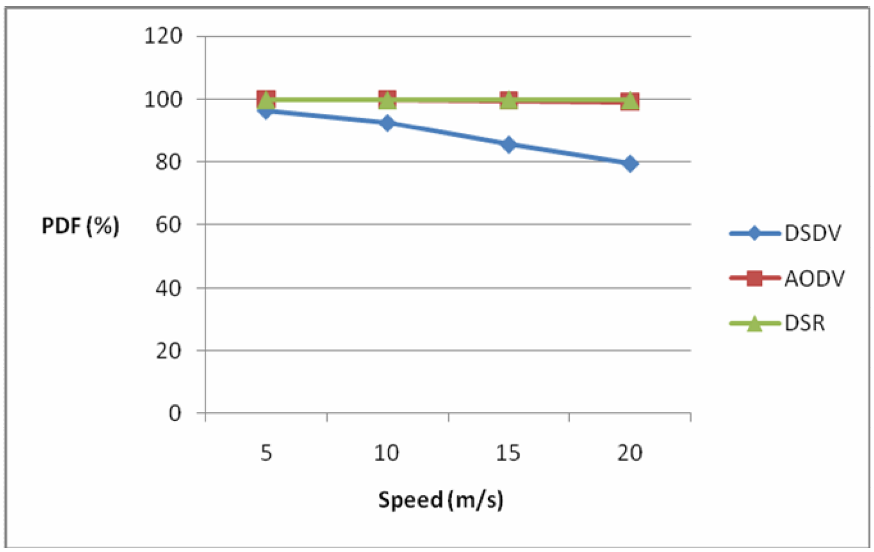

Fig. 4.10 (b): Packet Delivery Fraction Vs Speed

Fig. 4.11 depicts that the energy consumption of reactive protocols is considerably constant against the speed of nodes though it increases with the number of nodes. However, both the reactive protocols (AODV, DSR) have outperformed DSDV. The Energy Consumption per Successful Data Delivery (ECPSDD) of DSDV increases against the speed because the probability of link breakage also increases with the speed. Therefore, an additional amount (is variable depends on many factors such the distance of the node from the source, the maintenance policy adopted etc.) of energy is consumed in constructing new routes. The ECPSDD of DSR is less than AODV because DSR uses less number of routing overheads than AODV.

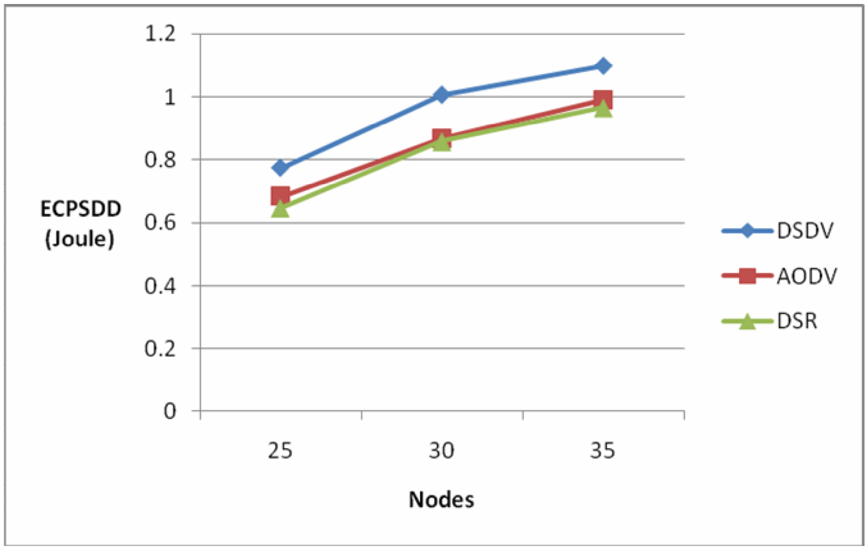

Fig. 4.11 (a): Energy Consumption per Successful Data Delivery Vs Nodes

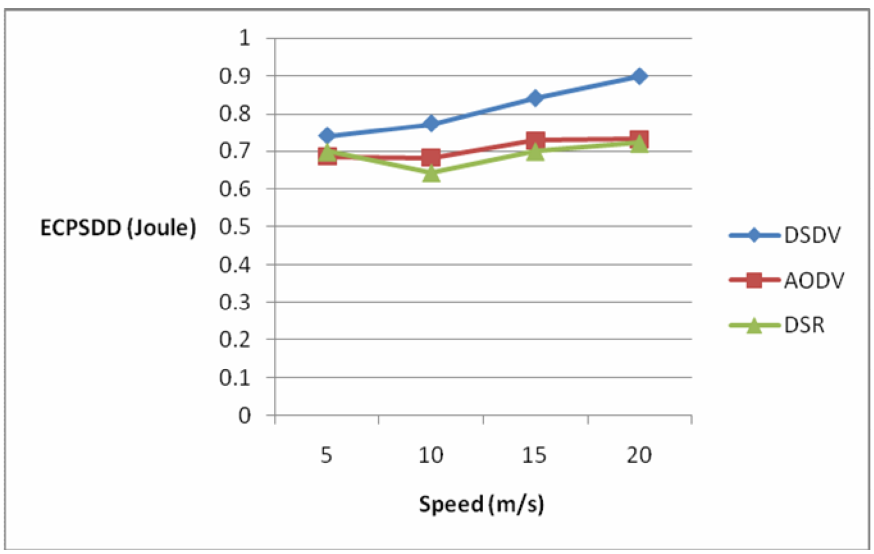

Fig. 4.11 (b): Energy Consumption per Successful Data Delivery Vs Speed

Fig. 4.12 shows the network life time of the chosen routing protocols. The DSDV protocol keeps the network energetic longer than the AODV and DSR. Fig. 4.13 shows that the energy variance of residual battery energy (EVRB) of the nodes of DSR is not distributed properly as compared to AODV and

DSDV. The DSDV prolonged the network lifetime although consumed more energy per packet than DSR and AODV, since the energy consumption for routing overhead is distributed among all the nodes of the network and results in minimizing the exploitation of specific nodes energy repeatedly and also fairly utilizes the nodes energy. In spite of being unfair utilization of nodes (exploitation) by DSR (Fig. 4.13), its network life time is more (Fig. 4.12), since the energy consumption per packet of DSR is less than AODV. However, the AODV have shown (Fig. 4.13) better load balancing than DSR. The network lifetime of AODV is shorter than DSR (Fig. 4.12), because high mobility causes link breakages and AODV is aggressive to maintain broken links incur energy cost.

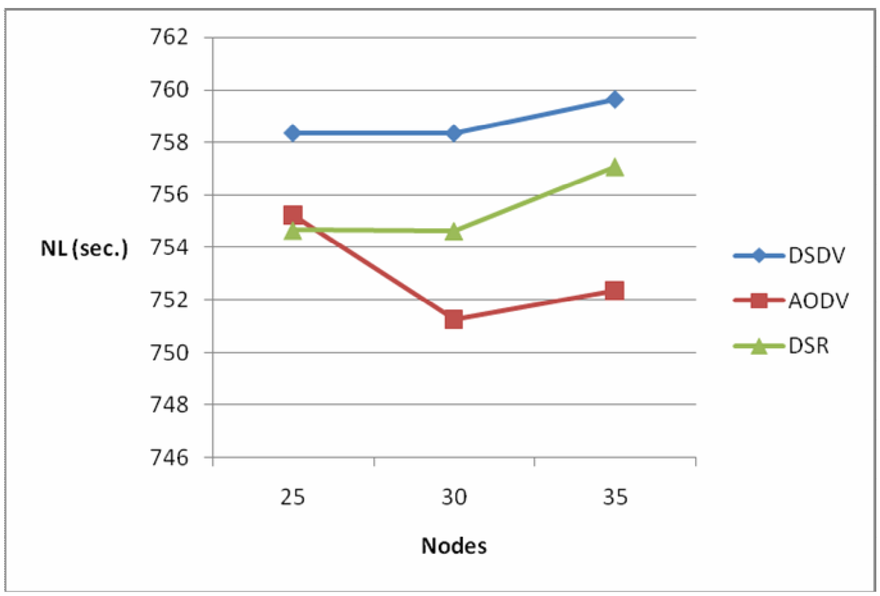

Fig. 4.12 (a): Network Lifetime Vs Nodes

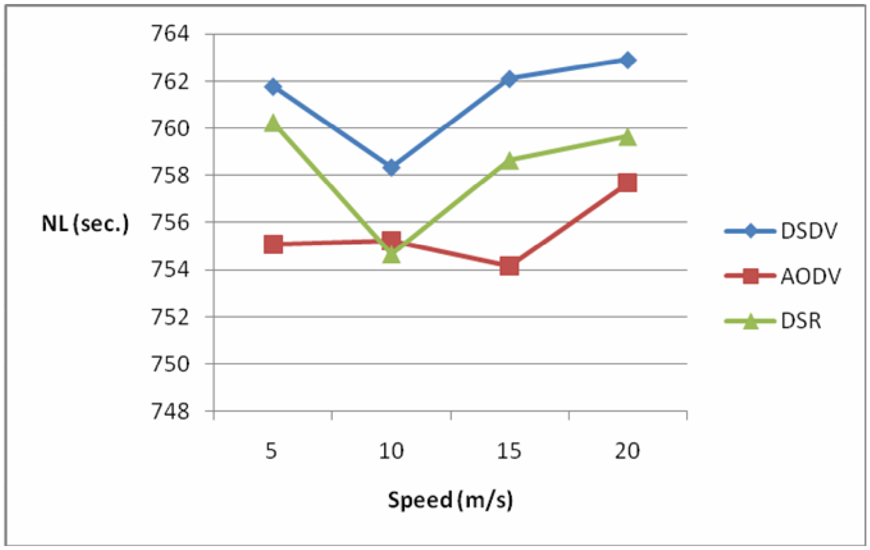

Fig. 4.12 (b): Network Lifetime Vs Speed

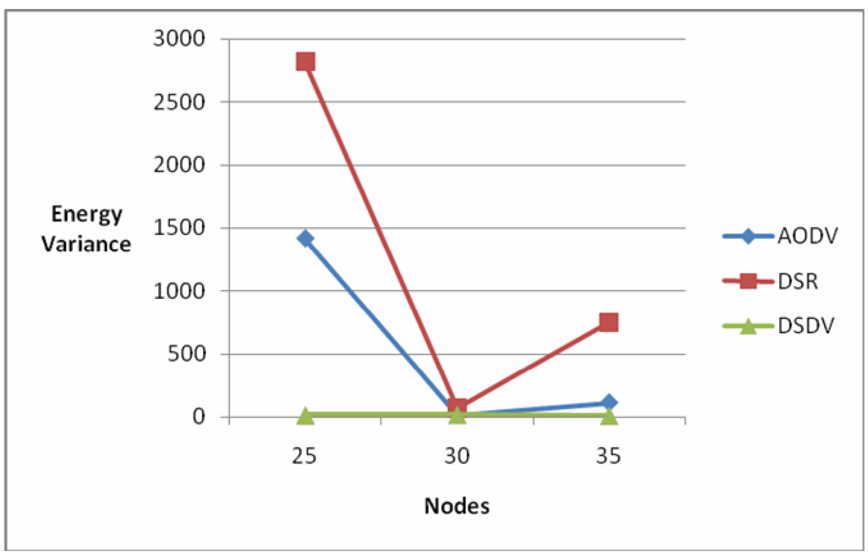

Fig. 4.13 (a): Energy Variance Vs Nodes

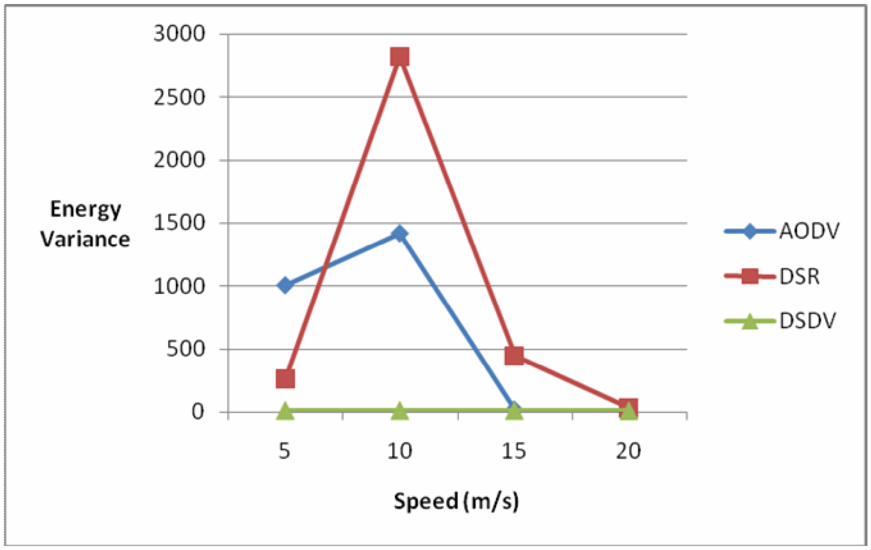

Fig. 4.13 (b): Energy Variance Vs Speed

Fig. 4.14 shows the number of link breaks detected by the routing protocols. The AODV have shown the minimum number of link breaks. The DSDV detects the maximum number of link breaks, since it is not able to adapt to the dynamic environment and the performance deteriorates further with the increase of mobility. The DSR link breaks are also increasing with the speed but AODV is able to adapt itself with the mobility and keeping the link breaks to minimum. We know Short Retry Limit of RTS (07) and Long Retry Limit of Data packet (04) is checked [52] before triggering a link failure in IEEE 802.11 MAC. And as per the considered Energy model, energy consumed in transmitting and receiving the packets, depends on the size of the packet sent/ received. Therefore, a link failure may cause at least 15.5 Joule (3.37 x 4 Joule for data packets and 2.02 Joule for RTS packets). Hence, the protocols reporting more link failures will consume larger amount of energy of the network.

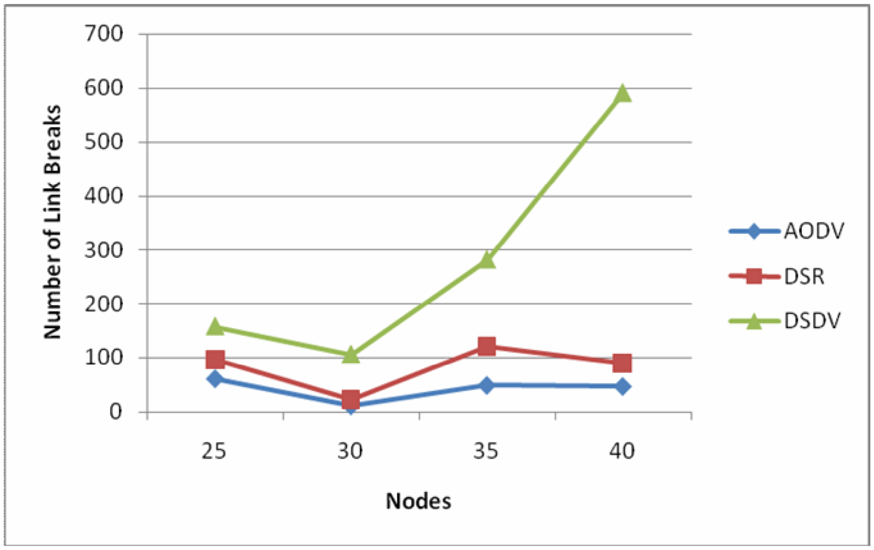

Fig. 4.14 (a): Link Breaks Vs Nodes

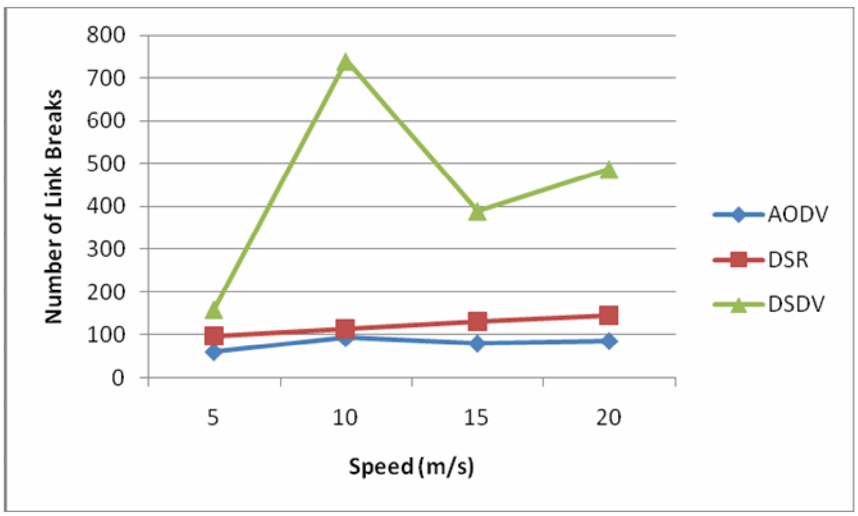

Fig. 4.14 (b): Link Breaks Vs Speed

4.6 PROTOCOL SELECTION TO REDUCE ENERGY CONSUMPTION INCURRED IN LINK BREAKS

The existing routing protocols of MANET have been designed to offer best efforts service with less delay and maximum throughput. They were not designed with the objective of energy efficiency so have shown significant differences in energy consumption. A single routing protocol does not qualify all the metrics of energy efficient routing. The throughput of DSDV decreases with the increase of either of the considered parameters i.e. nodes or speed whereas that of reactive protocols remain constant. Since, it is the most important measure from the network design efficient point of view. DSR outperforms others by consuming minimum energy per successful data delivery. DSDV makes network lifetime longer than others. However, taking into account the throughput performance of DSDV and it also consumes maximum energy among others for successful delivery of data packets, thus it will not be a wise choice. The AODV outperformed in some special scenarios. But throughput and the energy consumption per successful data delivery from our problem domain are the two main metrics which helps to determine the performance of the networks. DSR performed well for both the metrics. We know that a single cycle of DSR route discovery may return multiple paths thereby reducing the energy incurred in discovering multiple paths since the simultaneous multiple paths reduces the communication overhead exponentially [34]. The energy consumption in routing overhead for DSR is minimum. The ns2 implementation of DSR lacks of local recovery mechanism, reported more number of link breaks. In view of all these facts and reasons, the DSR was selected for the inclusion of our presented technique.

4.7 SUMMARY

In this chapter we have presented the concepts required to understand the simulation work. Section 2, give the energy consumption behavior of DSDV, AODV and DSR protocols considering various parameters such as the pause time, number of nodes, mobility, area and rate etc. The behavior of the protocols remained same against all the chosen parameters. Based on energy consumption analysis, only two parameters were considered for performance evaluation. The performance evaluation was done considering the metrics given in section 4.2. Finally section 4.6, concludes with the selection of a routing protocols favoring the present work.

CHAPTER 5 PROPOSED TECHNIQUE AND DESIGN OF EAEDSR

In this chapter we have described our proposed technique to measure the link stability. The energy aware link stability prediction metric for MANET is defined. The metric helps to predict the likely link break time. In order to select a stable and reliable path, the nodes over the path consider the received power strength and traffic levels of the nodes. The destination node selects the node disjoint multiple paths. The nodes over the path keep on monitoring the node's stability and the link lifetime. The link lifetime is measured by the received signal power strengths at different time intervals. The node's stability is measured by considering the available energy of the nodes. These two measures help to compute the link stability metric which is used as a preemptive criterion. The technique reduces the communication overhead exponentially. The design aspects of the inclusion of the proposed technique in DSR routing protocol have been described.

5.1 PROPOSED TECHNIQUE

The link and node's stability is measured using two metrics, the link expiration time (LET) [53] and remaining energy of the node. These metrics are combined to generate a measure which will reduce the cost of handling the link breaks. Since in normal condition the routing protocol searches for alternative paths only after the current path fails and the cost of failure detection is high since many retries have to time out before being pronounced dead [52]. The presented measure kept the cost low.

5.1.1 Predicting Link Expiration Time

Link Expiration Time (LET): The link expiration time prediction algorithm based on signal strength of receiving packets was proposed in [53]. But the algorithm assumes that the nodes are moving in the same direction with the same speed. But being ad hoc in nature the prediction based on speed and direction may not be accurate. We are presenting link expiration time (LET) prediction measurement based on the signal strengths of the receiving packets. According to the Fig. 5.1, node *B* receives the signals from node *A* at time t_o, t_1 and t_2. Suppose the strength of the received signals is P_0, P_1 and P_2 respectively. The signal power threshold, for the wireless interface is fixed. Suppose node *B* receive the packet at time *t* with signal strength equivalent to threshold P_s, then using the Lagrange interpolation the predicted ***LET*** (t) is given by Eqn. (5.1)

$$t = \frac{(P_s - P_0)(P_s - P_1)}{(P_2 - P_0)(P_2 - P_1)} t_2 + \frac{(P_s - P_1)(P_s - P_2)}{(P_0 - P_1)(P_0 - P_2)} t_0 + \frac{(P_s - P_0)(P_s - P_2)}{(P_1 - P_0)(P_1 - P_2)} t_1 \quad (5.1)$$

We have used the power strengths of the three signals and their time of occurrences. If the power strength of the two consecutive measurements remained same then we considered the one with the later time. We have also assumed that nodes are capable of measuring the strength of the received signals.

5.1.2 Node Stability (NS)

The power consumption at the network layer is because of the two operations namely the communication and the computation [36]. The communication power is consumed due to the transmission and the reception of packets of information. The power is also discharged even the node is idle and waiting for the packets. The computation power refers to the power spent in calculations that take place inside the node for routing and power adjustments etc. The energy consumption of a node at time t is given by Eqn. (5.2)

$$E_{c(t)} = N_t * p + N_r * q \quad (5.2)$$

Where:

$E_{c(t)}$ is the energy consumed by a node after time t

N_t is the number of packets transmitted by a node

N_r is the number of packets received by a node

p and *q* are constants factors

Thus if E_i is the initial energy of a nodes, then the remaining energy of a node after time t is given by Eqn. (5.3)

$$E_{r(t)} = E_i - E_{c(t)} \tag{5.3}$$

The main objective of the work was to find the stable path from source to a given destination and thereafter reducing the efforts required in handling the link breaks. The path stability is based on the stability of links on the path. In order to find the stable path we have considered received signal power strength and bandwidth as the main criterion. The stable path will reduce the number of link breaks resulting in cost reduction otherwise which have been incurred in handling the failures.

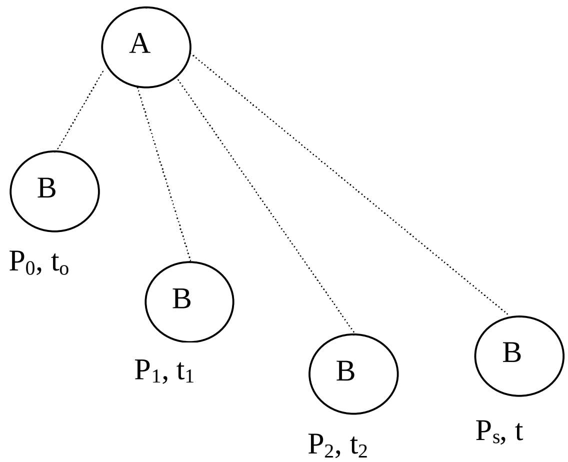

Fig. 5.1: Movement of nodes at different times

5.1.3 Link Stability Measure (LSM)

It can be inferred that link stability is directly proportional to Link Expiration Time because higher values of ***LET*** will increase the link duration (availability). It is also proportional to the nodes stability as higher energy balance of the node will improve the network lifetime. Therefore, we have taken the Link Stability Measure (LSM) as the product of both i.e. the ***LET*** and the ***NS*** and it is measured as given in Eqn. (5.4).

$$Link\ Stability\ Measure\ (LSM) = LET \times NS \tag{5.4}$$

The *LSM* value determines the network performance. We have used ***LSM*** as the preemptive measure in the modified *DSR*. We have chosen ***DSR*** [45] protocol as a candidate protocol. The presented Energy Aware Efficient DSR (EAEDSR) works in three phases.

The three phases are as follows:

1. Route Discovery
2. Route Selection
3. Route Maintenance

The path discovery is started by sending *RREQ* to all its neighbors satisfying the broadcasting condition. The *RREQ* packet has been modified to carry the Node's stability (NS), traffic level (TL), weak nodes (WN) and data type (real time traffic and non-real time traffic) in addition to standard information (as per standard DSR implementation). The traffic level of a node is the number of packets buffered in the interface queue of the node. The traffic level field of the *RREQ* packet carried the cumulative traffic of the nodes on the paths followed by the *RREQ* packet and initially by default the *TL* value is zero. Total energy balance was included to determine the paths for a particular data type (real time traffic and non real time traffic). The Fig. 5.2(a) shows the *RREQ* packet format. The initial value of *LSM* is zero at every node and it is updated as the data transmission goes through the node over the path. Every node maintained a table called Neighbor Table (NT). Fig. 5.2 (b) shows the structure of *NT*.

Src	Dstn	Type	ID	TTL	Hops	NS	ToD	WN	TL	Path

(a)

Src	Dstn	ID	Hops	RP	TL

(b)

Fig. 5.2: RREQ packet and NT table format

The route reply packet format has been modified to contain the weak node and traffic level information in addition to standard information (as per DSR implementation in NS2). The presented scheme does not allow source node to maintain route cache for the long time as the network conditions changes rapidly in terms of energy levels of nodes. When the source node refresh its cache the last predicted *LET* values of nodes on the path is used till the new one is computed. The nodes know about the energy balance of their neighbors from RREQ packets. When the energy balance of a node goes below a specific threshold (Section 4.3), we considered the node as a weak node. Thereby increased the weak node count (WN) by one.

5.2 MODIFIED DSR (EAEDSR)

5.2.1 Route Discovery and Selection

In the *DSR* routing protocol, when the source node wants to send the data packets to a destination node, it starts a route discovery by sending *RREQ* to all its neighbors. Upon receiving *RREQ* packet, the intermediate node checks whether its own address is listed in the path list of the received RREQ packet, if its address is present, then the packet is dropped. Otherwise, the node appends its own address to the list of path and before it rebroadcast the *RREQ* packet to all its neighbors, the intermediate node waits for a period, till the subsequent packets (RREQ) with the same identification number traveled through other paths has been received. When the *RREQ* packet is received by a node, it store its information i.e. traffic level and received power (RP) value in neighbor table. Since the *RREQ* packets have traveled through different paths hence may differ in link stability measured by received power signal strengths. For broadcast, only the neighbors having Traffic Level $<= TL_{th}$ are selected. When the wait period expires, the requests with *RP* values > threshold value are selected for broadcasting and the node's traffic level value is also added to the packet. The intermediate nodes on the path are not allowed to send RREP, from their local cache. Since, this may result in a route, which does not realize the considered requirements needed to maintain the network performance. The destination receives the multiple RREQ, and it selects the paths having disjoint nodes. If the type of data received is real time traffic then it selects the path with the minimum number of weak nodes and unicast the reply. The source can start transmitting the data. Otherwise i.e. in case of non real time traffic the destination generates multiple replies and unicast(s) them to the source. The source node has multiple node disjoint paths to the destination. The source sorts the path in the increasing order of the number of weak nodes. In case of multiple paths with the same number of weak nodes, the source node sorts the paths in the increasing order of traffic levels. If the traffic levels are also the same then the path with the minimum number of hops is selected. The algorithm for route discovery and selection is shown in Fig 5.3.

5.2.2 Route Maintenance

During the transmission if the *LSM* goes below LSM_{thr}, it informs to its predecessor node about node failure by sending *NODEFAIL* message. Once a node receives such a message it sends *ROUTEFAIL* message to the source node. The source node can then reroute the packets by backup routes, if available. If backup routes do not exist, then the source node starts the route discovery procedure. If the multiple routes found during route discovery are used as back up routes on one by one basis during primary route failure then a significant net gain in the probability of breakage may be obtained [34].

$$Net\ Gain = P_{pr} - P$$

```
Procedure RouteDiscover_Selection () {
        Source broadcast RREQ packets to all its neighbors
        Upon receiving a node checks its address in RREQ
                if present then drop the packet
                else    add its address and waits for a period
                        till RREQ with same id traveled through
                        other paths have been received
                        for     rebroadcast neighbors with Traffic
                                Level < TL_th and RREQ with RP > RP_th
                                selected. (Reduces routing overhead)
        Destination receives the multiple RREQ packets and  selects
        the multiple node disjoint paths
                if      data type is real time
                        Select the path with minimum number of weak
                        nodes and unicast the reply
                            Source start transmission
                else (non real time)
                        unicast multiple replies and source sorts
                        paths in the increasing order of weak nodes,
                        average traffic level, minimum number of hops
                                Source can transmit either
                                Using backup path approach or
                                parallel path approach
}
```

Fig. 5.3: Algorithm for route discovery and selection

Where P_{pr} is the primary route breakage probability and P is the multiplicative probability of backup routes. The routes are independent of each other and nodes disjoint. It has been proved that the performance of the *DSR* with the backup route approach is better than the conventional *DSR*. However, the problem with the backup route approach is that while the source is using the one route the other earlier discovered routes might fail and the source node may remain unaware of their failure and this situation poses a problem. The problem is overcome by using the multiple routes simultaneously and improves the communication between the two ends. It has been prove that the use of multiple routes simultaneously i.e. in parallel will reduce the probability of communication breakage exponentially.

The algorithm for route maintenance is shown in Fig. 5.4.

```
Procedure Maintenance () {
        if LSM < LSM_th,
                Node inform to its predecessor node by
                NODEFAIL message

                Upon receipt of this message receiving node
                send ROUTEFAIL message to source node

                Source node can either use backup routes if
                exist or can start new route discovery
}
```

Fig. 5.4: Algorithm for Route maintenance

5.3 SUMMARY

A link stability prediction metric based on link duration and node's stability is developed and its inclusion into *DSR* is also described. The link duration is computed by measuring the signal strength of the three packets having differing power levels. The design aspects of the algorithm to include into the DSR protocol are given in section 5.2, and also discussed the routing overhead reduction and addition of weak nodes information during the route discovery phase in the protocol. The information gathered during the route discovery phase aid the modified protocol to support the traffic types (real time and non real time traffic). The implementation and results analysis discussion of the prediction algorithm in DSR is given in chapter 6.

CHAPTER 6 IMPLEMENTATION AND RESULTS DISCUSSION

This chapter describes the implementation and analysis of the presented algorithm (given in chapter *5*). The reason that *DSR* was chosen for implementation is that it has comparable performance with the *AODV* and returns multiple paths in a single route discovery cycle. The more detailed discussion concerning the selection of protocol was discussed in section 4.6 of chapter 4.

6.1 IMPLEMENTATION DETAILS

DSR is implemented in NS-2. In order to have the *EAEDSR* in addition to *DSR* directory, the other directories such as mac, common, queue and *DSR* were modified to include the details required to implement the *EAEDSR*. The files *dsragent.cc* and *dsragent.h* define the *DSR* implementation. The functions *handlePacketReceipt()* and *handleRouteRequest()* were modified as per the *DSR* routing activity. The functions were modified to include the computation of required parameters such as the P_t. The *replyFromRouteCache()* function is modified not to reply from the local cache of the intermediate nodes. The source route header file in DSR directory defines the source route header and is modified to contain all the information as per packet structure (Section *5.1.3*). The common directory of NS-2 defines a *packet-stamp.h* file, it is used to stamp the packet with the information. The sender node stamps the packet with the residual battery energy and queue length information. The *packet.h* file defines the packet structure and contains the header and data information. The neighbor table is implemented in *node.h* and *node.cc*. The link stability metric computation implementation was done in the same files (*node.h* and *node.cc*). The *wireless-phy.cc* file of mac directory was modified to generate the threshold power value. These were the main modifications made to implement the EAEDSR in NS-2 simulator.

6.2 SIMULATION AND RESULT ANALYSIS OF EAEDSR

The protocol is simulated using ns2 [47]. The design and implementation guidelines are adopted from [50, 51]. The simulation area is of *500 x 500* sq. m size, where *25* nodes are placed. The selection of source and destination is done on random basis. The channel model used is free space. The traffic sources used in the simulations generated constant bit rate (CBR) data traffic. The energy model taken is the one given in the section *4.2* of chapter *4* of this thesis. The values used correspond to *2,400* MHz Wave LAN implementation of IEEE 802.11. The radio frequency value is set to *0.2818* W for the transmission range of *250* m. The packet size taken is *512* bytes. The nodes movement is modeled according to the random way point mobility model. The nodes movement speed is taken as *5.0* m/s. The packet sending rate is *4* packets/ sec. The initial energy of the nodes is *1000* Joule. The power consumed in transmitting and receiving the packets is *1.65* W and *1.15* W respectively. We have taken the power consumption due to the idle and sleep state of node into account and it is *1.0* W for idle and *0.001* W for sleep state. We have assumed that the link break occur when the receiving power is below the receive threshold (RXThresh = 3.65e-10 W). The Fig. 6.1 and 6.2 shows the reduction in the number of link breaks.

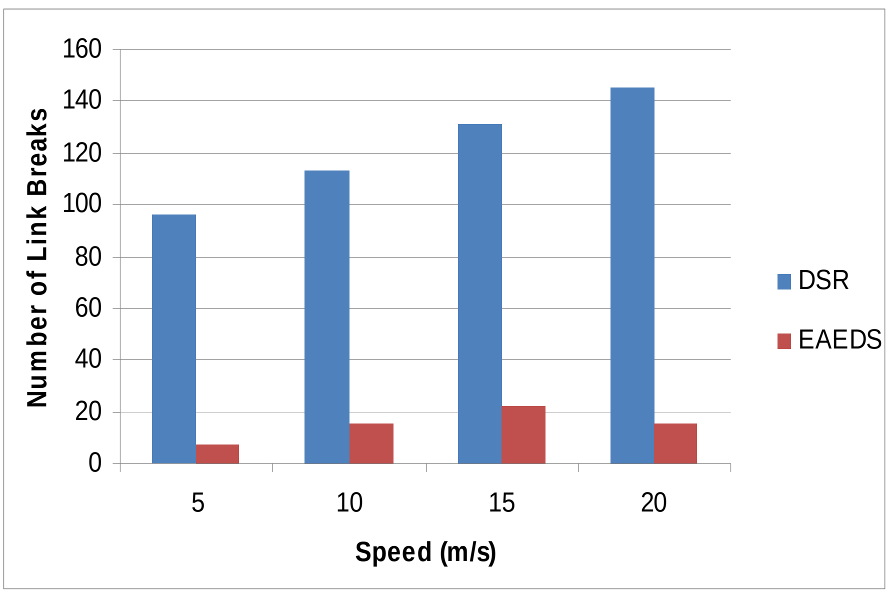

Fig. 6.1: Link Breaks Vs nodes

The EAEDSR reported significantly lesser number of link breaks as compared to the original DSR implementation. The results presented are under ideal network conditions so might differ slightly in real situation due to uncontrollable factors such as fading etc.

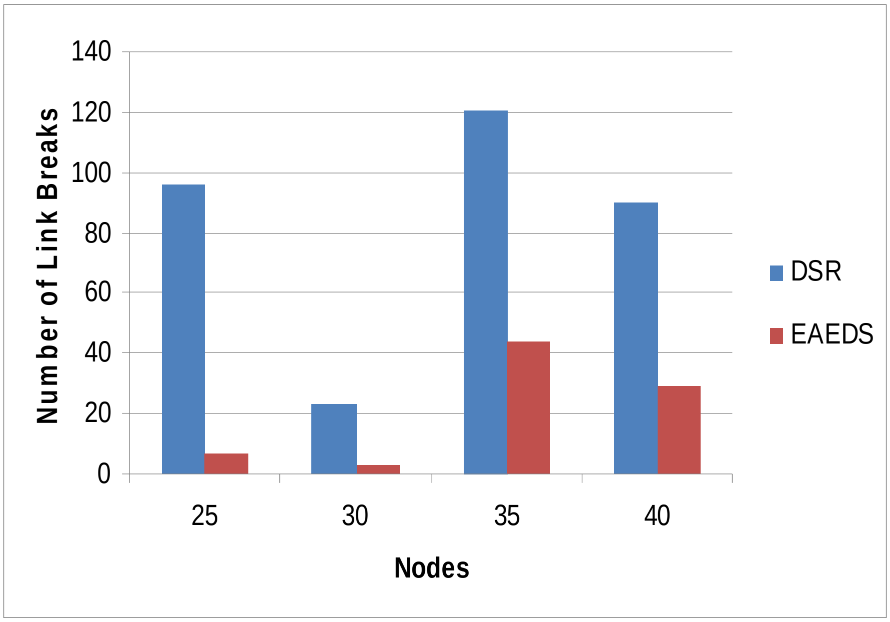

Fig. 6.2: Link Breaks Vs speed

The energy consumption of EAEDSR is also reduced due to lesser number of link breaks and is shown in Fig. 6.3. The energy saved in handling the link breaks improves the network lifetime is shown in Fig. 6.4. The increased network lifetime resulted in transmitting the more packets. The packet delivery fraction is has not shown significant improvement since the transmission of more packets leads to reception of more packets, hence the overall effect remain the same. However, the overall performance of the network improved. The ECPSDD is reduced and is shown in Fig. 6.5. The reduction in ECPSDD is obvious due the reduction in the energy consumption.

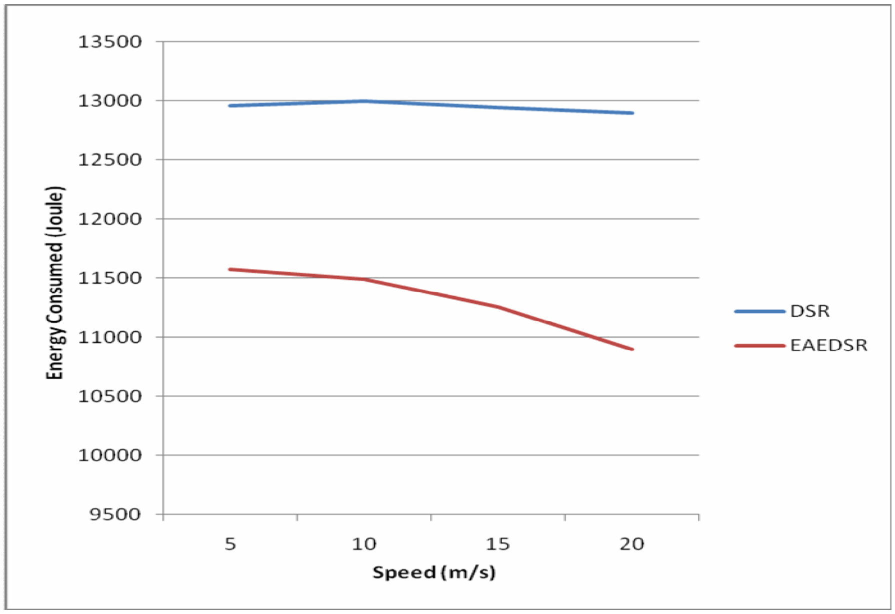

Fig. 6.3: Total energy consumption Vs speed

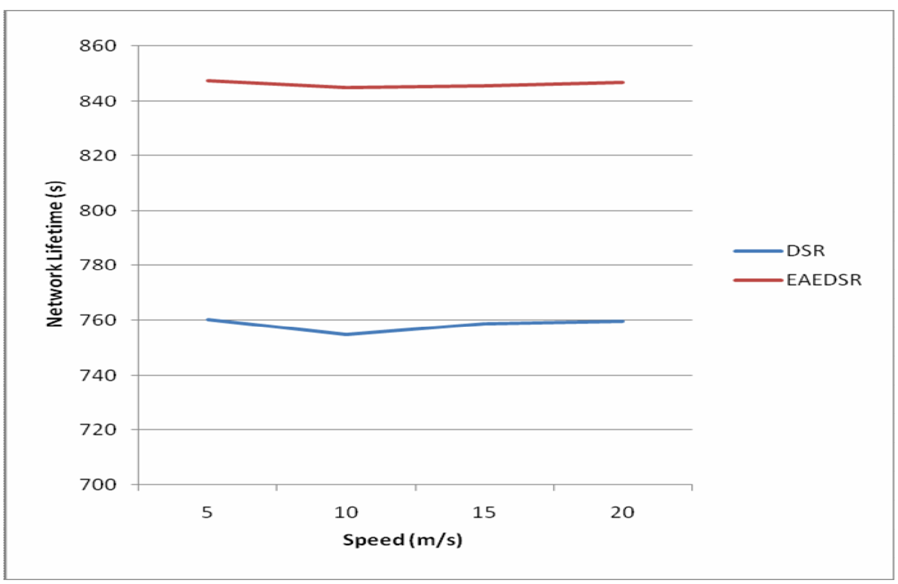

Fig. 6.4: Network Lifetime Vs speed

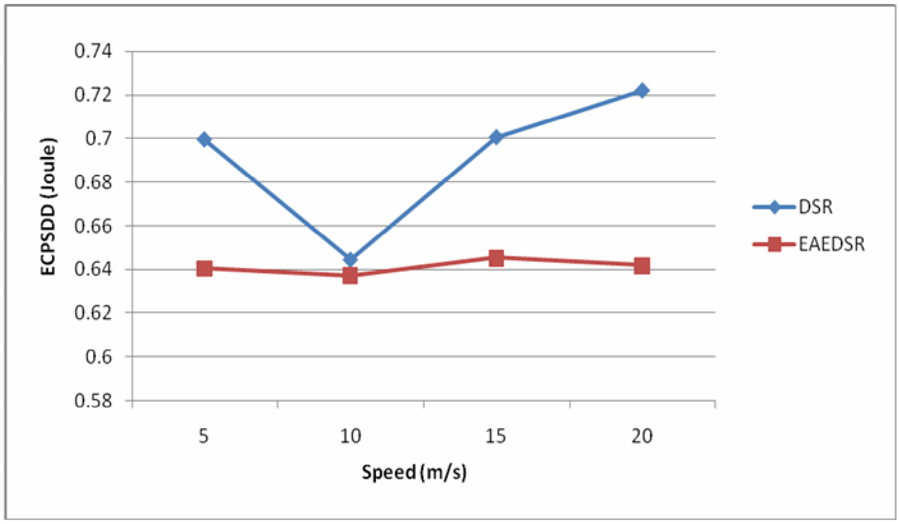

Fig. 6.5: ECPSDD Vs speed

6.3 SUMMARY

The chapter described the implementation and performance evaluation of the implementation of the presented technique in DSR. The modified DSR (EAEDSR) considers the link duration and node stability to determine link stability measure. Section *6.1* gives the main modification points that were performed to simulate the implementation of the presented technique in DSR. Section 6.2, give the performance evaluation of the EAEDSR in terms of the defined metrics (Section *4.3* of chapter *4*) i.e. link breaks, total energy consumption, packet delivery fraction, networks lifetime and energy consumption per successful data delivery. The result shows significant improvement in the performance of DSR routing protocol.

CHAPTER 7 CONCLUSION AND FUTURE WORK

The most important issue in the development and adaptation of MANET in the mission critical application is the design of efficient routing protocols due to its ad hoc nature. The nodes in MANET are equipped with lower energy reserve; hence an efficient utilization is needed. If the energy is not used efficiently it may lead to network partitioning, i.e. communication disrupt for significant amount of time. Moreover, the computation of a new path not only consumes resources such as the computation power and memory but also may put hindrance to the already ongoing transmission and moreover the increased traffic due to the broadcast introduces congestion. The new route discovery adds delay. Therefore, the higher frequency of link disconnection in such a dynamic environment incurs a significant cost in terms of energy consumption and limits its use for real time traffic.

The network lifetime is reduced either because of node moving out of the radio range or drained of its energy leading to link breaks and results in network partitioning. Since the detection of a link break takes place after a certain number of retry attempts have timed out which leads to significant energy consumption and compromise the network lifetime. In this thesis a link stability measurement (LSM) prediction algorithm is developed and implemented in *DSR*. The *LSM* measured the stability of the path and considered both the factors i.e. the node stability and the link duration and is used to preempt the transmission before the node goes out of the range or die. The link duration is calculated by measuring the signal power strength along each hop of the path. The links stability reduces with the time and reaches to the threshold value where preemption takes place. When the link is likely to break, the node sends a route error message to the source node of the packets. The upstream nodes of the route remove this link from their routes. After receiving route error message the source node finds an alternative route to the destination from the routes found during the route discovery (multiple routes), if it can not find an alternative route then the source node start a new route discovery by broadcasting route request packets.

Thus cost of handling the link break is saved with the presented mechanism. Although the technique may introduce some delay (due to wait period) but it is compensated by sending the broadcast *RREQ* packets over stable paths only. The neighbors were selected for broadcasting based on the stability and the bandwidth criterion, resulted in reduced routing overhead. Further, the technique may be used as multipath variant by distributing the traffics over multiple paths simultaneously. The route found satisfies the energy aware stability and traffic load constraint. The simulation results presented have shown that the EAEDSR protocol performed well and overall reduced the overhead and link breaks and improved the network lifetime. The technique resulted in the transmission of more data packets.

We propose that the following investigations can be taken as future works from the present work perspective. The performance can be improved further by including an adaptive link expiration time approach i.e. which works in indoor as well as in outdoor environments. The presented technique can be analyzed by varying the other parameters such as the terrain size and packets sending rate etc. Also, the presented technique performance can be investigated in the environment where nodes are with the variable transmission power.

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APPENDIX A

The following configuration was used for performing all the simulations described in this thesis:

Configuration: i3, Dell, 2 GB RAM

Operating System: Linux Fedora 14

NS2 version: ns-allinone-2.34

URL: http://www.isi.edu/nsnam/ns/index.html

1. Creating traffic generation files

The traffic generation scrip is available at

ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen

The command is used as follows:

ns cbrgent.tcl [-type cbr| tcp] [-nn nodes] [-seed seed] [-mc connections] [-rate rate]

2. The scenario files are generated using the following command

./setdest -v <1> -n <nodes> -p <pause time> -M <max speed> -t <simulation time> -x <max X> -y <max Y>

The script is available in the folder

ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/setdest

APPENDIX B

Typical TCL Scripts used for simulation

(A) DSR and EAEDSR Script

```
set opt(chan)           Channel/WirelessChannel
set opt(prop)           Propagation/TwoRayGround
set opt(netif)          Phy/WirelessPhy
set opt(mac)            Mac/802_11   ;# MAC type
set opt(ifq)            CMUPriQueue
set opt(ll)             LL
set opt(ant)            Antenna/OmniAntenna

set opt(x)              500   ;# X dimension of the topography
set opt(y)              500   ;# Y dimension of the topography
set opt(cp)             "cbr-25-LF"
set opt(sc)             "scen-n25-M5-LF"
set opt(ifqlen)         50          ;# max packet in ifq
set opt(nn)             25          ;# number of nodes
set opt(seed)           1.0
set opt(stop)           500         ;# simulation time
set opt(tr)             Test.tr     ;# trace file
set opt(nam)            Test.nam    ;# animation file
set opt(rp)              DSR         ;# routing protocol script
set opt(lm)              "off"       ;# log movement
set opt(energymodel)     EnergyModel ;
set opt(initialenergy)  1000        ;# Initial energy in Joules
set ns_          [new Simulator]
set topo         [new Topography]
set tracefd      [open $opt(tr) w]
set namtrace     [open $opt(nam) w]
set prop         [new $opt(prop)]


$topo load_flatgrid $opt(x) $opt(y)
ns-random 1.0
$ns_ trace-all $tracefd
$ns_ namtrace-all-wireless $namtrace $opt(x) $opt(y)

#
# Create god
#
create-god $opt(nn)


#global node setting

        $ns_ node-config -adhocRouting $opt(rp) \
                   -llType $opt(ll) \
                   -macType $opt(mac) \
                   -ifqType $opt(ifq) \
                   -ifqLen $opt(ifqlen) \
                   -antType $opt(ant) \
                   -propType $opt(prop) \
```

```
                   -phyType $opt(netif) \
                   -channelType $opt(chan) \
                   -topoInstance $topo \
                   -agentTrace ON \
                   -routerTrace ON \
                   -macTrace ON \
                   -energyModel $opt(energymodel) \
                   -idlePower 1.0 \
                   -rxPower 1.1 \
                   -txPower 1.65 \
                   -sleepPower 0.001 \
                   -transitionPower 0.6 \
                   -transitionTime 0.005 \
                   -initialEnergy $opt(initialenergy)

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

if { $opt(cp) == "" } {
      puts "*** NOTE: no connection pattern specified."
        set opt(cp) "none"
} else {
      puts "Loading connection pattern..."
      source $opt(cp)
}

if { $opt(sc) == "" } {
      puts "*** NOTE: no scenario file specified."
        set opt(sc) "none"
} else {
      puts "Loading scenario file..."
      source $opt(sc)
      puts "Load complete..."
}
proc finish {} {
        global ns_ namtrace
        $ns_ flush-trace
        #Close the NAM trace file
        close $namtrace
        #Execute NAM on the trace file
        exec nam Test.nam &
        exit 0
}
$ns_ at 500 "finish"
#
# Tell all the nodes when the simulation ends
#
for {set i 0} {$i < $opt(nn) } {incr i} {
    $ns_ at $opt(stop) "$node_($i) reset";
}
$ns_ at $opt(stop) "puts \"NS EXITING...\" ; $ns_ halt"

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

(B) AODV and DSDV Scripts

```
# Replace AODV by DSDV for DSDV script
set opt(chan)           Channel/WirelessChannel
set opt(prop)           Propagation/TwoRayGround
set opt(netif)          Phy/WirelessPhy
set opt(mac)            Mac/802_11                  ;# MAC type
set opt(ifq)            Queue/DropTail/PriQueue
set opt(ll)             LL
set opt(ant)            Antenna/OmniAntenna

set opt(x)              500   ;# X dimension of the topography
set opt(y)              500   ;# Y dimension of the topography
set opt(cp)             "cbr-25-LF"
set opt(sc)             "scen-n25-M15-LF"
set opt(ifqlen)         50         ;# max packet in ifq
set opt(nn)             25         ;# number of nodes
set opt(seed)           1.0
set opt(stop)           500        ;# simulation time
set opt(tr)             Test.tr    ;# trace file
set opt(nam)            Test.nam   ;# animation file
set opt(rp)              AODV       ;# routing protocol script
set opt(lm)              "off"      ;# log movement
set opt(energymodel)     EnergyModel     ;
set opt(initialenergy)  1000       ;# Initial energy in Joules

set ns_           [new Simulator]
set topo          [new Topography]
set tracefd       [open $opt(tr) w]
set namtrace      [open $opt(nam) w]
set prop          [new $opt(prop)]

$topo load_flatgrid $opt(x) $opt(y)
ns-random 1.0
$ns_ trace-all $tracefd
$ns_ namtrace-all-wireless $namtrace $opt(x) $opt(y)

#
# Create god
#
create-god $opt(nn)


#global node setting

        $ns_ node-config -adhocRouting $opt(rp) \
                   -llType $opt(ll) \
                   -macType $opt(mac) \
                   -ifqType $opt(ifq) \
                   -ifqLen $opt(ifqlen) \
                   -antType $opt(ant) \
                   -propType $opt(prop) \
                   -phyType $opt(netif) \
                   -channelType $opt(chan) \
                   -topoInstance $topo \
                   -agentTrace ON \
                   -routerTrace ON \
                   -macTrace ON \
                   -energyModel $opt(energymodel) \
```

```
                    -idlePower 1.0 \
                    -rxPower 1.1 \
                    -txPower 1.65 \
                    -sleepPower 0.001 \
                    -transitionPower 0.6 \
                    -transitionTime 0.005 \
                    -initialEnergy $opt(initialenergy)

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

if { $opt(cp) == "" } {
      puts "*** NOTE: no connection pattern specified."
      set opt(cp) "none"
} else {
      puts "Loading connection pattern..."
      source $opt(cp)
}

if { $opt(sc) == "" } {
      puts "*** NOTE: no scenario file specified."
      set opt(sc) "none"
} else {
      puts "Loading scenario file..."
      source $opt(sc)
      puts "Load complete..."
}
proc finish {} {
        global ns_ namtrace
        $ns_ flush-trace
        #Close the NAM trace file
        close $namtrace
        #Execute NAM on the trace file
        exec nam Test.nam &
        exit 0
}
$ns_ at 500 "finish"
#
# Tell all the nodes when the simulation ends
#
for {set i 0} {$i < $opt(nn) } {incr i} {
    $ns_ at $opt(stop) "$node_($i) reset";
}
$ns_ at $opt(stop) "puts \"NS EXITING...\" ; $ns_ halt"


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