EFFICIENT ENERGY AWARE ROUTING PROTOCOL FOR MOBILE AD HOC NETWORK

Ph.D. Thesis

by

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DISCIPLINE OF COMPUTER SCIENCE AND ENGINEERING

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"EFFICIENT ENERGY AWARE ROUTING PROTOCOL FOR MOBILE AD HOC NETWORK"** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DISCIPLINE OF COMPUTER SCIENCE AND ENGINEERING, Indian Institute of Technology Indore,** is an authentic record of my own work carried out during the time period from January 2012 to September 2018 under the supervision of Dr. NARENDRA S. CHAUDHARI, Professor, Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Signature of the student with date
(RAKESH KUMAR SAHU)

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Signature of Thesis Supervisor with date
(Dr. NARENDRA S. CHAUDHARI)

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RAKESH KUMAR SAHU has successfully given his Ph.D. Oral Examination held on

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(A) Publications from PhD thesis work:

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5. Rekha Saha, Rakesh Kr. Sahu and Narendra S. Chaudhari, *Analysis and security measures of malware in Mobile device*, International Journal of Electronics and Computer Science Engineering, Foundation of Electronics and Computer science, available at www.ijecse.org, Vol. 1(1), pp. 2424-2431, 2012.

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2. Rakesh Kr. Sahu and Narendra S. Chaudhari, *A Performance Evaluation of Ad hoc Network Under Black hole Attack*, IEEE International Conference, Second World Congress on Information and Communication Technologies (WICT 2012), 30^{th} - 02^{nd} of Nov, 2012, TRIVANDRUM, INDIA, pp 780-784.

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LIST OF ABBREVIATIONS

ACC	AODV based Congestion Control
AMODV	Adhoc On-demand Multipath distance Vector Routing
AMODV-ER	Energy Reduction Adhoc On-demand Multipath distance Vector Routing
AODV	Adhoc On-demand Distance Vector Routing
AOMR-LM	Adhoc On-demand Multipath Routing Life Maximization
CBR	Constant Bit Rate
DSDV	Destination Sequenced Distance Vector Routing
DSR	Dynamic Source Routing
E2E	End to End
FF-AOMDV	Fitness Function Adhoc On-demand Multipath distance Vector Routing
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
MAC	Medium Access Control
MANET	Mobile Adhoc Network
OEFS	On Demand Energy based Forwarding Strategy
PDR	Packet Delivery Ratio
QoS	Route Quality of Service
RD	Route Discovery
RERR	Route Error
RM	Route Maintenance
RREP	Route Reply
RREQ	Route Request
RSS	Received Signal Strength
RWP	Random Way Point
SRMP	Source Routing based Multipath Protocol
SD	Source To Destination
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
ZRP	Zone Routing Protocol

NOTATION

Symbols

W	Width of leaf structure
t_{lb}	Lower bound recoiled off time
t_{off}	Recoiled off time
t_{ub}	Upper bound recoiled off time
δ_d	Perpendicular distance
SD	Line joining source and destination node
(x_p, y_p)	Location of arbitrary node P
pkt	Packet to be served
Pid	Packet Id
$\Omega\,(t)$	Total consumption of battery charge
$a\,(t)$	Available charge
$u\,(t)$	unavailable charge

ABSTRACT

Wireless multi-hop ad hoc networks are self-organizing networks that can be spontaneously deployed without any need of fixed infrastructure. In order to enable communication, network nodes share their resources to store and forward other nodes data packets. However, the current hardware technology significantly limits the battery power network nodes run on. As a result, designing energy-efficient networking algorithms is of paramount importance for the viability of this type of networks. In previous work, we have studied networking algorithms that rely on packet redundancy to provide fair communication. This approach can significantly increase the number of transmissions and have a severe impact on the energy efficiency. Our main goal is to devise novel algorithms that efficiently handle packet redundancy in order to reduce the related energy costs without compromising the overall performance. We focus on to reduce the number of transmissions in order to save energy. To achieve this goal, three approaches have formulated. On of them is sense the network more than transmit, as transmission is costlier affair than sensing the network. Hence, algorithm limits the transmission of packets and reduce the replication of them. Packet redundancy not only spend more energy but also increase congestion in network, which result in adding average packet end to end delay and cutback network lifetime. Second algorithm reduces the congestion in network whereas third algorithm helps in optimizing the packet flow from one node to another.

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CHAPTER 1

INTRODUCTION

1.1. Background And Motivation

Wireless networks have been thoroughly studied over the past four decades. Today more than ever before, we witness the results of the research in this field, since users are connected wirelessly around the clock using a diverse range of devices, e.g., laptops, tablets and smartphones. However, in conventional wireless networks, network connectivity is still limited in the sense that it depends on the existence of a fixed infrastructure, such as an access point or a base station. To provide wireless communication when fixed infrastructure is absent, the research community introduced the concept of wireless ad hoc networks. In this class of networks, user devices form a self-organizing network that requires minimum user intervention and it is deployed easily with minimal cost and planning. Communication is direct when nodes are within each others range, otherwise nodes rely on other nodes to forward their packets. In the latter case, network nodes act as packet relays enabling multi-hop communication.

Despite their unique features, wireless ad hoc networks have yet to make the transition to the commercial world. Most real-world deployments are ephemeral and are built to provide short-term communication. Some of the application areas include battlefield communications in military operations, search and rescue operations during a disaster, data gathering of environmental conditions in hostile environments and communication for educational reasons in classrooms, campuses and conferences. Recently, the growing popularity of the concept of Internet of Things (IoT) is paving the way for commercially viable wireless ad hoc networks. The main idea is to extend Internet connectivity beyond traditional devices like personal computers, smart phones and tablets to a diverse range of devices and everyday things that will communicate and interact with the external environment. Towards this direction, wireless ad hoc networks can play an important role in enabling the communication between things/devices and relaying data traffic to the Internet infrastructure. Another area of deploying wireless ad hoc networks is when censorship disrupts or filters conventional communication networks. In these cases, the distributed nature and adaptability of ad hoc networks render them perfect to promote free speech and allow public communication. Furthermore, wireless ad hoc networks can be combined with the existing infrastructure in order to extend the network coverage, capacity and scalability. Especially, there is an increasing research interest in extending the capacity of cellular infrastructure through wireless ad hoc networks. Such approaches will have a great impact on the current carrier networks which are overloaded by high traffic demands.

Over the past years the research community introduced a diverse range of protocols that enable communication in wireless ad hoc networks. Multiple networking protocols were proposed able to adapt to the network conditions in a distributed fashion without using any kind of central synchronization. However, there still exist open issues that need to be solved. One main challenge is related to the energy costs of the networking protocols. Network nodes run on battery power which, despite the major advances in battery technology, is currently limited for mobile devices. Failing to provide energy-efficient networking could lead to situations where devices disjoin the network because either their battery was fully drained or the users were disappointed from the over-utilization of their devices. In these situations, the number of nodes can be reduced to critical levels, severely affecting the network stability.

1.2. Major Challenges

Restricted Wireless Transmission Range: The radio group will be restricted in the wireless networks and result, the data amount which it can provide is much slighter than what a bound network can provide. This involves routing procedures of wireless networks to use bandwidth in an ideal way. This can be achieved through protecting the overhead as minimum as conceivable. The restricted transmission range also enforces restraint on routing procedures for sustaining the topographical information. Particularly in Mobile Adhoc Networks (MANET) because of regular variations in topology, preserving the topological data for every node includes more controller overhead which results in additional bandwidth depletion.

Time-varying Wireless Link Characteristics: Wireless channel is liable to a range of broadcast disorders such as path harm, declining, intervention and obstruction. These features resist the series, data rate, and consistency of these cordless transmissions. The range of which these features disturb the transmission that rest on atmospheric situations and flexibility of receiver and transmitter. Even two dissimilar key restraints, Nyquists and Shannons theorems that rule over capability to communicate the information at diverse data degrees can be measured.

Broadcast Nature of the Wireless Medium: The broadcast nature of the radio channel, such as transmissions prepared by a device is established by all devices that are in its straight transmission covering area. When a device receives data, no other device in its neighborhood, apart from the sender, must transfer. A device can acquire access to the mutual medium when its communications cannot disturb any constant session. Meanwhile several devices may resist for medium con-temporarily, chance of data-packet crashes is very tall in wireless networks. Even the network is liable to concealed terminal issue and transmits storms. Concealed terminal issue mentions to the smash of data-packets at a receipt device because of immediate transmission of the nodes which are outside the straight communication series of the transmitter, but are inside the communication series of the receiver.

Packet losses due to Transmission Errors: Ad hoc wireless networks practices very advanced packet damage due to reasons such as extraordinary bit error rate (BER) in the wireless channel, enlarged crashes because of the existence of unseen terminals, occurrence of interventions, position reliant controversy, single directional associations, regular pathway breakages due to device movements, and the integral declining characteristics of wireless passage.

Mobility Induced Route changes: The network topology in adhoc is extremely dynamic in nature as any node can leave anytime and also new addition of node may take place without prior intimation or prediction in network, as a result numerous pathway breakages, suffer from transmission failure, packet retransmission, route rebuilt initiation etc.

Power constraints: It is due to restricted resources that arrange main limitation on the mobile devices in an ad hoc network. Nodes which are contained in such network have restrictions on the supremacy foundation in order to preserve mobility, dimension and capacity of the node. Due to accumulation of power and the processing capacity make the nodes heavyweight and less portable.Consequently only MANET devices have to use this resource.

Potentially frequent network partitions: Casually stirring nodes in an ad-hoc network may result in network panels. Certain cases involve middle nodes to be extremely effected by such separation.

Ease of snooping on wireless transmissions (security issues): Wireless passage being employed for ad hoc networks transmitted in natural surroundings. It is also shared by all devices in the network. Transmission of data through a device is acknowledged by all devices inside straight communication series. So invader is certain to sneak data/information which is communicated within network. The conditions of secrecy could be disrupted if enemy is capable in inferring data assembled by snooping. Routing: In MANETs routing is an important challenge for the performance degradation due to unicasting, multicasting and geo-casting demands by the network nodes in contrast to single hop wireless networks. Its because of rapid change in network topology and with different mobility speeds.

Quality of Service: In MANETs quality of service is an important challenge for the differed kind of quality level demands by the network nodes. It becomes very difficult to fulfill the different levels or priority demands related to quality of service. Hence, these networks required best control of QoS specially in case of multimedia.

Security: This network is on the fly network, which leaves behind many issues related to security of packet communication from one to another, challenge pertaining to network weaknesses. Hence, for secure communication network should comply with all critical security parameters.

1.3. Problem Statement

It is the stepping stone to our research, which figure out after study and investigation, the number of transmissions in existing algorithms are much higher in terms of redundancy of packets, which consume substantial portion of total battery and have a severe impact on the energy efficiency. Hence, significantly reduction in number transmissions is needed. Our main goal is to devise novel algorithms that efficiently handle packet redundancy (by limiting the transmission) and optimize the energy consumption of network at the large without compromising the overall performance.

1.4. Scope of Thesis

The main goal of this thesis is to improve the energy efficiency of networking algorithms in mobile ad hoc networks. We focus on techniques to limit the number of transmissions, improved route maintenance scheme and prediction based link lifetime. We study the implication of cost for packet transmission vis a vis cost for sensing of network and concluded that transmission of packet is far costlier than sensing a network. Hence, a failure of transmission tends to huge power loss of any node. The proposed recoiled off algorithm is capable enough to reduce the number of transmissions in network. We investigated the proposed novel scheme that are energy-efficient in the sense that they significantly reduce the number of transmissions (replications) without compromising the delivery and delay performance. Minimizing transmissions is crucial for the energy consumption at intermediate nodes since data transmission/reception is known to be the most energy-consuming operation in wireless devices.
Moving a step further, we enhance the routing process by utilizing battery characteristic (synchronization of battery relaxation time with node's recoiled off time).
Furthermore, work is carried out to enhance the result, we reduce the congestion in network by partitioning the entire network into sub-flows and each sub-flow is mathematically evaluated.
We have taken inconsideration all possible constraints under practical scenario and estimated the energy requirement for successful transmission of packet to intended destination.

1.5. Contribution and Outline of Thesis

We initially examine the problem of energy-efficient broadcasting in MANETs. Broadcasting is an essential networking component that allows nodes to send a packet to all other nodes in the network. It is extensively used when nodes engage in discovery phases including on-demand routing protocols for constructing a path, service discovery applications for finding a resource and peer databases for retrieving volatile data. Since broadcasting significantly affects the performance of other networking mechanisms, using energy-efficient approaches is of paramount importance.

The chapter two, a novel protocol namely Energy Reduction Multipath Routing Protocol for MANET using Recoil Technique (AOMDV-ER) is proposed which conserve the energy along with optimal network lifetime, routing overhead, packet delivery ratio and throughput. Algorithm performs transmission of packets to its destination smartly by using varying recoil off time technique based on their geographical location. This concept saves the number of transmission which results in the improvement of network lifetime. In addition, the local level route maintenance reduces the additional routing overhead. Lastly, the prediction based link lifetime of each node is estimated which helps in reducing the packet loss in the network. This protocol has three subparts. First optimal route discovery algorithm amalgamation with the residual energy and distance mechanism, second coordinated recoiled nodes algorithm which eliminates the number of transmissions in order to reduces the data redundancy, traffic redundant, routing overhead, end to end delay and enhance the network lifetime, last link reckoning and route maintenance algorithm to improve the packet delivery ratio and link stability in the network.

The chapter three focuses on an algorithm for better utilization of battery power by exploiting battery characteristic that is by synchronization of node's recoiled off time with the battery relaxation time in order to convert the unavailable charge into available charge.

The chapter four discusses on a scheme which forms congestion free route to enhanced throughput along with timely packet delivery. The proposed AODV based Congestion Control (ACC) algorithm overwhelm the problem up to some extent while considering the bandwidth matrix, link capacity, optimal distance and energy of node before forming the potential route. Mechanism used in this scheme partitioned the entire network into subflows and each sub-flow is mathematically assessed and experimentally observed to get the improved result. Apart from congestion control, this scheme utilizes a new statistical approach to check the reliability network based on its previous number of link failure during each transmission.

The chapter five of thesis had main objective to consider and assess all possible constraints to reduce the energy consumption in transmission. The objective function is formulated mathematically to find out the optimal path which required the minimum energy subjected to constraints on link broken and node failure in network. To formulate problem, three decision variables (total number of links, links in potential route and faulty links) have been taken into consideration subjected four possible constraints.

The chapter six talk about the conclusion and scope for future work. It also includes appendix, which categories the various protocols into three heads namely proactive routing, reactive routing and hybrid routing protocols with brief description.

CHAPTER 2

ENERGY REDUCTION USING LOCATION AWARE RECOILED TECHNIQUE

In Mobile Ad-hoc networks (MANET), power conservation and utilization is an acute problem and has received significant attention from academics and industry in last few years. Nodes in MANET functions on battery power which is rare and limited energy resource. Hence, its conservation and utilization should be done judiciously for the effective functioning of the network. In this work, a novel protocol namely Energy Reduction Multipath Routing Protocol for MANET using Recoil Technique (AOMDV-ER) is proposed which conserve energy along with optimal network lifetime, routing overhead, packet delivery ratio and throughput. It performs better than any other AODV based algorithms, as in AOMDV-ER, the nodes perform transmission of packets to its destination smartly by using varying recoil off time technique based on their geographical location. This concept saves the number of transmission which results in the improvement of network lifetime. In addition, the local level route maintenance reduces the additional routing overhead. Lastly, the prediction based link lifetime of each node is estimated which helps in reducing the packet loss in the network. This protocol has three subparts. First optimal route discovery algorithm amalgamation with the residual energy and distance mechanism, second coordinated recoiled nodes algorithm which eliminates the number of transmissions in order to reduces the data redundancy, traffic redundant, routing overhead, end to end delay and enhance the network lifetime, last link reckoning and route maintenance algorithm to improve the packet delivery ratio and link stability in the network. The experimental result shows that AOMDV-ER protocol save at least 16% energy consumption, 12% reduction in routing overhead, significant achievement in network lifetime and packet delivery ratio than Ad hoc on demand multipath distance vector routing protocol (AOMDV), Ad hoc on demand multipath distance vector routing protocol life maximization (AOMR-LM) and Source routing-based multicast protocol (SRMP) algorithms. Hence, AOMDV-ER algorithm performs better than these recently developed algorithms.

2.1. Introduction

MANET is infrastructureless wireless type network in which the packet transmission from one node to another takes place without any access point. Hence, MANET can be deployed in hostile and difficult situations where a wired network is not advisable or possible. Furthermore, it is deployed in adverse situations, where battery replacement in any node is not feasible. Thus, routing protocol plays a pivotal role while forwarding the packet in the network. Moreover, it is necessary to reduce the number of failed transmissions, data redundancies and traffic overhead of mobile nodes, which results in reduction of energy consumption substantially. The ad hoc network has many features such as easy deployment, when and where need arises, and hence it is gaining popularity in widespread applications such as in military battlefields to establish information networks amongst the soldiers, weapon systems, command control center and vehicles. The ad hoc network architecture is being used in many real time business applications in order to increase the efficiency and effectiveness along with a level of profit optimization at large in the corporate companies. The applications are spread in all dimensions of life and covers many scenarios and services via tactical networks, emergency services, civil/commercial arena, home and enterprise environment, education system, entertainment, sensor network and context aware services (call forwarding, location specific information, time dependent services, etc.). However, there are many challenges which require the attention of research to plug them in efficient manner, such as frequent link failure among the nodes (due to random and dynamic behavior), no central administration without infrastructure, being susceptible to attack, inordinate consumption of power (energy constraint operation), limited bandwidth, network scalability, device heterogeneity, muti-hop routing, self-creation, self-organization and self-administration. The acute problem related to energy consumption and link failure in networks has drawn the attention of many researchers and scientists which led to the development of various tools and techniques based on transmission energy consumption, residual energy consumption or both. One recent advancement in the area of routing protocol is multipath routing protocol. Still, there are certain issues in multipath routing protocols, one of them is energy consumption in the discovery of an optimal path, rediscovery of path when link failure encounters and retransmission of packets if required. Route discovery involves a reasonable amount of energy when network is small.

Subsequently, when the size of the network grows, then route discovery demands huge energy and becomes a problem of sustaining the network for long time, as the gigantic portion of energy is consumed in route discovery itself. There are many [1], many energy-aware packet forwarding routing protocols have been developed based on the criteria of link cost, link error, residual energy. The On-demand Energy-based Forwarding Strategy (OEFS) enables the node to consume less energy but the route selection criterion is not based on link stability and leads to frequent link error [2]. Further work was extended in FF-AOMDV [3], which was based on calculation of fitness function, while energy level and number of hop count are taken into consideration from source to destination before sending the packets. In our proposed AOMDV-ER protocol the foremost objectives are reduce to power consumption of route discovery, retransmission overhead and transmission failure (due to link failure). All these three issues conserve the battery power for subsequent fruitful transmission of packets, which leads to a better network lifetime.

The rest of this chapter is organized as follows. Section 2.2, focuses on previous work that has been done in this area; section 2.3, the proposed work, broadly consists of three subparts. Section 2.4, expresses the mathematical support for the result demonstration and section 2.5, demonstrates the experimental results of proposed protocol. Finally section 2.6, conveys the conclusion of proposed work.

2.2. Review of State of the Art and Main Contributions of the Work

The work in FF-AOMDV [3] is based on the calculation of the fitness function, where energy level and hop count are taken into consideration, between source and destination, before sending the packets. However, each of AOMDV, AOMR-LM and FF-AOMDV has a few shortcomings. For example, AOMDV requires the least energy of the three but throughput and end to end delay was degraded. AOMR-LM has the least end to end delay and a consumption of energy was achieved but also demonstrated the worst performance in packet delay ratio. Protocol FF-AOMDV addressed the problem encountered in discussed protocols, but could not resolve the problem of network lifetime [3]. In Ad-hoc network, packet transmission is a critical issue which was developed with geographic positioning protocols [4]. Buffer management is taken into consideration [5, 6] as well as the multipath delivery scheme. The work [7] proposed by author is based on an effective position based opportunistic protocol founded on the geographic routing based stateless and the nature of the transmission. The protocol focuses on virtual destination to avoid the communication holes. A multicast data transmission scheme [8] was used in multi-hop wireless networking that avoids support routing cycles or packet duplication. The author presented a table to avoid packet duplication in routing protocol. It has reached a high speed packet delivery as compared to mesh-based routing. The robust and secure routing scheme is proposed in [9] for highly dynamic ad hoc networks for calculating disjoined path nodes. The author has observed the reliability and security of the path to obtain a highly secure network routing. Based on the information of node location, the transmission overhead had been decreased during path discovery and maintenance. The path network progression is not taken into consideration. Based on security improvement mechanism, a secure end-to-end packet delivery was achieved [6]. A stable multicast routing path was established from source to destination expressed in mesh-based multicast routing mechanism [10]. The nodes which have high stable links, joined together to construct the stable path.The author has proposed citeR11, two schemes via a cluster based approach and location based approach, to avoid traffic and define each area of cluster. The relationship between mobile nodes and the appropriate size of the clustering area was determined. The opportunistic routing and encoding based on MAC-independent [12], was introduced to improve reliable communication. Both location information and transmission probability were used for efficient packet distribution. In this scheme, when information updating occurs, each node in the network can have the latest information up to two hop neighbors, when they are updated periodically. A new improved distribution channel access (IDCA) scheme based on contention algorithm and hub control [13] provides probabilistic and combined QoS support to regulate the controversial window and the scheme offers a traffic differentiation. In [14], a routing scheme based on the stability of the route measurements and residual energy during detection is presented. The estimation of link-connection stability was made based on the received signal strength. A Location based new routing scheme is proposed [15] to reduce the consumption energy. The hybrid delivery network content system has been proposed to combine routers with the new content overlay server [16]. The on demand multicast routing protocol has been developed [17], to build routes and keeps membership of multicast groups. However, the stability of the routes is being overlooked. In the intended approach, the protocol can endure all attacks and environmental defects. In [18], an improved version of topological multicast routing protocols performance analysis has been proposed. The author formulated a function based on route length and route energy to optimize the values of consumed energy using the binary particle swarm optimization (SWO) algorithm. The on-demand energy-based forwarding strategy (OEFS) enables the nodes to consume less energy but the route selection criterion is not based on reliability [2]. A protocol based on energy efficient routing was proposed, named AOMR-LM [19], which is an improvement on AOMDV [20]. Under work, [49] authors design a scheme based on position and energy consumption by each node which made balance between these two parameters using two metrics. The scheme [50] utilizes energy efficiently in routing protocol based on tracking system, with precise tracking of real target based problem has taken into consideration by author and demonstrated improved result. In work [51] proposed an algorithm to trimming down the energy utilization while reducing packet loss of wireless sensor networks. In work [53] studied in MAC sublayer and proposed a new MAC protocol to reduce the consumption of energy. Authors estimated performance of multipath routing in mobile scenario of vehicular network [42], using node-disjoint and also observe the the effect of mutual interference on the behavior of node-disjoint paths. The proposed method [45] opted a passage which has less packet loss and hight throughput of network, the path that has a high transmission bandwidth has been considered and further leads to less power consumption. The author proposed a decentralized self-organized relay selection algorithm based on a stochastic learning approach [57], where each player evolves toward a strategic equilibrium state in the sense of Nash. The work in [58], author devised a mechanism which was based on number of hop count and quality of services in network for large scale infrastructure in Mobile Ad hoc Networks. A method is proposed which is based on delay conscious and low overhead of network that combines mobile automata with the genetic algorithm used to select a group of routes that complied with constraints for delay and then select a reasonably best one using genetic algorithm.The author has considered distributed opportunistic routing policy with congestion diversity [79]. It measured draining time to opportunistically identify and route the packet along the path with an expected low overall congestion. The article [80] proposed scheme which is not only considered shortest path but also gives some weighted to longest path also in order to make balance the congestion in network. The congestion of network drop the performance of network while having packet drop and and transmission failure problem. Another back pressure algorithm [81], was proposed which uses LIFO queuing discipline (called LIFO-Back pressure) and acquire the utility under O(1/V) of the optimal value for any scalar $V > 1$, while upholding an average end to end delay of O([log(V)]2) for all cases of traffic in the network. The article [82] provided a solution for throughput optimal routing/scheduling in a multi-hop constrained queuing network using the random connectivity scenario, which has special case of input queue fabric and opportunistic multi-hop. It faces the challenge to make out adequate and general function with negative expected drift. It has described the big class of throughput optimal routing policies to control the traffic along with small path for a large class of state space. The author described an algorithm [83] based on CSMA using adaptive feature to achieve the optimal throughput in ad hoc network while undertaking few assumptions in order to combine end to end traffic control and get congestion free transmission. In article [84] the back pressure mechanism has been implemented in Internet of Things (IoT) in order to control the traffic, reduce the congestion and improves the throughput of the network. The emergency packets are left in case of emergency IoT.

Our approach discovers the route in such a way that it can reduce data redundancy and minimize the traffic overhead, which aids in the power conservation and leads to the enhancement of network life time. The concept of recoiled nodes further reduces the routing overhead whereas the last part of algorithm, namely the link reckoning algorithm, ensures break free packet transmission, lowers the packet loss and protects from inordinate delay in the network. Details of protocol are given in subsequent sections of this chapter.

2.3. Proposed Protocol (AOMDV-ER)

Some recently proposed algorithms, namely AOMR-LM, FF-AOMDV [3] and AOMDV, have some shortcomings. TheAOMDVand AOMR-LM have the least end to end delay and consumption of energy but demonstrated the worst performance in packet delay ratio. Whereas the other protocol FF-AOMDV addressed the problem encountered in the AOMR-LM protocols, but could not resolve the problem of network lifetime [3]. These algorithms did not consider the node battery level evaluation and link strength estimation

before making them (nodes) as the part of the route. However, the proposed algorithm AOMDV-ER has given due weight to this parameter.
The Energy Reduction Multipath Routing Protocol for MANET using Recoil Technique (AOMDV-ER), is the improvement over the well-known ad hoc on demand distance vector routing (AODV), and ad hoc on demand multipath distance vector routing AOMDV, AOMR-LM and FF-AOMDV.

The proposed routing consists of three optimized algorithms via optimal route discovery; coordinated recoiled node algorithm, to reduce the further reduction in battery power; and the last algorithm takes care of the route maintenance efficiently, to reduce the chances of retransmission, which is an important provision for saving the energy. First algorithm is discovers the path using optimal distance, recoiled off time and residual energy whereas its maintenance work is being carried out by third algorithm based on estimation of link strength prior to its occurrence. It also took probability distribution with random variables took into account for all possible nodes.

2.3.1. Optimal Route Discovery Algorithm

The algorithm is based on residual energy and geographical location which uses the recoil technique. The link cost of each route is evaluated on the basis of node distance from SD line. The least value is assigned to the node nearer to the SD line. This optimal route discovery algorithm is depicted in Algorithm (1).
The working of algorithm (1) and algorithm (2) can be better understood with the help of an example (refer to figure 2.1). Figure (refer to figure 2.1a) traces minimum energy required between two nodes whereas, figure (refer to figure 2.1a) maintains balance with residual energy in each node in the path (algorithm (1)). The recoiled off time assignment to eligible node is managed by algorithm (2). To reduce the wastage of energy in transmission of packet due to frequent link failure, route maintenance scheme along with node mobility approach continuously works in place.This approach also maintains threshold energy level of each node in the network for the sake of high probability of success in transmission. Furthermore, the mathematical formulation in form of lemmas have been provided for the verification of result for the various parameters namely routing overhead, packet loss percentage,energy consumption with mobility.

Algorithm 1: Optimal Route Discovery

1 k

1: **begin**

R $\leftarrow$ Set of routes ;

N $\leftarrow$ Set of nodes;

RE $\leftarrow$ Residual energy (set of routes) greater than threshold value;

MD $\leftarrow$ single optimal route (from the set of RE) having minimum distance from SD-line;

R $\leftarrow \{r_1, r_2, r_3, ...r_n\}$;

RE$\leftarrow$ threshold_Energy_Path (R);

MD $\leftarrow$ argmin ($f(RE)$);

N $\leftarrow$ transmit(MD, pkt);

2: **if** (flag==0) **then**

3: coordinated_recoiled_node( );

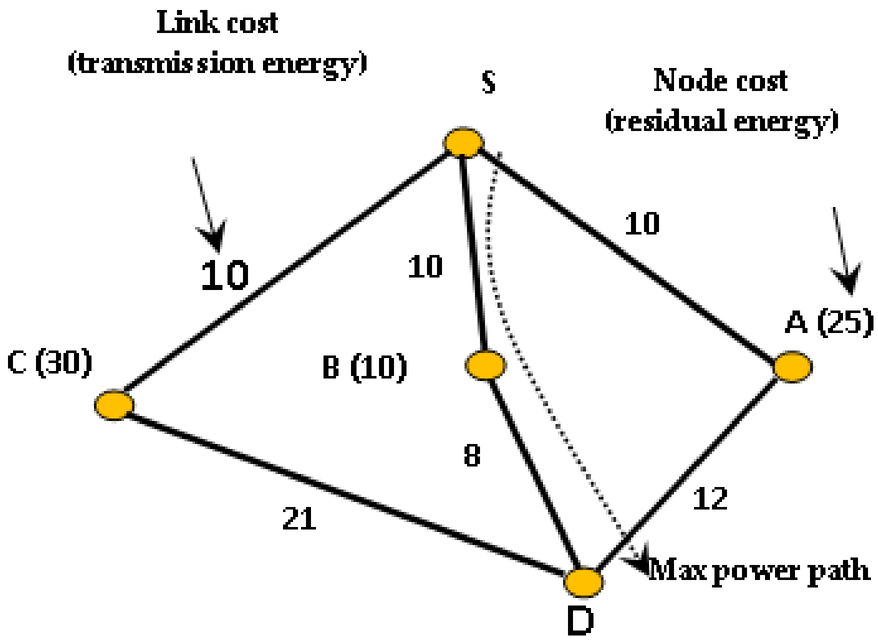
4: **else**

5: search_other( );

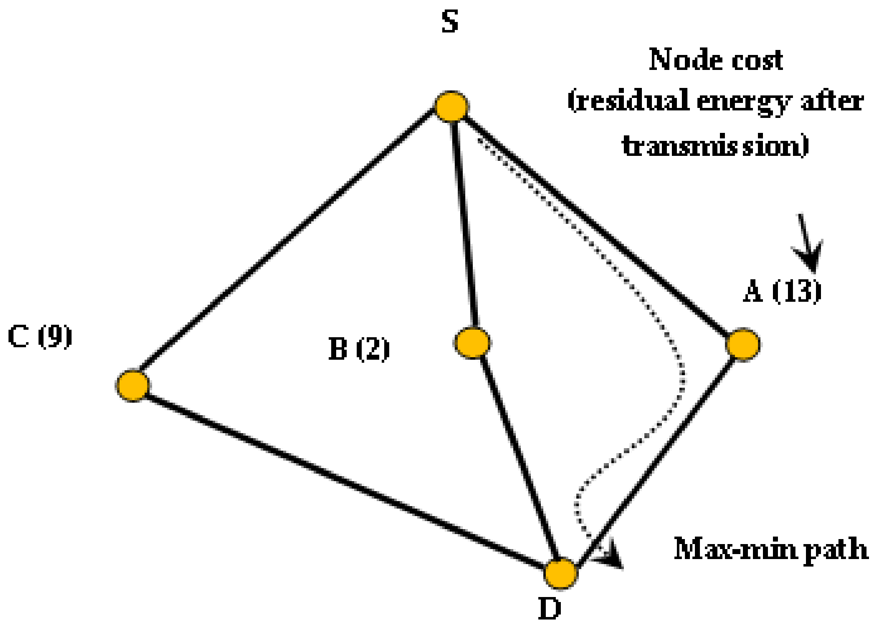
6: **end if**

7: **end**

Given S: source and D: destination. As shown in figure 2.1a and 2.1b, $(S \rightarrow B \rightarrow D)$ $(S \rightarrow C \rightarrow D)$ and $(S \rightarrow A \rightarrow D)$ are three probable routes from source to destination. Now there are many ways to select the path between S and D, one traditional way is to obtained path with minimum energy consumption path concept (route with minimum cost). Which is shown in figure $(S \rightarrow B \rightarrow D)$. But if an algorithm chooses this path then it would be difficult in future as the residual energy at the intermediate route become too less to transmit the same (refer figure 2.1b). Hence, the other way is take care of upcoming transmission between same pair of source and destination (optimized path based on residual energy) thereby, the optimized path is based on the max-min metric, which is $(S \rightarrow A \rightarrow D)$. The figure 2.2a, describes cost of route on the basis of distance from the line joining S and D. The proposed algorithm chooses the path while considering the metric based on maximum residual energy, minimum cost along, recoiled off time along with minimum perpendicular distance from SD line of intermediate nodes (refer to figure 2.2a).

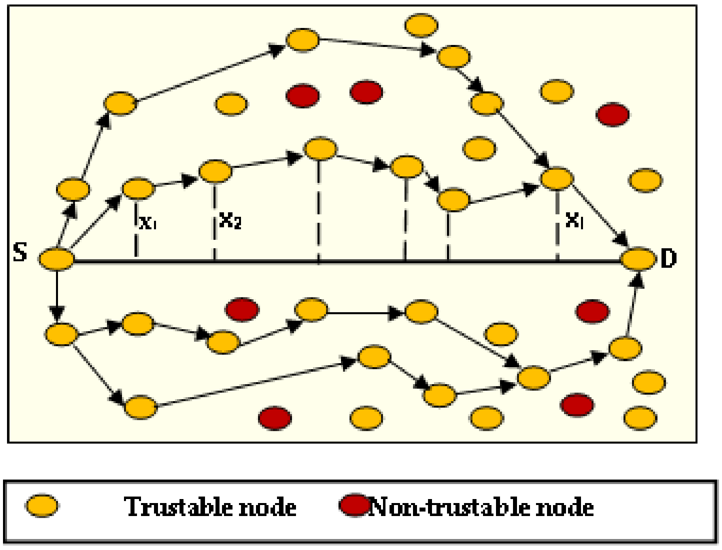


(A) Min-Power Route

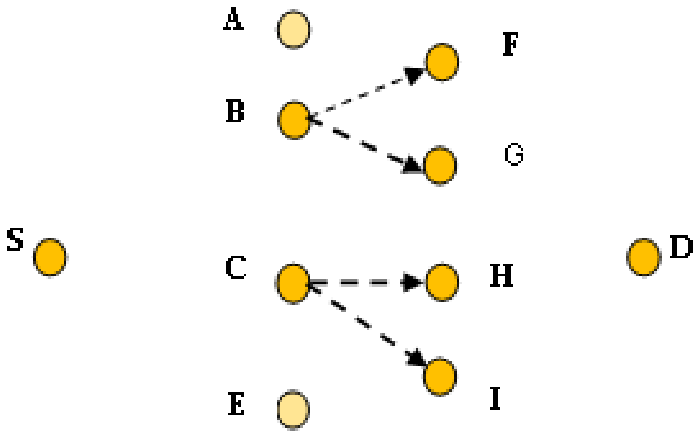


(B) Max-Min Energy Distance Path

FIGURE 2.1. Maximum Energy and Minimum Distance Path



(A) Min Distance from SD Line.



(B) Recoil Technique with Recoiled Nodes (A and E).

Figure 2.2. Route Selected Using Proposed Techniques

2.3.2. Coordinated Recoiled Node Algorithm

In routing, usually a node floods the packet to its neighborhood and this process continues till the packet reaches its destination. However, in the proposed approach, instead of all nodes transmitting the packet, only a few eligible nodes participate in transmission. These specific nodes are called recoiled nodes and the selection of recoiled nodes is made as per the algorithm based on nodes location illustrated below.

Algorithm 2: Coordinated Recoiled Node

begin

sdloc ← coordinate of point S and D ;

nodeloc ← coordinate of eligible node for transmission;

errpt ← error point;

if $(nodeloc + errpt == sdloc)||(nodeloc - errpt = sdloc)$ **then**

$transmit\_pkt()$;

else

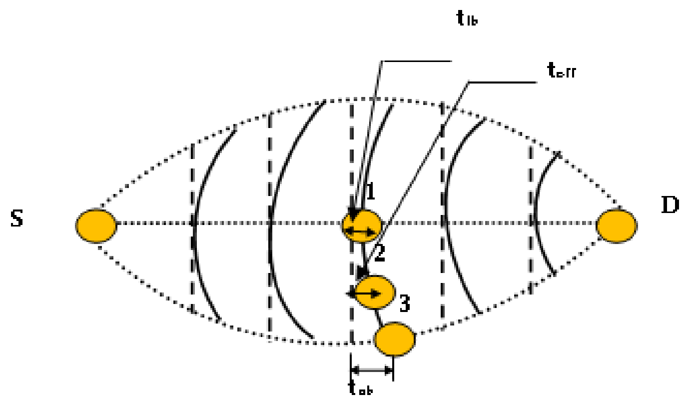
$recoil = coordinated\_time()$;

end if

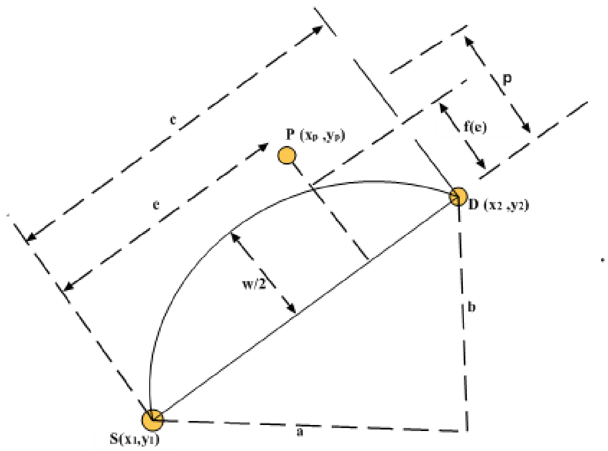
end

As algorithm (2) expresses, only few of them are eligible to transmit the packet and the remaining will retain the packet with them as transmission requires more power than sensing the network. Figure (2.2), shows the same strategy: node S transmits the packet to node A, B, C and node E. Further, out of these four nodes, only two eligible nodes (node B and C) can transmit the packet to their neighbors and the remaining nodes (node A and E) wait for their eligibility, called recoil nodes. The eligibility of a node is based on the eligibility function of variable location from the SD line. Nodes which are on the SD line transmit and those which are away from the SD line will be assigned variable recoil time. Figure (2.3a), shows recoil time (waiting time) to $node1, node2$ and $node3$ as per the location, i.e., $node1 < node2 < node3$. Hence, lower valued recoil time nodes turn out to be part of primary routes. However, if any point of time transmission is failed (due to any reason like packet loss, link error) then retransmission by the recoiled becomes inevitable. The prediction of link error is address in subsequent section.

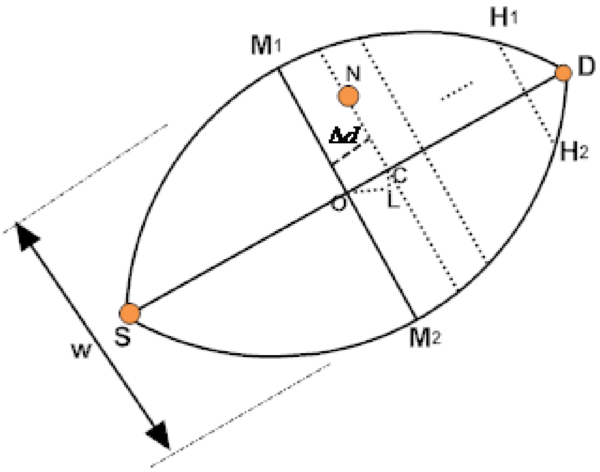
Generally Route discovery is used when a source node desires to send a packet to some destination node and does not already have a valid route to that destination; in which the source node initiates a route discovery process to locate the destination. It broadcasts a route request (RREQ) packet to its neighbours, which then forward the request to their neighbours. During the forwarding process, each node has destination id with the intermediate nodes record in its route tables. Once the RREQ reaches the destination, destination responds with a route reply (RREP) packet back to the source node through the route from which it first received the RREQ.



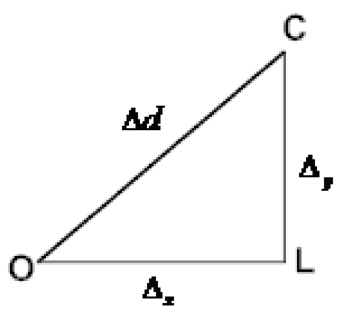
(A) Recoiled off Time Distribution to Nodes 1, 2 and 3.



(B) Recoiled off Time Calculation.



(C) Recoiled off time Calculation for an Arbitrary Node N.



$$\Delta d^2 = \Delta_x^2 + \Delta_y^2$$

(D) Relation.

Figure 2.3. Computation and Distribution of Recoiled off Time

2.3.3. Computation of Recoiled off time

Figure(2.3b) shows the calculation for computation of recoil off to any node which is inside the curve. First, it is necessary to find out whether a point $P\left(x_p, y_p\right)$ is inside the curve or not. And related calculation is as follows (refer to equation 2.1 - equation 2.7).

$$c^2 = a^2 + b^2, a = x_2 - x_1, b = y_2 - y_1$$

The slope of SD line $m = b/a$ and the equation can be written as

$$y - y_1 = m\left(x - x_1\right) \tag{2.1}$$

$$y - y_1 = b/a\left(x - x_1\right)$$

$$bx - ay - \left(bx_1 - ay_1\right) = 0 \tag{2.2}$$

The perpendicular distance of $P\left(x_p, y_p\right)$ from SD line can be express as under

$$p = \frac{\left|bx_p - ay_p - bx_1 + ay_1\right|}{\sqrt{a_2 + b_2}} = \frac{\left|a\left(y_1 - y_p\right) - b\left(x_1 - x_p\right)\right.}{c} \tag{2.3}$$

The equation of line perpendicular to SD line and passing through point P can be given as

$$y - y_p = -a/b\left(x - x_p\right)$$

$$ax + by - \left(ax_p + by_p\right) = 0 \tag{2.4}$$

The value of e is the perpendicular distance on line (2.4) from point S.

$$e = \frac{\left|ax_1 + by_1 - \left(ax_p + by_p\right)\right|}{c}$$

$$e = \frac{a\left(x_p - x_1\right) + b\left(y_p - y_1\right)}{c} \tag{2.5}$$

The shape of curve is approximately an ellipse. Hence, the function $f(e)$, which gives the extreme value for point P in order to be inside the ellipse. The center coordinate $(C1)$ of an ellipse, equation of an ellipse and value of the $f(e)$ can be calculated as below.

$$C_1\left(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2}\right)$$

Equation of an ellipse

$$\frac{\left[x - \frac{(x_1+x_2)}{2}\right]^2}{\left(\frac{c}{2}\right)^2} + \frac{\left[y - \frac{(y_1+y_2)}{2}\right]^2}{\left(\frac{w}{2}\right)^2} = 1 \tag{2.6}$$

$$f(e) = \begin{cases} 0, & when \ \alpha = 0 \\ \sqrt{\alpha.\beta^2}, & otherwise \end{cases} \tag{2.7}$$

where $\alpha = 1 - \left[\frac{\left(e-\frac{c}{2}\right)}{\delta}\right]^2$, $\beta = \frac{w}{2}$ and $\delta = c/2$.
The recoil off time (for recoil nodes) is directly proportional to the magnitude of perpendicular distance from point N to SD line as shown in figure (2.3c). It means recoil off time increases with the perpendicular distance on SD line. Let us consider an arbitrary recoiled node, say N, at distance Δd from M_1M_2 and the coordinate of point $C\left(\frac{x_1+x_2+\Delta x}{2}, \frac{y_1+y_2+\Delta y}{2}\right)$.The equation of a line passing through point N, can be expressed as given below (refer to equation 2.9) , we get

$$b\left[y - \frac{(y_1+y_2+\Delta y)}{2}\right] = -a\left[x - \frac{(x_1+x_2+\Delta x)}{2}\right] \tag{2.8}$$

$$2ax + 2by - b\,(y_1+y_2+\Delta y) - a\,(x_1+x_2+\Delta x) = 0 \tag{2.9}$$

In ΔCLO, relation exist (refer to equation(2.10))

$$\Delta d^2 = \Delta x^2 + \Delta y^2 \tag{2.10}$$

Additionally, a line passing through the center of curve (hence, putting $\Delta x = 0$ and $\Delta y = 0$ in equation (2.8))

$$b\left[y - \frac{(y_1+y_2)}{2}\right] = -a\left[x - \frac{(x_1+x_2)}{2}\right]$$

$$2ax + 2by - b\,(y_1+y_2) - a\,(x_1+x_2) = 0 \tag{2.11}$$

Equation (2.9) and equation (2.10) calclate the value of recoil off time for any node.

2.3.4. Link Reckoning and Route Maintenance Algorithm

The link strength reckoning can be carried out or estimated before the link error occurs, which helps in ensuring the improved packet delivery ratio. Let us consider there are n nodes between source and destination. The required transmission energy in each link can be expressed as $p_{i,i+1} = as^{\alpha}_{i,i+1}$, where $s_{i,i+1}$ refers to link cost between nodes i and $i+1$, a is a environmental constant and $\alpha > 2$. Each link in a route has an independent link error rate assuming $e_{i,i+1}$. The number of transmissions between nodes i and $i+1$ can be expressed by using distributed random variable X (geometrically), such that

$$Prob(X = x) = e^{x-1}_{i,i+1}.(1 - e_{i,i+1}); \forall x \tag{2.12}$$

For the successful transmission of a packet, the required mean $\frac{1}{(1-e_{i,i+1})}$. Thus, the effective transmission energy between nodes i and $i+1$, (including the effect of link error) is given by (refer to equation (2.13)).

$$Ci, i+1 = \frac{p_{i,i+1}}{(1 - e_{i,i+1})} = \frac{as^{\alpha}_{i,i+1}}{(1 - e_{i,i+1})} \tag{2.13}$$

But the link error rate changes frequently, hence, the probability distributions with random variables have been taken into consideration, which is given by equation (2.12) and similar case is for the transmission energy between two corresponding nodes. However, the prediction based link lifetime of a node can be estimated before the link error occurs between two nodes, which are expressed as (refer to equation (2.14)).

$$P_r = \frac{P_T}{4\pi d_i^2}$$

$$d_i^2 = \frac{P_T}{den} 4\pi P_r \tag{2.14}$$

Distance and transmission power are the determinant factors for computing the strength of received signal. Consider the *points* P, A, B, E and M as a few locations of *node* P (refer to figure (2.4)). The relative speed and the distance determines link lifetime of node in network. The *nodeP* moves from A to B in Δt_2 time interval and from node B to node E in Δt_1 time interval ($\Delta t_1 = \Delta t_2 = \Delta t_3$). Similarly, several such reference points are taken into consideration in order to determine the link lifetime and the relative speed.

The relative speed can be expressed by equation(2.17) (using cosine rule)

$$d_i^2 = d_j^2 + AB^2 - 2d_j.AB\cos\alpha \tag{2.15}$$

$$d_k^2 = d_j^2 + AB^2 - 2d_j.AB\cos\beta \tag{2.16}$$

where d_i, d_j and d_k are calculated by equation (2.16) and (2.16). However, $\cos\alpha = -\cos\beta$, we get

$$2AB^2 = d_i^2 + d_k^2 - 2d_j^2$$

$$2(v.\Delta t)^2 = d_i^2 + d_k^2 - 2d_j^2$$

hence, the speed of node

$$v = \frac{\sqrt{d_i^2 + d_k^2 - 2d_j^2}}{2\Delta t^2} \tag{2.17}$$

To compute link lifetime T_L

$$T_L = T_d - T_E$$

where T_d represents time taken by node to move from reference $pointA$ to $pointB$ and T_E stands for time elapse by node moving from $pointB$ to current position E (refer to figure (2.4)). According to the sine rule, it can be obtained as

$$T_d = \frac{R.\sin\theta}{v.\sin\beta}$$

$$T_d = \frac{2\Delta t^2.R\sin\theta}{\sin\beta\sqrt{d_i^2 + d_k^2 - 2d_j^2}} \tag{2.18}$$

where θ represents angle $\angle BSD$. The value of node speed and link lifetime are expressed by equation(2.17) and equation(2.18) respectively.

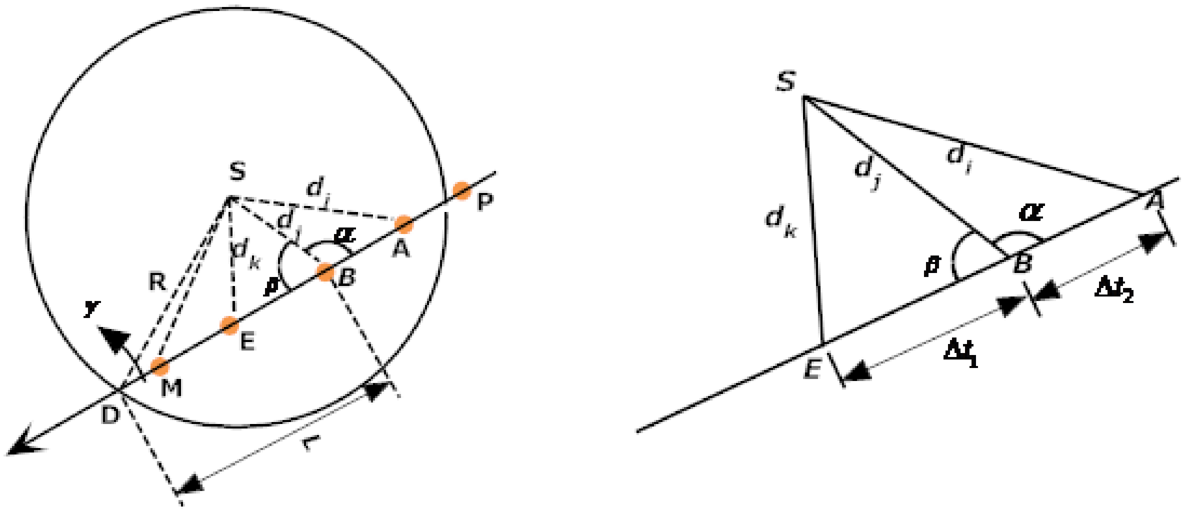
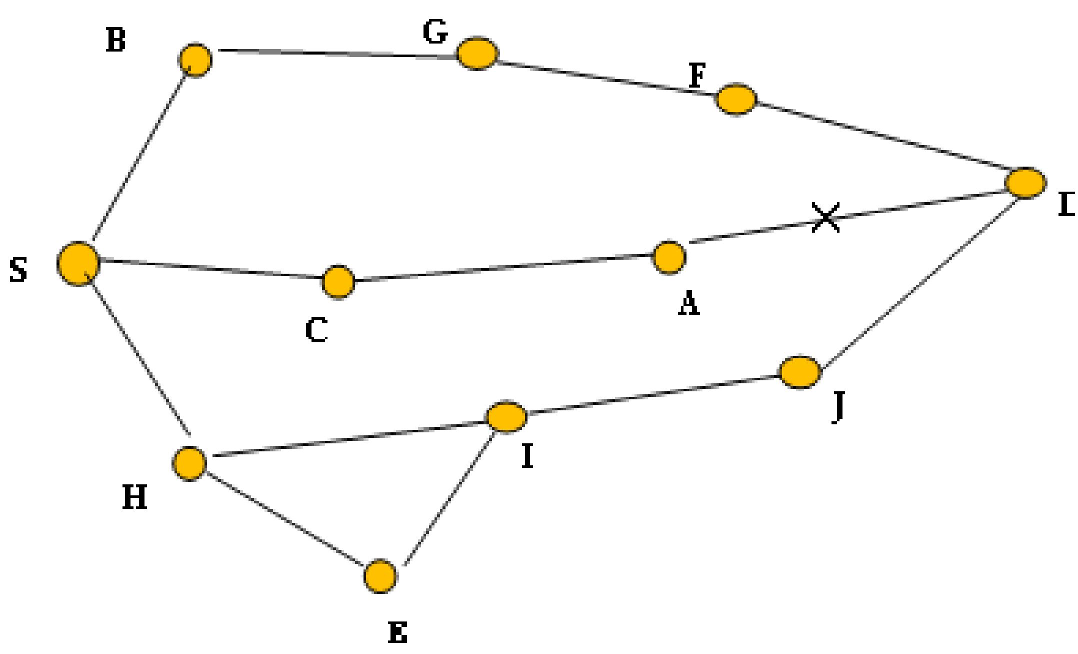


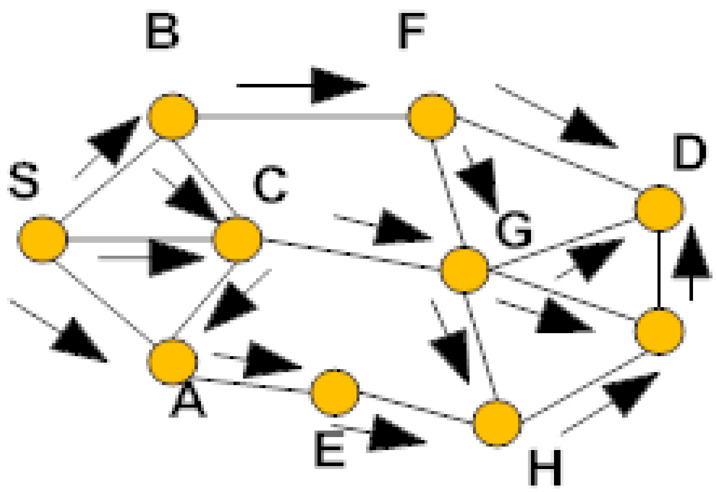
FIGURE 2.4. Mobility Estimation of Node in Network

Unlike AODV, the maintenance operation can be done at local level when link error is encountered which reduces the extra overhead in the network. The proposed approach is based on received signal strength (RSS) to carry out the maintenance at the nearest failure link, which requires keeping two additional entries in the routing table in addition to existing entries (as in AODV protocol, (refer to table (2.1) for AODV protocol) and (refer to table (2.2) for AOMDV protocol). These entries are Receive Signal Strength (RSS) of the last node and RSS difference at the last hop with next node. These value keep updating at fixed intervals of time and are compared to RSS threshold value (THRS). If it is found below the THRS, then new link need to be established. Hence, RMA (Route Maintenance Algorithm) needs to be called in order to remove such undesirable problem.

For route $S \to C \to A \to D$ and link AD (refer to figure (2.5a)) is broken due to erroneous condition. Now, *nodeA* (last node) sets the $flag = false$ for route leading from A to D. Furthermore, *nodeA* carries out repair at a local level instead of sending RERR to source. During local repair mechanism, when *nodeF* receives RREQ from A, send back RREP as it has route to *nodeD*, now creates a route entry in its routing table with D as its destination node. However, A does not send RREQ to J and wait till recoil time expires. If *nodeF* is fails to reply within the recoil time then the same steps are repeated with *nodeJ* till path is repaired. The REPLY message is sent back to the source (S), which contains the number of hop information.



(A) Route Maintenance between Node A and D.



(B) Packet Transmission
between S to D.

FIGURE 2.5. Illustration of Route Maintenance in Network

The pseudo code for optimal route discovery is given by algorithm(3)

Algorithm 3: Route Maintenance

```
begin
if (S send data to D) then
   AODV ( );
end if
for (each node between S and D) do
   for (each link between S and D) do
      manage a table containing parameters
      RSS of last hop, addrss of last hop,
       distance variation, difference in RSS);
   end for
end for
end
```

TABLE 2.1. Routing table (AODV)

Routing Table Field
destinationId
seqNum
hopCount
expirationTimeout
nxthop

TABLE 2.2. Routing table (AOMDV)

Routing Table Field
destinationId
seqNum
advtHopCount
expirationTimeout
routeList $[(nxthop_1, hopCount_1), (nxthop_2, hopCount_2), ..., (nxthop_n, hopCount_n)]$

TABLE 2.3. Routing table (AOMDV-ER)

Routing Table Field
destinationId
seqNum
advtHopCount
routeList $[(nxthop_1, hopCount_1), (nxthop_2, hopCount_2), ..., (nxthop_n, hopCount_n)]$
residualEnergyLevel
thresholdEnergyLevel
recvSignalStrength
diffBetRSSval
recoiledoffTime

Tables (2.1 to 2.3) show the routing field in routing table for AODV, AOMDV and AOMDV-ER respectively.

The principal structure of routing table entry in the three mentioned protocols is shown in Table (2.1). There are few main differences, namely; (*i*) the hopcount is replaced by advertised hopcount in AOMDV and AOMDV-ER; (*ii*) the nxthop is replaced by *routeList*, where AOMDV and AOMDV-ER keep the field nxthop along with the corresponding number of hops in the route and they utilizes multiple path to the destination; (*iii*) AOMDV-ER has residual energy, threshold energy in order to select the Max-Min path in the network (refer to figure(2.1b)); (*iv*) furthermore, to estimate the link strength receive signal strength and difference between RSS values are kept; and (*v*) recoiled off time is necessary to limit the number of transmissions. The function of algorithm has been shown in Figure 2.3b and the corresponding values are depicted in Table (2.3). The received signal strength ($recvSignalStrength$) is calculated with the help of the signal received by the antenna whereas recoiled off time ($recoiledoffTime$) is configured just before the execution of algorithm in the simulator. Threshold energy ($thresholdEnergyLevel$) of each node (the minimum energy required to transmit a packet to its neighbor) is also set, which helps in the selection of path compared with the residual energy at that instance.

TABLE 2.4. Routing table (AOMDV-ER)

d_id	seq_no	adv_hcnt	route_lst	res_eng	thr_eng	rss_val	dif_rss	recoil_time
D	11	3	(B,3)	17J	1J	16	1	2s
D	11	5	(A,5)	19J	1J	15	2	2s
D	11	3	(C,3)	23J	1J	21	0	2s

TABLE 2.5. Parameter setting in simulation

Parameter	Value	Unit
Number of nodes	150	-
Traffic type	CBR	-
Area Size	$1500x1500$	$Meter^2$
Mobility Model	RWP	-
Transmission range	500	Meter
Packet size	64,128,256,512,1024	Bytes
Routing Protocols	AOMDV, AOMDV-ER, AOMR-LM, SRMP	Protocol
Node speed	0.25, 5, 7.5 and 10	Meter/Sec
Simulation Time	10,20,30,40,50	Sec
Initial energy	75	Joules
Transmission energy consumption	0.02	Joules
Receive energy consumption	0.01	Joules
Queue size	50	Packets
Number of runs	5	Number

2.4. Mathematical Support to Proposed Model for Results

In order to verify the proposed algorithms for analysis, a set of Lemmas are formulated. These Lemmas are based on system parameters such as protocol overhead, node mobility and packet loss.

Lemma 2.1. *The term mobility refers to the nodes average speed during the simulation. The lemma states that the routing overhead increases (in either cases proactive or reactive* *protocols) with mobility, which can be expressed using equations (2.19) and (2.20).*

$$If M_1 > M_2 \implies \phi_P(M_1) > \phi_P(M_2) \tag{2.19}$$

$$If M_1 > M_2 \implies \phi_R(M_1) > \phi_R(M_2) \tag{2.20}$$

Proof : Routing overhead is the overhead bear by a protocol to keep updated information about the network. Hence, the number of routing packets is required for the transmission of single data packet. The wired network requires route discovery once and routing overhead incurred only a single time given no mobility in nodes (fixed topology). However, in ad hoc networks, scenario is entirely different as dynamic topology needs frequently route discovery. Additionally, mobility (more frequently changing the topology) of nodes gives rise to multiplier effect to the route discovery and route maintenance means higher mobility, which requires more route discovery, leading to a higher routing overhead.
Suppose each node has probability pr to retransmit the RREQ packet to its destination; let the average destination be N_{avg} and there are m hops to reach the destination. Hence, the routing overhead for the first hop is $p_r \times N_{avg}$. The overall routing overhead from source to destination is denoted by Re and is given by equation (2.21)

$$R_e = 1 + p_r.N_{avg} + p_r^2.N_{avg}.N_f + p_r^3.N_{avg}.N_f^2 + ... + p_r^m.N_{avg}.N_f^{m-1}$$

$$R_e = 1 + p_r.N_{avg} \sum_{i=0}^{m-1} (p_r.N_f)^i \tag{2.21}$$

where N_f represent total neighbors number of a node that receive route request packet RREQ, from that node and rebroadcast the same RREQ packet to the next hop with probability p_r. The equation (2.21) is the summation of finite geometric progression, and reduces to equation (2.22).

$$R_e = \begin{cases} 1 + p_r.N_{avg}\left(\frac{1-(p_r.N_f)^m}{1-p_r.N_f}\right); & for\ \ any\ \ p_r\ \ and\ \ N_f \\ 1 + m.p_r.N_{avg}; & for\ \ p_r.N_f = 1 \end{cases} \tag{2.22}$$

Consider the case for reactive routing (e.g., AODV), where intermediate nodes always perform the rebroadcast, hence, $p_r = 1$, and we obtain

$$R_e^{AODV} = \begin{cases} 1 + N_{avg}\left(\frac{1-(N_f)^m}{1-N_f}\right); & for\ \ any\ \ N_f \\ 1 + m.N_{avg}; & for\ \ N_f = 1 \end{cases} \tag{2.23}$$

When mobility of nodes increases, the frequency of route discovery also increases and the value of routing overhead in single route discovery is expressed by equation (2.23). Hence, it is proved routing overhead increases with mobility of nodes.
Simulation result (refer to figure (2.11a)) shows the slope of tangent line (parallel to $y = 3.72x + 17.2$ *best fit line equation) on routing overhead curve, equal to 3.72, which is greater than 0. Hence, the result shows that the routing overhead function is monotonically increasing with the mobility of node . The slope of tangent on curve always equal to slope of best fit line on curve, hence, used here interchangeably.*

Lemma 2.2. *The packet loss percentage increases with node mobility in either case, i.e., reactive or proactive protocols, and can be expressed as (refer to equations(2.24)) and equation(2.25).*

$$If M_1 > M_2 \implies PL_P(M_1) > PL_P(M_2) \tag{2.24}$$

$$If M_1 > M_2 \implies PL_R(M_1) > PL_R(M_2) \tag{2.25}$$

Proof: As per lemma 2.1, it is stated that on increasing in mobility leads to augmentation of route discovery process due to the frequent link failure. And link failure definitely escalates the chances of packet loss. Hence, it is concluded that packet loss percentage increases with mobility.
M_1 *and* M_2 *signify two different values of mobility. The derivatives* $PL_P^{'}(M) > 0$ *and* $PL_R^{'}(M) > 0$ *show the packet loss function increases with mobility.*
The simulation result (refer to figure (2.11b)), shows that the slope of tangent line (parallel to $y = -1.64x + 98$ *best fit line equation) on PDR curve, equal to -1.64, which is negative. Hence, the slope of packet loss function would always be greater than 0 (PDR opposite to packet loss ratio). Hence, it is concluded that the packet loss percentage function is monotonically increasing with the mobility of node.*

Lemma 2.3. *The energy consumption in routing protocol increases with node mobility in network in both proactive and reactive protocols. It can be represented as (refer to equation(2.26)).*

$$If M_1 > M_2 \implies E(M_1) > E(M_2) \tag{2.26}$$

Proof: The energy consumed by the protocol, the summation of energy consumption in performing route discovery (RD) and energy consumed in routing maintenance (RM), that is, the cost paid in the RD and RM processes, can be illustrated as (refer to equation(2.27)).

$$E^p = E_{RD} + E_{RM} \tag{2.27}$$

where E_p, *represents energy consumed in routing protocol,* E_{RD} *notation used for energy consumed in route discovery process, and* E_{RM} *stands for route maintenance. The energy in route discovery would be summation of cost incurred in RREQ packet and RREP packet during route discovery and can be expressed as below (refer to equation(2.28)).*

$$E_p = \begin{cases} \sum_{R_i=1}^{R_{max}} (E_{R_i})R_i & if \;\; no \;\; RREP \;\; received \\ E_{rrep} + \sum_{j=1}^{n_{rrep}} (RREP)_j; & if \;\; R_{rrep} = 1 \\ \sum_{R_i=1}^{R_{rrep}} (E_{R_i})R_i + \sum_{j=1}^{n_{rrep}} (RREP)_j; & otherwise \end{cases} \tag{2.28}$$

where, R_{rrep} *and rrep are same and takes the value* $rrep = 1, 23, ...max$. *The energy consumption in RM process completion can be expressed as below in equation (2.29).*

$$E_{RM} = E_{l_{mon}} + E_{LLR} + \sum_{k=0}^{j} (RREP)_k \tag{2.29}$$

where $E_{l_{mon}}$ *represents the link monitoring energy consumed in protocol. The total energy consume is calculated as sum of equations (2.28) and equation (2.29), which is expressed by equation(2.27). When the mobility of nodes increases, routing overhead increases along with corresponding energy consumption in process. Hence, the value of equation (2.27) holds the inequality (refer to equation (2.26)).*

The first order derivative $E^{'}(M) > 0$, *shows that the packet delay function increases with number of nodes.*

The simulation result (refer to figure (2.11c)), shows that the slope of tangent line (parallel to $y = 3.12x + 51.68$ *best fit line equation) on energy consumption curve, equal to 3.12, which is greater than zero. Hence, the slope of energy consumption is also increasing with mobility of nodes, hence result complied as per lemma stated.*

2.5. Results and Discussion

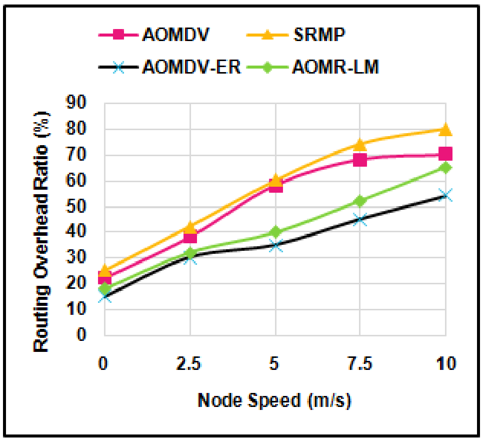
This section, we experimentally demonstrate the proposed multipath routing protocol named AOMDV-ER. This protocol is an enhancement of the well-known AOMDV and AOMR-LR routing protocols. An enhancement is observed in terms of network lifetime, routing overheads, PDR and energy consumption over the existing protocols. We have demonstrated the formally proved Lemmas through experiment. The performance evaluation has been carried out by considering various parameters. The NS2.35 has been used for the simulation with 150 nodes using random way point (RWP) model in an area of $1500 \times 1500m$ (refer to table 2.5). The RWP model facilitates realistic mobility model thereby, any node can move randomly within specified are and remains in the position for defined period of time called as pause time and further they can move to random way and so on. The number of nodes in defined area are reasonably dense which consonance with transmission range.

2.5.1. Routing Overhead

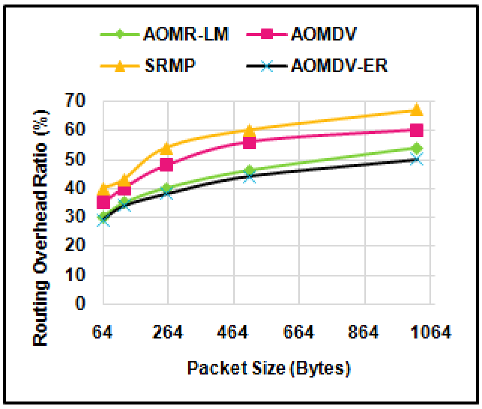
Figure(2.6a) represents the deviation in routing overheads value in AOMR-LM, AOMDV, SRMP and AOMDV-ER. When the node mobility increases like (0, 2.5, 5, 7.5, 10 m/s), routing overhead of AOMDV increases from 20% to 70%, AOMR-LM varies from 18% to 65%, SRMP increases from 25% to 80%, and our proposed AOMD-ER only increase from 15% to 54%. The AOMD-ER shows least routing overhead among all because it uses the path which has the strong links where route failure chances is negligible.

Figure(2.6b), expresses the variation in routing overhead for AOMR-LM, AOMDV, SRMP and AOMDV-ER. The packet size varies, routing overhead in AOMDV increases from 35% to 60%, in AOMR-LM varies from 30% to 54%, in SRMP increases from 40% to 67%, and our proposed AOMD-ER only increases from 29% to 50%. The AOMD-ER requires the least routing overhead among all as it required less discovery process along with verification of link stability.

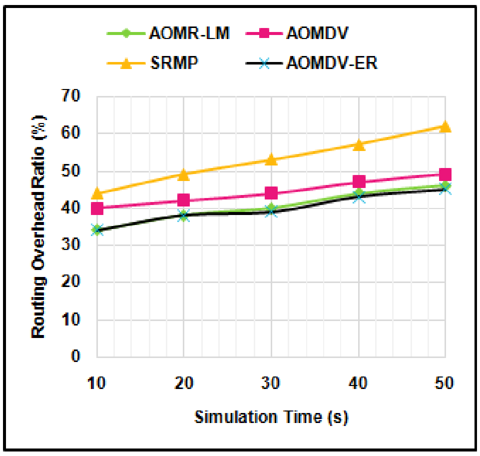
Figure(2.6c), the simulation time is varied, the overhead of AOMDV increases from 40% to 49%, AOMR-LM varies from 34% to 46%, SRMP increases from 44% to 62%, and AOMD-ER from 34% to 45%. The comparison shows that the performance of AOMD-ER is better than other routing protocols.



(A) Overhead Vs node speed



(B) Overhead Vs packet size.



(C) Overhead Vs simulation time.

FIGURE 2.6. Routing overhead in different scenarios.

2.5.2. Network Lifetime

Experimental results of network lifetime have been discussed, for the same protocols. Figure(2.7a), shows the comparison among the network lifetime for the aforementioned protocols. Figure (2.7b), represents exhausted nodes increases with the packet size. The AOMDV-ER performs better than AOMR-LM because it employs a proficient recoiled node technique. The figure(2.7c) show the exhausted node increase with simulation time.

Figure(2.8a) and figure(2.8b) show the energy consumption with varying simulation time in protocols. The AOMDV-ER performs best because of the recoil node technique, thereby conserving the energy level in nodes while reducing the number of transmission.

2.5.3. Packet Delivery Ratio

Figure(2.9a), shows all the protocols the packet delivery ratio (PDR) decreases with mobility; specifically in AOMDV, there is a decrease from 94% to 65%; in AOMR-LM, a decline from 95% to 78%; SRMP decreases from 80% to 47%; and our proposed AOMD-ER decreases from 97% to 82%. The AOMD-ER performs better because transmission is on strong and stable link.

Figure(2.9b) represents the PDR decreases with packet size. The PDR in AOMDV decreases from 90% to 72%, AOMR-LM reduces from 96% to 80%, SRMP decreases from 85% to 65% and our proposed AOMD-ER only decreases from 98% to 86%, due to a smaller drop ratio (using strong link).

Figure(2.9c) illustrates PDR increasing with simulation time. The PDR of AOMDV increases from 70% to 76%, AOMR-LM increases from 75% to 78%, SRMP increases from 67% to 70%, and in AOMD-ER from 77% to 86%. The figure (2.9c) shows the PDR% with varying simulation of time. Hence, AOMD-ER out performs other algorithms as it uses the stable link nodes and optimal path.

$$PacketDeliveryRatio(PDR) = \frac{Numberofpacketssuccessfullyreceived}{Totalnumberofpacketssent} \tag{2.30}$$

2.5.4. Throughput

Figure(2.10a) depicts throughput of protocols; it decreases with mobility. In AOMDV, there is a decrease from 1110 to 870 Kbps; in AOMR-LM, a reduction from 1120 to 940 Kbps; SRMP decreases from 1000 to 665; and the proposed AOMD-ER decreases 1080 to 810 Kbps. The AOMR-LM performs best as it requires least time to discover route despite of link error.

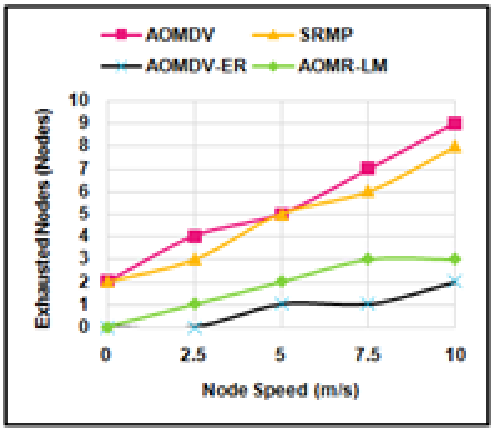
Figure(2.10b) shows throughput decreases with packet size. In AOMDV decreases from 1110 to 830 Kbps, AOMR-LM reduces from 1117 to 950 Kbps, SRMP decreases from 1010 to 720 Kbps, and proposed AOMD-ER only reduces from 1080 to 790 Kbps. AOMR-LM performed better as it requires least time to discover route.

Figure(2.10c) represents throughput increasing with simulation time of the network. Throughput of AOMDV increases from 150 to 980 Kbps, in AOMR-LM varies from 180 to 1110 Kbps, in SRMP increases from 70 to 651 Kbps and in AOMD-ER from 121 to 801 Kbps. The algorithm AOMR-LM out performs other algorithm by reducing load balancing between high level and average level path during transmission.

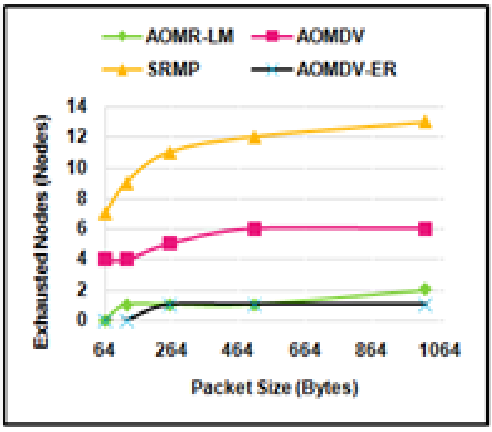
Packet delivery ratio (PDR) is defined on the basis of number of packets received and generated packets for particular period of time. It is a ratio of packets that are received successfully delivered to a destination compared to number of packets that have been sent by sender. Where as, throughput is a measurement of performance and quality of link connections of a network. It is estimated as the number bits per second passing through over the network. It is an important parameter for the calculation of packet drop, link failure, quality of service etc.

2.5.5. Energy Consumption

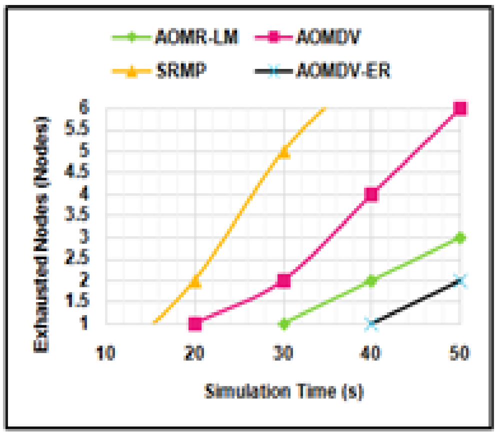
The experimental results in the figures of energy consumption have been discussed. Figure(2.12a) expresses the variation of energy consumption in various protocols AOMR-LM, AOMDV, SRMP and AOMDV-ER. In AOMDV, it increases from 70 J to 156 J; AOMR-LM varies from 60 J to 100 J; SRMP increases from 80 J to 170 J; and in AOMD-ER, there is an increase from 54 J to 86 J. The AOMD-ER outperforms others because in this protocol flooding of packets are limited and only eligible nodes participate in the transmission and remaining nodes wait and sense the network and act only when needed (recoiled technique).



(A) Network lifetime Vs node speed

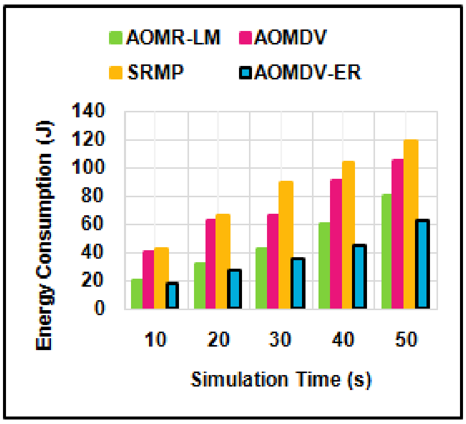


(B) Network lifetime Vs packet size.

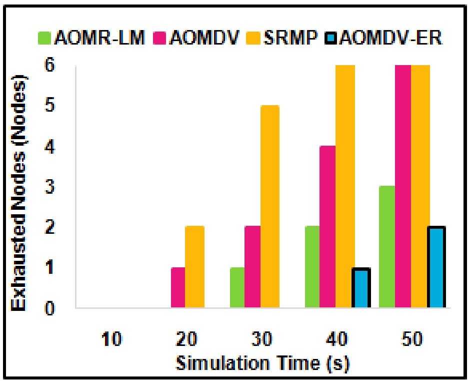


(C) Network lifetime Vs simulation time.

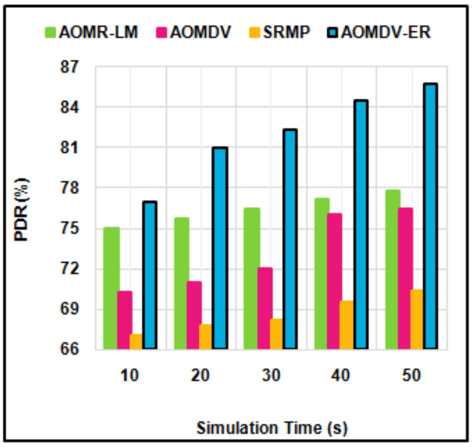
FIGURE 2.7. Network lifetime in different scenarios.



(A) Energy consumption with simulation time.

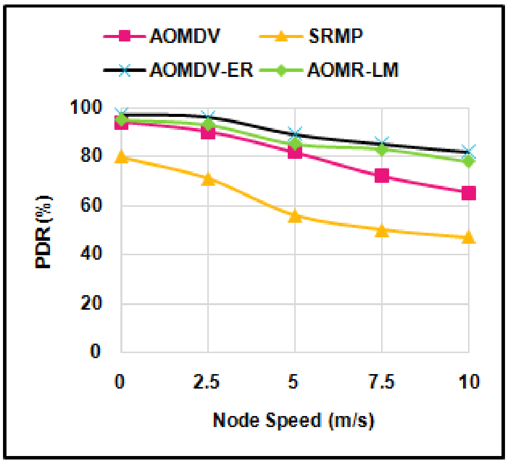


(B) Exhausted nodes with simulation time.

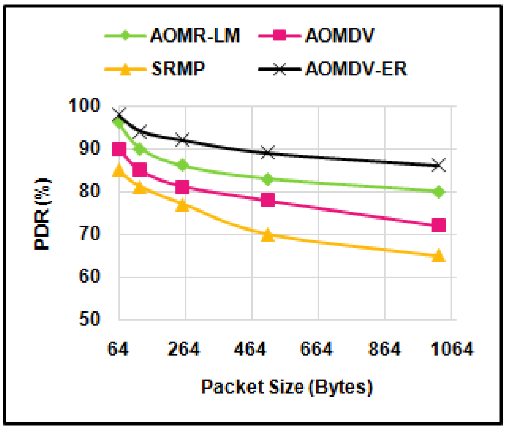


(C) Packet delivery ratio with simulation time

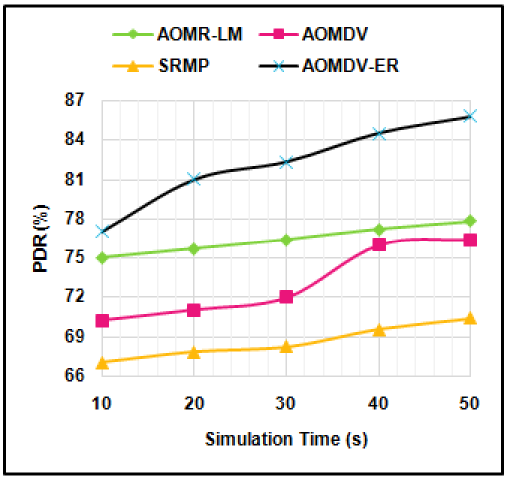
FIGURE 2.8. Various parameters Vs simulation time



(A) Packet delivery ratio Vs node speed.

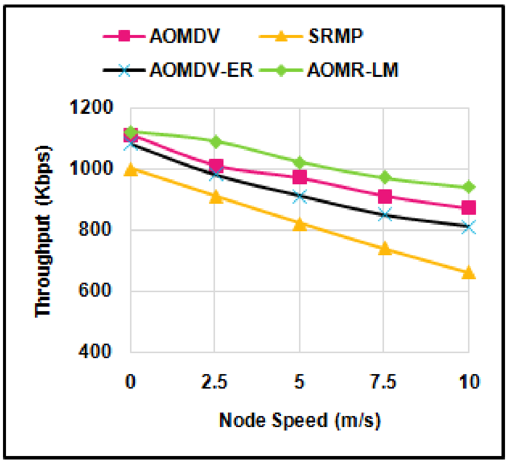


(B) Packet delivery ratio Vs packet size.

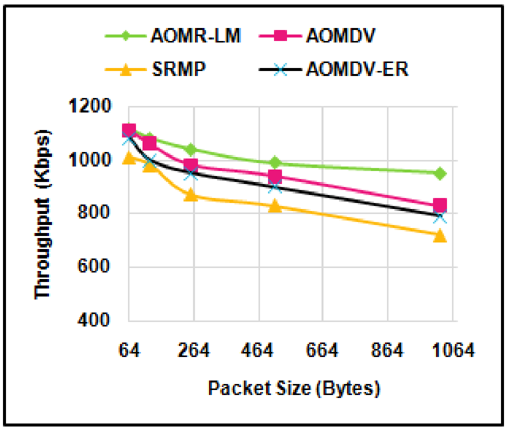


(C) Packet delivery ratio Vs Simulation time.

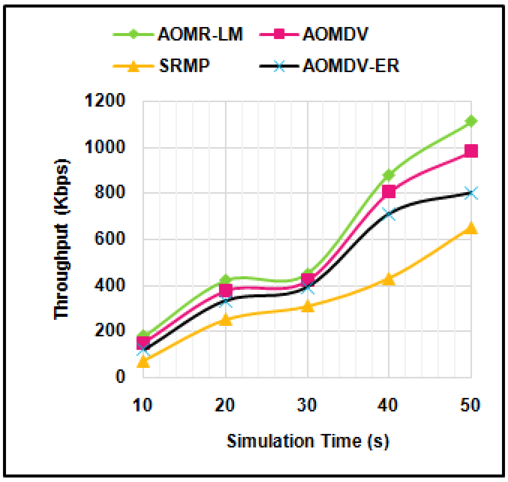
FIGURE 2.9. Packet delivery ratio in different scenarios.



(A) Throughput Vs node speed.



(B) Throughput Vs packet size.



(C) Throughput Vs simulation time.

FIGURE 2.10. Throughput of network in different scenarios.

Figure(2.12b) illustrates the energy consumption increase with packet size. In AOMR-LM, there is variation from 20 J to 80 J; in SRMP, an increase from 42 J to 119 J; and in AOMD-ER 18 J to 62 J. The AOMD-ER performs best as it conserves energy while restricting flooding and follows the path that has less chance for link error.

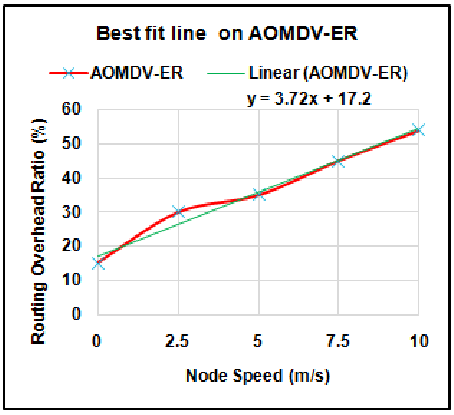
Figure(2.12c) shows the power consumption increases with simulation time. The power consumption in AOMDV increases from 40 J to 105 J, AOMR-LM varies from 20 J to 80 J, SRMP increases from 42 J to 119 J and AOMD-ER changes from 18 J to 62 J. The result shows that performance of AOMD-ER is best among all, as it senses more and transmits less.

Figure(2.12a) to Figure(2.12c) shown below depicts the energy consumption in the different scenarios, which are discussed experimentally in various protocols.

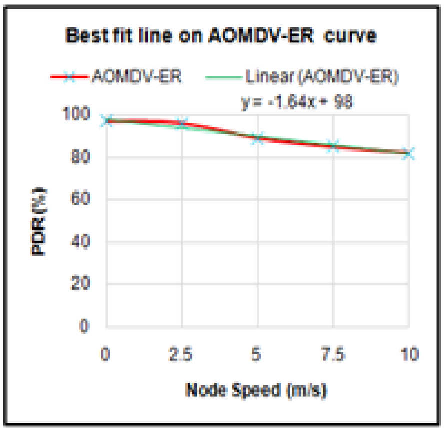
In AOMDV, there is an increase from 70 to 156 Joule; in AOMR-LM, a variation from 60 to 100 J; in SRMP there is an increase from 80 to 170 J; and in AOMD-ER as increase from 54 to 86 J. The AOMD-ER outperforms the others since, in this protocol, flooding of packets is limited and only eligible nodes participate in transmission and the remaining wait and sense the network, which act only when needed.

Figure(2.12b) illustrates the energy consumption increase with packet size. In AOMR-LM varies from 20 to 80 J, in SRMP increases from 42 to 119 J and in AOMD-ER 18 to 62 J. Routing AOMD-ER performs best given it conserves energy while restricting flooding and follows the path that has less chance for link error.

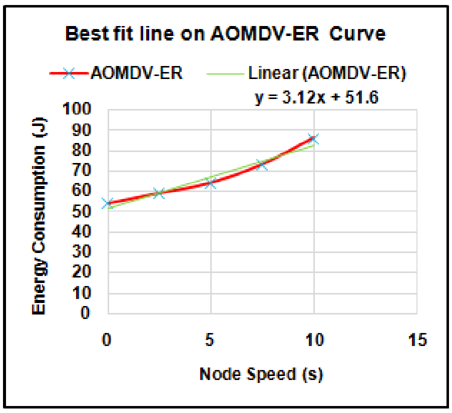
Figure(2.12c) shows the power consumption increase with simulation time. The power consumption in AOMDV increases from 40 to 105 J, in AOMR-LM varies from 20 to 80 J, in SRMP increases from 42 to 119 J and in AOMD-ER from 18 to 62 J. The result shows that performance of AOMD-ER is best among all, as it senses more and transmits less.



(A) Best fit line on AODV-ER (Routing overhead).

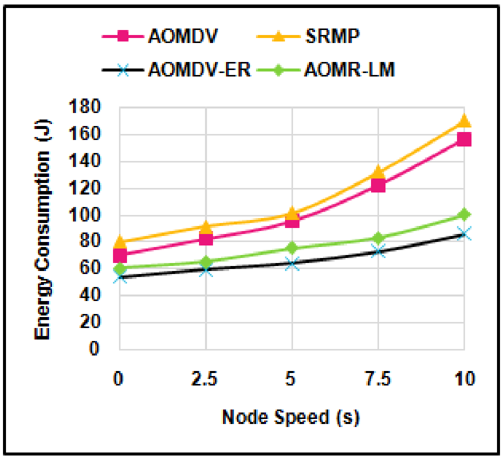


(B) Best fit line on AODV-ER (PDR).

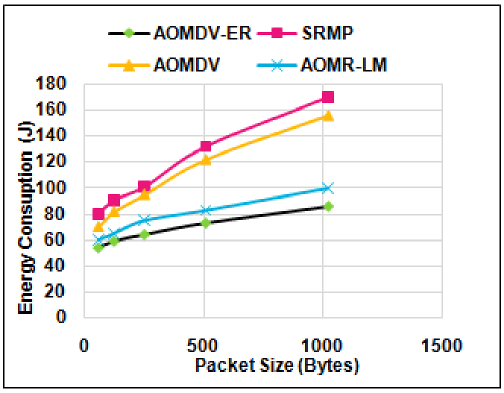


(C) Best fit line on AODV-ER (Energy Cons.).

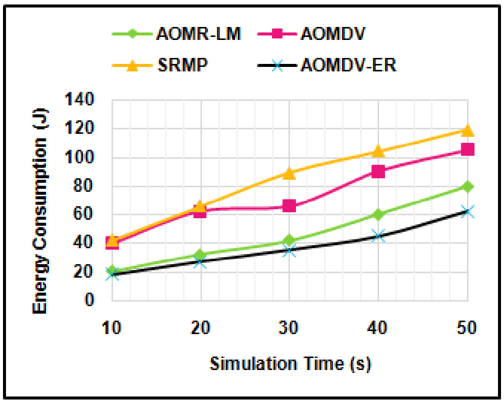
FIGURE 2.11. Best fit line parallel to tangent on curve.



(A) Energy consumption Vs node speed.



(B) Energy consumption Vs packet size.



(C) Energy consumption Vs simulation time.

Figure 2.12. Energy consumption in different scenarios.

2.6. Conclusion

The energy reduction in multipath routing protocol using recoil technique (AOMDV-ER), ad hoc on demand distance multipath routing with life maximization (AOMR-LM) and ad hoc on demand multipath distance vector routing protocol with fitness function (FF-AOMDV), are all an improvement over the AODV protocol. In this work, the proposed AOMDV-ER outperforms the existing algorithms, namely AOMR-LM, AOMDV and SRMP, in terms of routing overhead, network lifetime, packet delivery ratio and energy consumption. It is found that AOMDV-ER protocol, the nodes perform transmission of packets to destinations smartly using varying recoil off time based on their geographical location. The experimental result shows that AOMDV-ER reduces 22% and 6% of the routing overhead, an improvement of 26% and 33% of network lifetime, 6% and 12% of packet delivery ratio and reduces 14% and 31% of power consumption in comparison to AOMDV and AOMR-LM protocols respectively.

CHAPTER 3

BORS : ENERGY COMPUTATION FOR ROUTING PROTOCOL IN MOBILE ADHOC NETWORK (BACK OFF RELAXATION SYNCHRONIZATION SCHEME)

The Mobile Ad hoc Network (MANET) is defined as autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links. As the nodes are mobile, the network topology may change rapidly and unpredictably over time.The energy computation and consumption in an MANET is one of the significant key aspect for the better lifetime of the network as it is limited resource available to each device in network. The recent studies and research shows that the routing of packets is a striking feature in order to reduce the energy consumption as routing protocol requires a substantial portion of total consumed energy. This proposed algorithm is focused on the better utilization of battery power by exploiting the battery characteristic that is by synchronization of node's recoiled off time with the battery relaxation time in order to convert the unavailable charge into available charge.This work compares the result with proposed and the existing algorithms and evaluates the performance on the basis of various parameters. Furthermore, the battery preliminaries and its effect have been discussed thoroughly with respect to the single and multiple batteries based nodes.

3.1. Introduction and preliminaries

Over the last two decade, a large number of mobile devices have been evolved due to technological paradigm shift from wired to wireless technology. The MANET was revived as a potential technology when it comes to commercial applications. Mobile adhoc is on the fly network which has no infrastructure, nodes communicate without relying on any backbone, inherently dynamic with higher degree of freedom and astonishing behavior of network. It leads to acute problem of keeping track of nodes in network , which is necessary for the packet transmission in the interest of communication between any two arbitrary nodes. Hence, routing in such network came in the picture, where it should have adequate features like adaptability (as network highly dynamism demands) along with the optimality. The conventional routing protocols known for wired networks do not cater work proficiently as they have not been developed with the dynamic network topology as in ad hoc networks.Hence, the transmission of packet is a vital aspect in the mobile ad hoc network in order to save the energy while choosing the best path among possible paths. Saving energy of nodes in the network brings improvement in network lifetime. This work focuses on the scheme, which is the synchronization of back off time and the battery relaxation time. The back off time of a node is that time for eligible node during that span, it has to wait for the transmission of packet to its neighbor nodes. And the relaxation time is a phenomenon of a battery in that duration it recreate its charge if stay idle. With an intention, battery has been allowed to go for intentional relaxation and during this span battery recharge itself. In second approach, the multi battery have been used to serve the packets in each node. In this approach, the node's battery may get more time as one battery is serving packet and other is in relaxed mode whereby rebuilding the charge. The occurrence of relaxation in both approaches recharges the battery of a node and can effectively increase the number of transmission of packets to the other nodes in the mobile adhoc network. On the other hand it enlarge the battery life in the network. This battery life expansion or network lifetime enhancement may add the delay in packet service in the network but certainly it helps in reducing the network traffic and the network life time. In order to analyze the performance of such schemes in mobile ad-hoc network system, we have simulated the network and quantified the network performance under various parameters namely number of packet served, end to end delay and number of busy cycles etc.

The objectives of the work is to explore a new dimension in order to optimism the battery power utilization and enhance the network lifetime of mobile ad-hoc network over the existing techniques namely AODV (Adhoc On demand Distance Vector), DSR (Dynamic Source Routing) and ZRP (Zone Routing Protocol) protocols. The other objective is to analyze the network theoretically and its experimental verification using certain network parameters.

The organization of this chapter is as follows. The Section 3.2 provides a detailed summary of related work and motivation of efficient energy based routing protocols in adhoc network. Section 3.3, we provide the proposed algorithm, battery's phenomenon and behavior with the mobile devise, examine the theoretical network model with discharge profile, battery preliminaries with varying load. The section 3.4 explains the experimental result and discussion in terms of as number of packet served, end to end delay in both rigorous and non-rigorous services in the network and in section 3.5, conclusion is provided of entire work along with future work.

3.2. Related Work and Motivation

Many researchers has addressed this problem by employing various techniques in preceding years. This work can be categorized under following subsections.

3.2.1. Power Oriented Scheme

Routing is one of the pivot solution to reduce the energy consumption and this problem has been addressed by many scholars and evolved many effective, efficient and optimized ideas in this area. The mechanism proposed in [38, 107] was based on power consumption and battery power remaining in nodes. And optimal path was traced out by flooding two time of a packet before any transmission. The algorithm proposed in [26] was based on the behavior of battery before performing on routing path. Further formulated light weight computational battery model and also determined the fatigue batteries for recovery of routing path in mobile adhoc network. work [28] proposed an model to determine the reliability of any model. The algorithm proposed [29] cross-layer energy efficiency model for mobile sensor network which consider three layers in mechanism to reduce the energy consumption in network. The mechanism proposed in [32] used the strategy to cut shot the wastage of energy in transmission of packets. The algorithm proposed in [33] gave general framework for mobile adhoc network and evaluated the energy efficiency of a class of multiple access schemes. In [34] proposed an model to construct a dominating tree which work as backbone in the transmission of packets using minimum amount of energy. The work proposed in [35, 39] was focused on designing protocol and algorithm based on physical layer driven approach which consume the less energy in network and taking care of hardware model of wireless system. The method proposed in [23, 24, 71], where harvesting of energy of nodes was employed using the RF signals of transmitters. The work proposed in [46] was focused on method that used network coding mechanism which reduced the energy consumption in packet transmission.In work [47, 52] proposed a new MAC protocols which saves power for a single hop mobile adhoc network by allowing the host to sleep for more multiple interval. In [48] author determined a cost metric based on power which was based on node liftetime and distance. In work [49] authors proposed a mechanism based on position and energy consumption by each node which made balance between these two parameters using two metrics. The method in [50] proposed an energy-efficient routing protocol based on localization and Tracking system, with precise tracking of target.In [51] author proposed an algorithm to reduce the energy consumption while decreasing the packet loss of wireless sensor networks. In work [53] studied in MAC sublayer and proposed a new MAC protocol to reduce the consumption of energy. The method proposed in [54] work is based on dynamic connectivity factor of neighbor without the intervention of administrator and prepared connectivity metric. This routing protocol probed dynamically the status of network without the interaction of user.

3.2.2. Cluster Based Approach

In works [22, 25] proposed the green routing protocol to reduce the routing overhead by utilizing the fixed clustering head and reducing the number of cluster head changes in network. In [24] author proposed self organization based clustering scheme using zero based group mobility [60]. In work [27] the authors proposed a mechanism named as hybrid energy-efficient distributed clustering algorithm. This algorithm chooses cluster head on on the basis of residual energy and node proximity.

In [36] author proposed an algorithm based on regional energy clustering mechanism utilizing an isolated nodes method. It gave cost based on power at every node level in adhoc network. In [55] author proposed an mathematical formulation of routing protocol which taken into consideration many constraints like link error, node failure and packet lost and optimized the energy function of the network. In work [56] proposed ant colony optimization algorithm using 2 strategies to reduce the overhead in transmission by predicting mobility of node and formation of cluster. The method proposed in [61] proposes a scheme which consist of two sub algorithms clustering and routing phase using harmony search to improve the energy efficiency for wireless networks. In [62] author proposed single-path and multi-path quality of services aware routing algorithms under harsh environmental conditions to compute their service differentiation capabilities in reliability and timeliness domains. In work [63] review the key issues in the emerging technology of mobile adhoc networks like Smart Dust the possible solution to these issues. The method proposed in [64] was based on two schemes, in first scheme ad hoc network was made with one cluster head and other nodes are member of it. In second scheme one cluster heads and it associate members. In work [65] author proposed multi-objectives particle swarm optimization (MOPSO) algorithm and found out the multi-objectives solution to optimize the number of clusters in an ad hoc network as well as energy dissipation in nodes in order to provide an energy-efficient solution and also reduce the network traffic [66].

3.2.3. Optimal Route Approach

The method proposed in [23] was using a fitness function to find the optimal between two nodes say source and destination to reduce the consumption of battery power in network.In [30] author proposed an algorithm in which limited number of nodes participate in the transmission of packets in network using back off technique, which reduces not only the energy consumption but also the traffic in substantial amount. The method proposed in [31] which modified DSR (Dynamic Search Algorithm) and select the selfish nodes in order to choose the optimal path to reduce the power consumption of the network. The method proposed in [37] the devices which consume the low energy in order to achieve the higher network lifetime of the system. In [40] author proposed an algorithm Optimal Path Selection Model which finds routes that are having higher power ratio links and link duration so number nodes failure do not make the wastage of energy. The method proposed in [41] identify the transmission which amounted to energy efficient routing and enhance the network life, end-to-end packet delay and increase the packet delivery ratio. In work [42] determine the performance of multipath routing in VANETs using node-disjoint and also observe the the effect of mutual interference on the behavior of node-disjoint paths.

The method proposed in [45] selects a high delivery rate of packet path or path that has a high transmission bandwidth that can reduce transmission distance which further leads to less power consumption. In [57] a decentralized self-organized relay selection algorithm is proposed based on a stochastic learning approach where each player evolves toward a

strategic equilibrium state in the sense of Nash. In [58] author proposed an scheme which was based k-hop scalability and quality of services topology management for large scale network in Mobile Ad Hoc Networks. In work [59] proposed a scheme called a delay aware routing method that combines mobile automata with the genetic algorithm used to select a group of routes that complied with constraints for delay and then select a reasonably best one using genetic algorithm.
The many concepts of wireless and their fundamental experiments have been discussed in [108] by many eminent authors .

Motivation

After such vast literature survey, it is found that the technique of efficient energy using multiple battery needs to be addressed for mobile adhoc network as very small work have been carried out in last two decades.The work published which is carried out mostly based on clustering in network, optimal path routing, optimization of power consumption merely based on obtaining minimum distance transmission of packets or reducing the energy in transmissions while decreasing the number of failure transmission or reduction in retransmission after finding less crowded path etc. The above work does not cover up enough dimensions in order to give complete thrust in this domain. So far the battery characteristics such as synchronization of back off time of node with battery relaxation has not been taken up in the network. The work in this dimension has made an attempt to come up with a construct step toward the optimal battery utilization in order to achieve the network lifetime and enhance the network service at the large. The novelty of this work lies in its theoretical model along with the experimental demonstration in the form of simulation of the entire scheme.

3.3. Proposed Algorithm -BORS (Backoff Relaxation Synchronous Scheme)

The proposed algorithm BORS is an amalgamation of two scheme that is recoiled off technique routing with relaxation time of battery (namely rigorous service with relaxation,non-rigorous service with relaxation and multi-battery system). Each case has been described in subsequent section under below in detail. The battery preliminaries are also described in the following section of the algorithm.

This algorithm uses the battery characteristics, which considers single and dual battery model, which optimized battery utilization to achieve network lifetime and enhance the network service. It can be further extended for multiple batteries also.

3.3.1. Recoiled off Technique or Back off technique

Under this technique, instead of all the nodes in ad-hoc network need not to serve the packets to their neighbor, only eligible nodes participate in the transmission process. And the eligibility is a function of node's geographical position and the other parameters of ellipse shape (figure (2.3a)). The nodes those are inside this ellipse kind figure are the qualified criterion for the transmission. And these nodes get different values of recoiled off time means instead of all the qualified nodes transmit together only few of them will do so. The remaining qualified nodes wait for their assigned recoiled time to elapse, if transmission if failed in the mentioned time interval. In (figure (2.3a)) , assuming all are eligible nodes hence, they have given the recoiled off time as per function value. The node A and node E get the higher value of recoiled time due their geographical position. Hence, nodes B and C participate in first phase and node A and node E wait for their expiry of recoiled off time (served the packets to their neighbors if transmission is failed by the nodes B and C) [30].

The Computation of Recoil off time to any arbitrary node can be determined as shown in figures of previous chapter (refer to figure(2.3b), figure (2.3c) and figure (2.3d))

The parameters setting in simulation of algorithm traffic type, transmission range, protocol standard, initial energy of node, queue size and node speed etc are shown in table (3.1). The parameters related to the structure of leaf, arbitrary point P (a node), source to destination line, upper bound, lower bound of recoiled off time and other notation have placed in table (3.2). In algorithm 4, all the nodes inside the leaf need not transmit the packet. Instead, few of them behave like recoil node (suspend the transmission). Further the nodes whose recoiled off time is expired, serves the packet to their neighbor.

Table 3.1. Parameter setting in simulation

Parameter	**Value**	**Unit**
Number of nodes	200	-
Traffic type	CBR	-
Area Size	1400×1400	$Meter^2$
Mobility Model	RWP	-
Transmission range	500	Meter
Packet size	64	Bytes
Routing Protocols	AODV based BORS	Protocol
Node speed	7.5 and 10	Meter/Sec
Simulation Time	500	Sec
Initial energy	75	Joules
Queue size	50	Packets

Table 3.2. parameters in leaf routing

Parameter	**Symbol**
Width of leaf	w
Lower bound recoiled off time	t_{lb}
Recoiled off time	t_{off}
Upper bound recoiled off time	t_{ub}
Perpendicular distance	δd
Source to destination line	SD
Location of arbitrary point P	(x_p, y_p)

Algorithm 4: Recoiled off routing protocol

Initialization

Nloc ← Node initial value ;

Dloc ← Destination location value;

Pid ← Packet Id;

PAR ← Pitch Adjusting Ratio;

W ← Width initial Value;

pkt← Packet data value;

if (Nloc==Dloc) **then**

  Check Transmission

  successful → yes then quit;

else if (InsideLeaf(Nloc,Pid)) **then**

  Check for packet already sent

else if (pidList[ ]==pid) **then**

  Drop the Packet and quit;

else

  pidList[x++]=pid;

  recoil=CoordinatedTime();

  WBuff[y++]=pkt;

end if

The algorithm for Coordinated time function called above is computed as per the following algorithm 5.

3.3.2. Multiple batteries in device

One of the three scenarios (viz. Rigorous service with relaxation, Non-rigorous service with relaxation and System driven by multi-battery) is multi-batteries driven device based node network. The dual battery system has been taken into consideration. The algorithm has been implemented in NS-2 simulator for mobile ad-hoc network [111]. After creating and setting the basic requirements in NS2, all instance variable and procedures have been defined. The parameters like type of antenna, the radio-propagation model and ad-hoc routing protocol are also used by mobile nodes etc.

3.3.2.1. *Battery Preliminaries.* Modeling the behavior of batteries is not an easy task as it has nonlinear outcome during discharge [113]. The voltage remains constant during discharge in ideal case and instantaneously drop to null when the battery is fully drained as shown in figure (refer figure (3.1)). All energy stored in battery would be used for the transmission of packets and ideal capacity remains constant for all discharge currents [114].

Algorithm 5: Coordinated determination of recoiled off time

Initialization

SDloc[ ] ← co-ordinates of SD line initial value

Nloc ← coordinates of current node initial value

eloc← some error point initial value

if ((Nloc + eloc ==SDloc) || (Nloc - eloc ==SDloc)) **then**

  Transmit pkt;

else

  Recoil=coordinatedTime(ms);

end if

But in practical, the voltage gradually drops during the discharge of battery. The discharge current and effective capacity are inversely proportional to each others. Figure (3.2) expresses the battery's available and unavailable charges with respect to time is called battery relaxation effect.

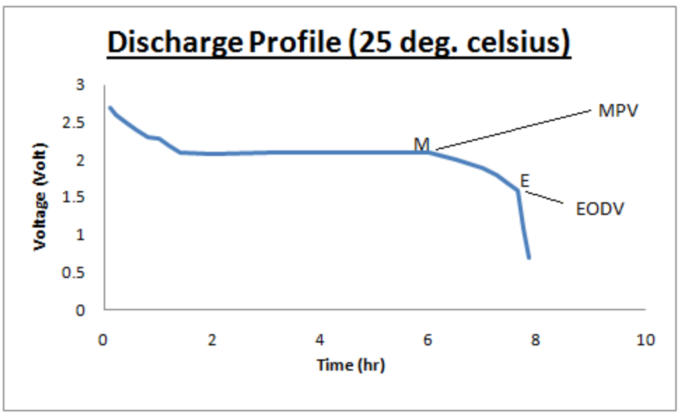


FIGURE 3.1. Discharge profile (potential Vs time)

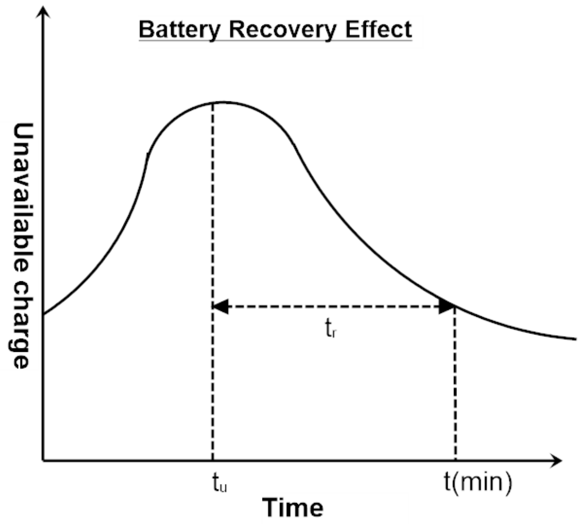


FIGURE 3.2. Battery relaxation effect (t_u : time at maximum unavailable charge)

The limited power resource in terms of battery needs to be judiciously utilization of this resource leads to improvement in entire network performance. The packet transmission and other various services (eg. sensing network) require some power. The output voltage of battery varies as its charge is changed i.e it varies when it charges or discharges with time (trend is shown in figure (3.1)) [50]. The middle point voltage (MPV) point M, is the average voltage use to measure the existing charge where as end discharge voltage (EODV) point E, is refers as the end of life for a battery. After this point E battery rapidly starts discharging and it potential difference fall down below E. On the other hand the MPV is the nominal voltage of the cell, and is the voltage that is measured when the battery has discharged 50 % of its total energy. And EODV is determined when battery is about to discharge completely.

The unavailable charges increases with the number of busy cycles (packet transmission period) and furthermore, if battery works continuously the available charge decreases whereas the unavailable charges increases with the adaptive principle.Moreover, part of this unavailable charges get convert into available one (called recovery of charges under relaxation) when an idle cycle is inserted between two consecutive busy cycles during the two adjacent tasks (refer to figure (3.2)) [50] . Hence, the insertion of idle cycle(s) between the busy cycles become inevitable in order to improve the quantity of available charge as this quantity is directly proportional to network lifetime of mobile ad hoc network.

Let be assume a(t) is available charge, u(t) represents the unavailable charge and l(t) expresses the lost charge in the battery. The packet transmission load at battery at different time slots is expressed by a sequence J_1, J_2, J_3, ..., J_M and the load at time t_k requires time to complete in time $\Delta_t = t_{k+1} - t_k$. Hence, the total consumption battery charges $\Omega(t)$ in terms of these parameters can be represented as

(3.1) $$\Omega(t) = l(t) + u(t)$$

(3.2) $$\Omega(t) = \underbrace{\sum_{k=1}^{M} J_k \Delta_k}_{l(t)} + \underbrace{\sum_{k=1}^{M} 2J_k \sum_{l=1}^{\infty} \frac{e^{-\gamma 2m^2 t}(e^{\gamma 2m^2 \Delta}{}_k - 1)}{\gamma^2 m^2} e^{\gamma 2m^2 t_k}}_{u(t)}$$

Proof :-. The inherit electrochemical property of battery in terms of diffusion and concentration of electrolyte can be given by two Fick's laws. And the concentration behavior in case of 1-dimension diffusion can be represented by following relations [111]

(3.2a) $$-R(x,t) = D\frac{\partial C(x,t)}{\partial x}$$

(3.2b) $$\frac{\partial C(x,t)}{\partial t} = D\frac{\partial^2 C(x,t)}{\partial x^2}$$

In equation 3.2a, R(x,t) denotes the flux of species at distance x at time t and D represents the diffusion coefficient.

According to Faraday's law, the flux at electrode surface (x=0) is directly proportional to the current at time t, i.e. j(t). Assume F be the Faraday's constant and area of electrode surface is A. Hence, the diffusion at electrode surface and at other boundary of diffusion (x=w) can be expressed as :

(3.2c) $$-R(x,t) = \frac{j(t)}{\nu F A} = D\frac{\partial C(x,t)}{\partial x}; \qquad at \;\; x = 0$$

$$0 = D\frac{\partial C(x,t)}{\partial x}; \qquad at \;\; x = w \tag{3.2d}$$

The solution of above pair of partial differential equations (at x=0 and x=w) is given by following equation

$$\kappa(t) = \frac{1}{FAwC}\left[\int_0^t j(\tau)d\tau + \lim_{x\to 0^+}\sum_{n=1}^{\infty}\int_0^{t-E} j(\tau)e^{-\frac{\pi^2 D(t-\tau)m^2}{w^2}}d\tau\right] \tag{3.2e}$$

$$\kappa(L).\nu FAwC^* = \int_0^L j(\tau)d\tau + \lim_{\epsilon\to 0^+}\sum_{n=1}^{\infty}\int_0^{L-E} j(\tau)e^{-\frac{\pi^2 D(L-\tau)m^2}{w^2}}d\tau \tag{3.2f}$$

$$u(t) = \int_0^L j(\tau)d\tau + \lim_{\epsilon\to 0^+}\sum_{n=1}^{\infty}\int_0^{L-E} j(\tau)e^{-\frac{\pi^2 D(L-\tau)m^2}{w^2}}d\tau \tag{3.2g}$$

Equation (3.2f), assume $\beta = \pi\ \frac{\sqrt{D}}{w}$, C^* is initial concentration of battery and L is time when reaction at electrode no longer take place. And $u(t) = \kappa(L)\nu FAwC^*$.

The step function has to be taken into consideration in computation of unavailable charge as we know the battery in any device has variable load, hence, the variable load can be written in terms of step function $U(t)$ with variable load $j(t)$ in interval [0,t] as

$$j(t) \approx \sum_{k=1}^{n} J_k\Big[U(t-t_k) - U(t-t_{k+1})\Big] \tag{3.2h}$$

Substituting the value of $j(t)$ in equation (3.2g) and integrating the sum term by term, we get

$$u(t) = \sum_{k=1}^{n} 2J_k \sum_{l=1}^{\infty} \frac{e^{-\gamma 2m^2 t}(e^{\gamma 2m^2 \Delta}{}_k - 1)}{\gamma^2 m^2} e^{\gamma 2m^2 t_k} \tag{3.2i}$$

Refer to equation (3.2i) and figure 3.2 show battery relaxation effect which includes the unavailable charges with respect to time and part of it changed into available charges as inserted the idle period (relaxation). Furthermore, it is determined in subsequent section.

Moreover, the focus of this algorithm is on the routing scheme and its synchronization with relaxation of battery in order to acquire the higher battery usability in terms of network lifetime of ad-hoc network. This proposed algorithm does not bother processing inside processor, digital signal processing, power in chip, heat dissipation etc. In order to achieve the outstanding performance of battery, the relaxation phenomenon in battery is employed. There are two scenarios i) Battery lifetime enhance due to idle time existing with it. ii) Give relaxation to battery (server) intentionally before taking next busy cycle just after serving all pending packets in queue called rigorous service cum relaxation model. And its opposite is named as non-rigorous service cum relaxation model, where the server relax within busy period (cycle is the time takes in between one relaxation phase and one serving phase). The quantity of nodes serve would be directly proportional to the charge left at end of the first busy cycle. In order to compute the predicted number of cycles possible in battery till it goes to empty can be expressed as below :

$$Y_i = Z_i - A_i \tag{3.3}$$

where A_i is the charge drawn on in busy cycle and Z_i amount of charge add on due having idle cycle in i^{th} cycle. Hence, the charge gained or lost would be in defined by the value of A_i and Z_i in the i^{th} cycle. If $A_i > Z_i$ then charge lost else gained.Suppose ϕ represents the predicted number of cycles before battery goes to null and quantity of charge available at the end of initial busy cycle is expressed by random variable say y, then ϕ can be computed as :

$$\phi = inf\{n : \sum_{i=1}^{n} Y_i \leq -y\} \tag{3.4}$$

The predicted number of cycles possible after the initial busy cycle is expressed by $F_y[\phi]$ and can be determined by equation (3.5). If battery is completely discharged in first busy cycle itself, this condition is taken care in subsequently.

$$F_y[\phi] = P[Y_1 \leq -y] + \int_{-y}^{N-y} (1 + F_{Y_1}[\phi]).dE_{Y_1}(Y_1) \tag{3.5}$$

Where, $dE_{Y_1}(Y_1)$ represents the cumulative density function of Y_i. In above equation the first term corresponds to condition where battery gets discharged in first busy cycle and second term is taken care the charge remaining.

$$= P[Y_1 \leq N - y] + \int_{-y}^{N-y} F_{Y_1}[\phi].dE_{Y_1}(Y_1) = 1 + \int_{-y}^{N-y} F_{Y_1}[\phi].dE_{Y_1}(Y_1) \tag{3.6}$$

The distribution of Z_i and A_i helps in obtaining the distribution of Y_i. Let T_i be the idle time span of i^{th} cycle and y' represents the charge remaining at starting of i^{th} cycle. Hence, the distribution of Z_i can be determined as :

$$Z_i = min(r_k T_i, N - y') \tag{3.7}$$

and

$$E_{z_i}(z) = \begin{cases} E_{T_i}(z/r_k), & z \leq N - y' \\ 1, & z > N - y' \end{cases} \tag{3.8}$$

Where y' is charged threshold values which determines $k\varepsilon[1, 2..., P+1]$ as T_i is distributed as $\exp(\mu)$ and the cumulative density function is expressed by :

$$E_{z_i}(z) = \begin{cases} 1 - e^{-\lambda z'}, & z \leq N - y' \\ 1, & z > N - y' \end{cases} \tag{3.9}$$

Where $z'=\frac{z}{rk}$ and distribution of Z_i is based on y'.

Now, it is easy to show a general recharging function that can be added, for an example let be $r(y(t))$ be the recharge slope in the battery when charge remaining in battery is y, then distribution of Z_i is again given by above equation. But the z and z' are related by the following relation. Suppose $y(t)$ be the solution of differential equation:

$$\frac{dy(t)}{dt} = r(y(t)).XY(0) = Y'then \quad z = y(z')$$

It is not easy to determine the distribution of A_i for a queue, hence, it is better to limit the computation up to exponential times with rate λ.

$$D_{B_i}(b) = \frac{G_1(2b\sqrt{\mu\lambda})}{b\sqrt{\eta}}.e^{-b(\mu+\lambda)} \qquad where \quad \eta = \frac{\mu}{\lambda} \tag{3.10}$$

Where $G_1(.)$ is the first order Bessel function and $\eta = \frac{\mu}{\lambda}$. The cumulative density function of Y_i, $E_{Y_1}(y_1)$ is expressed as :

$$E_{Y_1}(y_1) = \int_{max(0,y_1)}^{\infty} F_{Z_1}(y_1 + b) D_{B_1}(b) \; db$$

it can be further split as

$$E_{Y_1}(y_1) = \int_{max(0,y_1)}^{(N-y-y_1)} F_{Z_1}(y_1+b)D_{B_1}(b)\ \ db + (N-y-y_1)^{\infty} D_{B_1}(b)\ \ db \tag{3.11}$$

The equation (3.12) can be rewritten after the numerical solution as under :

$$F[\phi] = \int_0^N F_{N-y}[\phi]\ \ dF_{B_0}(y) \tag{3.12}$$

F_{B_0}, the first order busy cycle distribution . The predicted number of customers can be served during the busy cycle with the predict number of cycles is expressed as

$$C = (1 + F[\phi])\frac{1}{1-\mu} \tag{3.13}$$

λT, be the upper bound of theoretical battery capacity in order to serve the customers and average delay in packets arrival can be written as under

$$\bar{U} = \frac{\mu}{\lambda^2(1-\eta)} \tag{3.14}$$

The general service time computation is quit possible of a queue but it is little tough to estimate. For an example, the Laplace transform of service period A_i can be determined as $F[e^{sA_i}]$ and the Laplace transform [109] and [110] can be obtained for Y_i similarly

3.3.3. Generalized Solution to Problem

The three scenarios have been taken into consideration to formulate the comprehensive situation of this problem. These are i) Rigorous Service with Relaxation, ii) Non-rigorous Service with Relaxation and, iii) System driven by multi-battery. Take details one by one as :

3.3.3.1. *Rigorous Service with Relaxation.* One of the ways to increase the life of battery is to take relaxation purposely. Under scheme one of this scenarios is considered where takes the relaxation as soon as complete the service to packets in the queue.Moreover, after a slot relaxation, if queue does not have any packet to be served then go for new slot of relaxation and so on. The slot of relaxation is determined by the system parameter exp(α). It is given as (refer equation (3.15))

$$D_B(b) = \frac{4(\mu+\alpha)\sqrt{\mu\lambda\alpha}}{\mu}.\frac{e^{-b(\mu+\lambda)}}{\sqrt{b}}.\int_0^{\infty} \frac{e^{-2u(\mu+\alpha)}I_1(2\sqrt{\mu\lambda(2u+b)})}{\sqrt{(2u+b)}}\ \ du \tag{3.15}$$

The average delay of the system along with relaxation can be rewritten as under (refer to equation (3.16))

$$\bar{U} = \frac{\mu}{\lambda^2(1-\eta)} + \frac{1}{\alpha} \tag{3.16}$$

Algorithm 6: Rigorous service with relaxation

```
Begin
initialization
var
ac: available charge of battery
uc: unavailable charge of battery
tc: total charge of battery
queue: queue of packets to be transferred
b: battery to process packets of queue
tc=ac+uc
repeat
  while (queue !=NULL) do
    ProcessQueue(b) ;
    ac=ac-1 ;
    uc=uc+1 ;
  relax(b) ;
  ac=ac+1 ;
  uc=uc-1 ;
  tc=ac+uc ;
until (tc)
End begin
```

Algorithm.

3.3.3.2. *Non-rigorous Service with Relaxation.* In order to enhance the battery life for improved network lifetime of ad-hoc network, interrupt all services (if possible) during busy cycle and give permission to battery for relaxation. This occurs in every K packets are served (extracted from queue) in network by a device. The α and K become the deterministic parameters for allocating the value of this relaxation time period.

$$D_{A_1}(b) = \frac{\lambda^K b^{(K-1)} e^{-\lambda b}}{(K-1)!} \tag{3.17}$$

$$S = \frac{KF[\phi]}{\lambda} \tag{3.18}$$

The number of packet served S, in allocated time is given by equation (3.18). And $F[\phi]$ represents the number of predicted cycles before battery gets discharge to zero.

Algorithm 7: Non-rigorous service with relaxation

Begin

initialization

var

ac: available charge of battery

uc: unavailable charge of battery

tc: total charge of battery

queue: queue of packets to be transferred

b: battery to process packets of queue

repeat

if (ac>0) **then**

while *(ac)* **do**

ProcessQueue(b) ;

ac=ac-1 ;

uc=uc+1 ;

else

while *(uc)* **do**

relax(b)

ac=ac+1

uc=uc-1

end if

tc=ac+uc ;

until (tc)

End begin

3.3.3.3. *System driven by multi-battery.* Consider dual battery driven adhoc network, which works on natural relaxation based phenomenon, when one battery serves the packets to it neighbor, other battery gets idle period to rejuvenate itself and improves the battery life. Let there be a packet to be served by battery one with probability p and by battery with (1-p) probability. It is important to adapt a scheduling scheme in order to get improved battery life. The predicted number of cycles and number of packets to be served until one of the batteries get empty. Here the analysis has been taken place under following points :

1. Computation of the distribution of charge in both batteries after the completion of first busy cycle.
2. Prediction of cycles after the completion of first busy cycle till the battery gets empty.
3. Determine the possible number of packets served under the condition 2(above).
4. Calculation of possible number of packets served by the second battery by using its remaining charge as first battery has already finished its charge. Now battery system work as single battery device where no relaxation is allowed.

All these above is computing as below :

Assumes n packets need to be served and k packets are served by battery one in busy cycle then (n-k) packets would be transmitted by battery two.

A cumulative density function of busy period of the first busy cycle can be expressed as by equation (3.19) and the first battery served k out of n packets during its busy schedule, it is expressed in terms of probability as :

$$P(T_{1b} \le t) = Pr\left(\sum_{i=1}^{k} C_i \le t\right) \tag{3.19}$$

The probability to serve n packets during the busy schedule can be denoted by the following equation (3.20)

$$P(X = n) = \frac{1}{n}\binom{2n-2}{n-1}\eta^{(n-1)}(1+\eta)^{(1-2n)} \tag{3.20}$$

Where $\eta = \frac{\mu}{\lambda}$ and now equation (3.20) can be rewritten as

$$P(T_{1b} \le t) = \sum_{n=1}^{N}\sum_{k=1}^{n} Pr\left(\sum_{j=1}^{k} C_i \le t \mid k\, packets\ have\ been\ served\ by\ first\ battery.\right)$$

Further the value is replaced by equation and obtained as

$$P(T_{1b} \le t) = \sum_{n=1}^{N}\sum_{k=1}^{n} Pr\left(\sum_{i=1}^{k} C_i \le t\right)\frac{1}{n}\binom{2n-2}{n-1}$$

$$\eta^{(n-1)}(1+\eta)^{(1-2n)}\binom{n}{k}p^k(1-p)^{(n-k)} \tag{3.21}$$

The probability density function of busy cycle can be expressed again by equation (3.22) in terms of Erlang distribution $[d_s(t)]$ as

$$D_{T_{1b}}(t) = \sum_{n=1}^{N}\sum_{k=1}^{n}\frac{1}{n}\binom{2n-2}{n-1}\eta^{(n-1)}(1+\eta)^{(1-2n)}\binom{n}{k}p^k(1-p)^{(n-k)}.d_s(t) \tag{3.22}$$

Where the Erlang distribution is represented by

$$d_s(t) = \frac{\lambda(\lambda t)^{(k-1)}e^{-\lambda t}}{(k-1)!}$$

The cumulative density function and probabilistic density function for second battery are similarly computed by the following equations

$$P(T_{2b} \le t) = \sum_{n=1}^{N}\sum_{k=1}^{n} Pr\left(\sum_{i=1}^{n-k} C_i \le t\right)\frac{1}{n}\binom{2n-2}{n-1}\eta^{(n-1)}$$

$$(1+\eta)^{(1-2n)}\binom{n}{n-k}p^k(1-p)^{(n-k)} \tag{3.23}$$

$$D_{T_{2b}}(t) = \sum_{n=1}^{N}\sum_{k=1}^{n}\frac{1}{n}\binom{2n-2}{n-1}\binom{n}{n-k}\left(\frac{\mu+\lambda}{\mu}\right)$$

$$\left(\frac{\eta(1-p)}{(1+\mu)^2}\right)^n\left(\frac{p}{1-p}\right)^k\left(\frac{\lambda(\lambda t)^{(n-k-1)}e^{-\lambda t}}{(n-k-1)!}\right) \tag{3.24}$$

The idle period distribution of first battery out of two batteries would be (i) idle period of battery first which is available (free time of first battery) and busy period of second battery. (ii) Similarly the idle period for second battery would be existing free time of second battery and service time of first battery. Further the probabilistic density function can be represented as :

$$D_{T_{1i}}(t) = D_{T_{2b}}(t) * D_{T_i}(t) \tag{3.25}$$

where D_{T_i}(t)= $\mu e^{-\mu t}$ and the value of transform domain

$$D_{T_{1i}}(s) = D_{T_{2b}}(s) * D_{T_i}(s) \tag{3.26}$$

where $D_{T_{1b}}(\text{s})$ and $D_{T_{2b}}(s)$ are expressed by

$$D_{T_{1i}}(s) = \frac{\mu}{(s+\mu)}$$

(3.27)

$$D_{T_{2b}}(s) = \sum_{n=1}^{N}\sum_{k=1}^{n}\frac{1}{n}\binom{2n-2}{n-1}\binom{n}{n-k}\left(\frac{\mu+\lambda}{\mu}\right)\left(\frac{\eta(1-p)}{(1+\mu)^2}\right)^n\left(\frac{p}{1-p}\right)^k\left(\frac{\lambda}{s+\lambda}\right)^{n-k}$$

The Laplace transformation can be computed as below (refer equation (3.28))

$$\frac{\mu}{(s+\mu)}\left(\frac{\lambda}{s+\lambda}\right)^{n-k} = \frac{e^{-\mu t}\lambda^{n-k}(\lambda-\mu)^{-(n-k)}}{\Gamma(n-k)}.\frac{\mu(\Gamma(n-k)-\Gamma(k,(\lambda-\mu)t))}{\Gamma(n-k)} \tag{3.28}$$

$$\begin{aligned} D_{T_{1i}}(t) &= \sum_{n=1}^{N}\sum_{k=1}^{n}\frac{1}{n}\binom{2n-2}{n-1}\binom{n}{n-k}\left(\frac{\mu+\lambda}{\mu}\right)\left(\frac{\eta(1-p)}{(1+\mu)^2}\right)^n\left(\frac{p}{1-p}\right)^k \\ &\left(\frac{e^{-\mu t}\lambda^{n-k}(\lambda-\mu)^{-(n-k)}\mu(\Gamma(n-k)-\Gamma(n-k,(\lambda-\mu)t))}{\Gamma(n-k)}\right) \end{aligned} \tag{3.29}$$

In same way the probabilistic density function of second battery in adhoc network can be expressed as (refer equation (3.30))

$$D_{T_{2i}}(t) = D_{T_{1b}}(t) * D_{T_i}(t) \tag{3.30}$$

This can further be expanded using fundamental variables as (equation (3.31))

$$\begin{aligned} D_{T_{1i}}(t) &= \sum_{n=1}^{N}\sum_{k=1}^{n}\frac{1}{n}\binom{2n-2}{n-1}\binom{n}{n-k}\left(\frac{\mu+\lambda}{\mu}\right)\left(\frac{\eta(1-p)}{(1+\mu)^2}\right)^n\left(\frac{p}{1-p}\right)^k \\ &\left(\frac{e^{-\mu t}\lambda^{k}(\lambda-\mu)^{-k}\mu(\Gamma(k)-\Gamma(k,(\lambda-\mu)t))}{\Gamma(k)}\right) \end{aligned} \tag{3.31}$$

The number of packets to be transmitted by the multiple battery is directly proportional to the number of actual cycles that have been performed by the battery. The predicted (expected) number of cycles for a battery before expires can be computed based on random variable ϕ , which represents the number of predicted cycles before going to complete discharge of a battery. Let ϕ_1 and ϕ_2 be the random variables denoting the predicted cycles before diminishing the battery first and second of a packet serving device in network. The average number of packets transmitted or received by a node before one of the two batteries get discharge, can be expressed by equation (3.32)

$$S_1 = (1+x)\frac{p}{(1-\eta)} + (1+x)\frac{1-p}{(1-\eta)} = (1+x)\frac{1}{(1-\eta)} \tag{3.32}$$

Let i and j are the suffixes to represent the batteries. These two suffixes are complement to each other. The remaining charge of battery can be determine by equation (3.33)

$$x = \int_0^{N_1} C_{N_1 - Y_{\bar{j}}}[\phi] \; dF_{T_{\bar{j}b}}(y_{\bar{j}}) \tag{3.33}$$

Once a battery is exhausted, the other battery has to serve the packet without any relaxation. The charge available in other battery $N - N_1$ contributes in the number of cycles until the whole battery discharged. After the other battery discharge it works as single operated battery device. The number of cycles can be calculated in $N-N_1$ available charge as (refer equation (3.34))

$$C[\phi] = \int_0^{N-N_1} C_{N-N_1-Y}[\phi] \; dF_{T_b}(y) \tag{3.34}$$

Here $F_{T_b}(y)$ denotes the probabilistic density function under busy period of single battery as one battery is discharged before. The number of packets served, S_2 can be evaluated by using the earlier equation in previous section. Hence, the predicted number of packets served can be determined as $S = S_1 + S_2$ till the both two batteries have discharged completely.

Algorithm.

3.4. Results and Discussion

Three routing protocols (AODV, DSR and ZRP) have been considered in order to compare with proposed routing scheme. In figure (3.3) to figure (3.9) the parameters used are set in NS-2 simulator (e.g. the parameter end to end delay is calculated while keeping transmission time stamp of each hop directly stored in the data packet inside and time at each hop for every received packet whereas for the number packets served by a node has been taken care sequence number available in the packet format). The packets are queued and calculated the delay of packet in queue (in case of rigorous with relaxation scheme, battery takes relaxation just after the serving all the packets available in queue,

Algorithm 8: Packet traithnsmission with multiple battery node (dual battery)

Result: Battery coversion from unavailable to available charge completed

Input: Var initialization

$x \leftarrow$ Available charge of battery;

$uc \leftarrow$ Unavailable charge of battery;

$tc \leftarrow$ Total charge of battery ;

$queue \leftarrow$ Queue of packets to be transferred;

$b_1, b_2 \leftarrow$ Two Batteries to process packet of queue;

$battery \leftarrow b_1$;

while *(queue!=Null)* **do**

    if $(b_1.tc > 0)$ **then**

        ProcessQueue(battery) ;

        $x = x - 1$;

        $uc = uc + 1$;

        Compute remaining charge (x) and Number of cycles

        $Compute(x)$;

        $Compute(C[\phi])$;

        $Transmit(packet)\ relax(b)$;

        $x = x + 1$;

        $uc = uc - 1$;

        $tc = x + uc$;

    else

        $swap(battery)$;

        RepeatAlgorithm

but in other case without caring of packets in queue, battery acquire relaxation slot as its scheduled time). The value parameter different arrival rate $'\lambda'$ has been obtained by setting various speed of packets using different scenarios. Figure (3.6) represents, number of packet served with battery scheduling probability. The value of P is obtained while switching the control from first battery to second battery and vice versa for the packets transmission while giving time slot to each battery as per the scheduling probability.

Hence, simulator behaves like single battery model when P= 0 or 1 (only one battery will serve the packets till drain out completely)and maximize the number of packets when both batteries get equal chance to serve the packet (i.e. case when P =0.5). In figure (3.9), one of the two parameter is number of busy cycles, which is taken into consideration in non-rigorous with relaxation scheme. The value of this parameter is computed with help of number of recoiled off time slot utilization by each node and number of queues served (by battery), which is incorporated in algorithm. And the other parameter relaxation time is kept fix for one scenario.

3.4.1. Number of Packets Served

This section demonstrates and analyzes the numerical results related to the number of packets transmitted. The parameters used in this analysis have been summarized below:
Parameter of transmission time $\lambda = 1$ (Single battery)
Number of charge units (capacity) = 100
Threshold values ω_1= 70, ω_2= 50, and ω_1= 20
Thresholds numbers L= 3
Slopes of recharge e_1= 0.5, e_2= 0.4, e_3= 0.3 and e_4= 0.2

Table 3.3. Packet served by various protocols at different packet arrival rate

BORS	**AODV**	**DSR**	**ZRP**
170	145	130	108
160	135	119	88
150	120	99	76
135	110	87	67

TABLE 3.4. Packet served case: non-rigorous service with relaxation

BORS	**AODV**	**DSR**	**ZRP**
290	270	248	235
145	124	103	93
132	110	91	85
125	102	83	80
120	98	75	74
115	93	70	65
113	90	68	61
111	87	61	57
108	86	60	55

The performance of ad hoc network under single battery driven devices is depicted by figure (3.3). Here, simulation [48] result in figure shows that the packets transferred by all four protocols viz BORS, AODV, DSR and ZRP at different arrival rate (μ). The proposed BORS algorithm performs better than all three as it utilizes synchronization of relaxation time with the recoiled off time. The BORS algorithm works 12%, 17%, and 19% better than welknown AODV, DSR and ZRP algorithms respectively as value shown in table (3.3) .

When we consider the dual battery (multi battery) system, it is found that the number of packet communicated more than twice of the single battery driven devices which can be seen in simulation results shown in figure (3.4). The figure shows that the number of packet served in non-rigorous service with relaxation at high rate of arrival and the value is tabulated in table (3.4). It is assumed the packets in queue are always available and needs to be served but waiting for the busy cycle of either of the batteries. The results in figure expresses the gained in terms of extra packet served in different protocols. It is observed that the proposed BORS algorithm gained 5%, 7% and 8% extra than the AODV, DSR and ZRP protocol. The improvement in performance is achieved because this technique (recoiled off nodes) uses the recoiled off time in consonance with battery relaxation time.

Figure (3.5) shows the number of packet served by all standard routing protocols and compares these value with existing algorithms in case of dual battery operated device in each node of the network. The experimental values are depicted in table (3.5).

TABLE 3.5. Packet served case:dual battery

BORS	**AODV**	**DSR**	**ZRP**
1500	412	1290	1210
1111	1010	890	840
870	760	680	611
741	650	551	501
610	511	441	401
521	411	301	240
411	314	242	210
391	281	212	207

Figure (3.6) expresses the number of packet served function with scheduling probability. For the value of P=0.5, algorithm maximizes their value. It is also observed that the value at P=0 is very much similar with the value at P=1 as system behave like single battery scheme. The experimental values are shown in table(3.6). It is because the curve is just inverse after the value P=0.5.

Figure (3.7) and figure (3.8), represent the relaxation of battery with average end to end delay of packets of proposed algorithm and its comparison with other algorithms. Figure (3.7) is drawn in rigorous scenario of battery whereas figure (3.8) focuses on non-rigorous service scenario. When we increase the relaxation time in algorithm, the delay in packet arrival is almost constant but after crossing a threshold value of relaxation time, delay starts increasing rapidly. In case of BORS algorithm the average delay is lesser than at least 10% (than AODV protocol). It is because of BORS considers and uses the other shorter path in the network.

Table 3.6. Packet served having scheduling probability (Case: dual battery)

BORS	**AODV**	**DSR**	**ZRP**
370	311	298	278
410	370	349	329
461	421	399	378
581	501	451	432
671	603	551	535
751	711	610	589
666	605	552	534
576	502	453	434
455	421	401	380
411	401	354	330
371	310	299	281

Figure (3.9), shows the simulation result of the relaxation time with possible number of busy cycles in battery for each algorithm. It can be seen that the number of busy cycles at beginning the value of busy cycle rising slowly but after a value it increases very fast then again does not change as faster as before. It is because of the characteristic of a battery called battery recovery effect. To be specific, each algorithm requires a fixed value of power for constant size of packet transmission to its neighbors in network. Hence, each algorithm differs in energy consumption and it can be figured out that BORS algorithm has highest number of busy cycles as compare with other considered algorithms as it has less power burning up in every service of packet transmission.

Parameter of transmission time $\lambda = 1$ and α (dual battery)

Number of charge units (capacity) per battery = 100

Threshold values ω_1= 70, ω_2= 50, and ω_1= 20

Thresholds numbers L= 3

Slopes of recharge e_1= 0.5, e_2= 0.4, e_3= 0.3 and e_4= 0.2

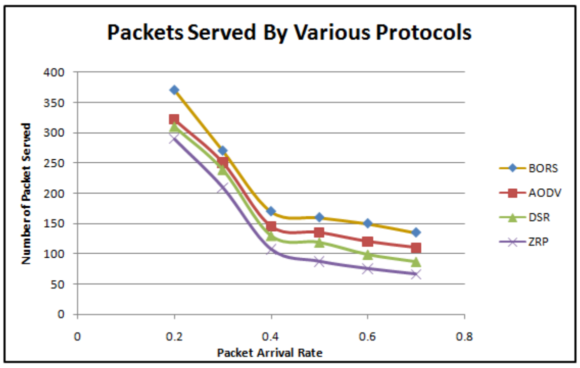


FIGURE 3.3. Packet served by various protocols in single battery based device

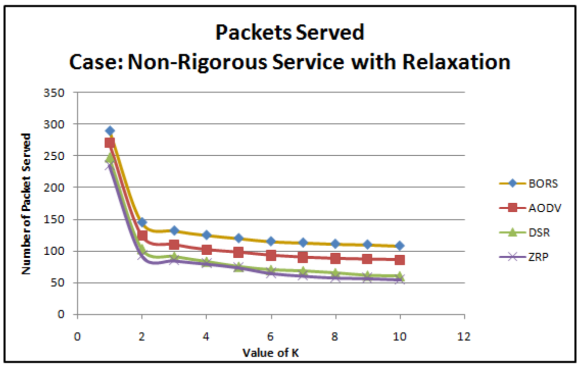


FIGURE 3.4. Packets served case: non-rigorous service with relaxation time (sec.)

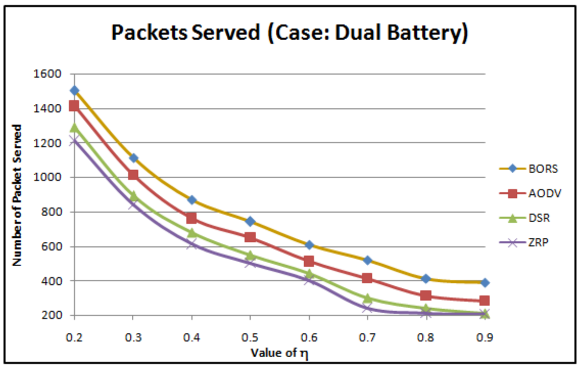


FIGURE 3.5. Packets served (case: dual battery)

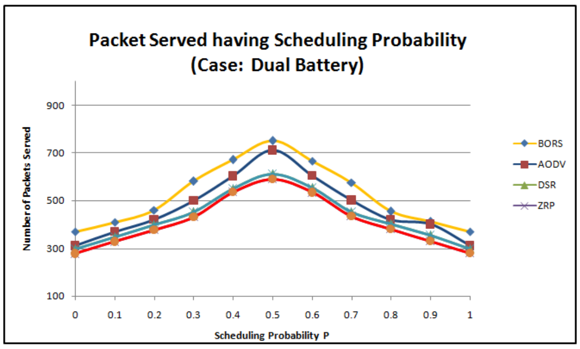


FIGURE 3.6. Packet served having scheduling probability (case: dual battery)

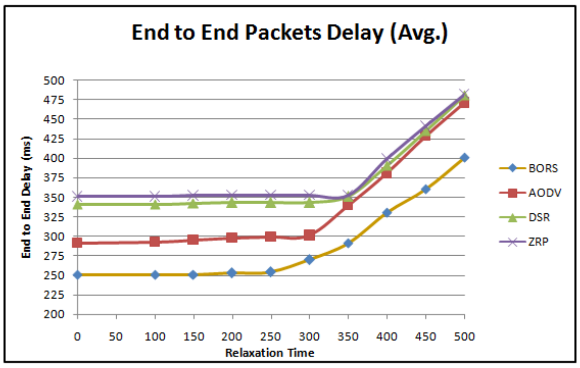


FIGURE 3.7. Rigorous service with relaxation time (sec.) Vs average end to end delay

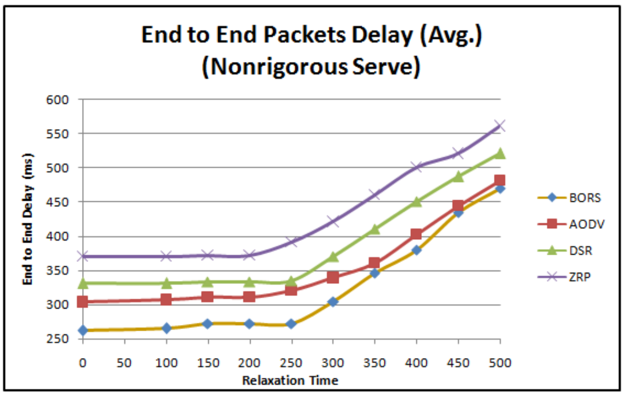


FIGURE 3.8. Non-rigorous service with relaxation (sec.) Vs average end to end delay

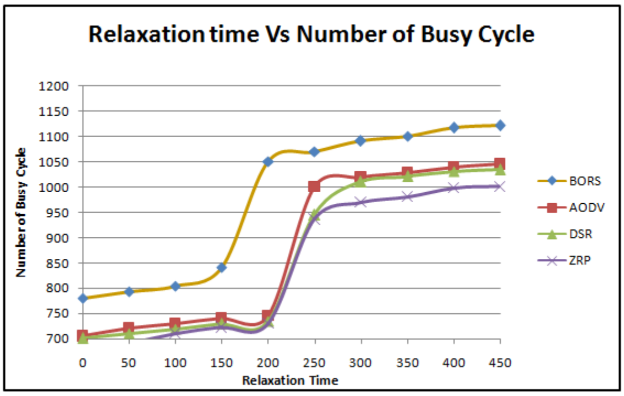


FIGURE 3.9. Relaxation time (sec.) Vs number of busy cycle

3.5. Conclusion and Future work

In this work, battery aware BORS algorithm has been proposed for mobile adhoc networks. The three scenarios of battery have been taken into consideration and also compared the performance of BORS with AODV, DSR (reactive protocols) and ZRP (hybrid protocol) well-known battery aware routing protocols. The Rigorous service with relaxation, Non-rigorous service with relaxation and Multi-batteries cases have been taken in account in our simulation and analysis. It is observed that our proposed algorithm (BORS) achieves the highest network lifetime in all three cases. The proposed algorithm has performed 12%, 17% and 19% batter than the AODV, DSR, ZRP algorithms respectively. This findings can be relevant and valid to any network with similar constitution. For instance wireless sensor networks, wireless mesh networks etc have similar kind of structure.

For future work, algorithm can be expanded with the reliability of networks while considering the link strength, node failure prediction, packet loss assessment. Furthermore, this work may also be extended with the incorporation of any scheme related to throughput of entire network.However the algorithm is tested for single and dual battery model but another way to look at this work by implementing the multiple battery with more than two in each mobile device. And also can try to synchronize the back off time with the relaxation time of each battery. Furthermore, the work can be extended by computing the probability of each network link and multiple mobile device failure and assessment of network reliability.

CHAPTER 4

CONGESTION FREE PACKET TRANSMISSION: RING SECTOR SENSING SCHEME IN MOBILE ADHOC NETWORK

Enhanced throughput along with timely packet delivery to the destination is one of the challenges in the Mobile Ad hoc Networks (MANET), which has worried researchers to overcome the problem from last two decades. The proposed AODV based Congestion Control (ACC) algorithm tries to overwhelm the problem up to some extent while considering the bandwidth matrix, link capacity, optimal distance and energy of node before forming the potential route for the destination. Furthermore, the proposed algorithm considers partition of entire network into sub-flows and each sub-flow is mathematically assessed and experimentally observed to get the improved result. It has reduced end to end delay over than 20% and 50%, improved 10% and 20% in throughput and 16% and 50% in packet delivery ratio in comparison to AOMDV and AODV respectively. Moreover, to improve further, the congestion in path is controlled by utilizing the mechanism to share the transmission overhead on priority basis among the sub-paths of sub-flow. Apart from congestion control, this work also proposes a new stastistical approach to check the reliability of the network based on its previous number of link failure during each transmission.

4.1. Introduction

This proposed algorithm ACC is advancement over ADOV protocol which uses the backbone of AODV and added new evolutionary mechanism to control the traffic load and improved the performance of the network transmission. The load balancing is the key mechanism in traffic engineering, which improves throughput along with packet delivery ratio and reduces routing overhead and end to end delay in multicast routing to attain smooth transmission. This algorithm is based on generalized multicast multipath mechanism (GMM) , which allows the network to compute the flow components using different distribution tree for multicasting several flows in the transmission. To handle the transmission flow, the traffic is partitioned in various component called flow. Each flow utilises multiple interchangeable path called subflow . These subflows are analysed and estimated on the basis of different network viz. maximum link utilization, total hop count , average hop count , maximum delay , average delay, total bandwidth consumption, average bandwidth consumption , link capacity constraints etc. All these parameter guarantees the minimization of packet loss, link failure, delay which plays the key role for the success of transmission. Furthermore to reduce the transmission time, distance mechanism is also well-thought-out.

4.2. Related Work

The algorithm distributes [68] the whole transmission into the sections of sub transmissions, and allow computing of total flow in network, the summation of all section flows in order to have the control on the traffic of the network. The authors steer a route discovery based on estimated distance in the general direction of a destination [71], within limits the transmission range of route request (RREQ) and reduces the congestion and traffic overhead. This basis idea of the algorithm is on the signal strength. The author considers the routing path using interchangeability among the different paths. The algorithm [72] selects path having low degree of data packet transmission nodes in the process of route searching. The algorithm [74], describes the mechanism based on density of the nodes nearby the node of the route and discusses the route repair at local level during the failure in the transmission in network. An algorithm given by author R. Vadivel explains the solution for congestion and route error by using bypass route selection in MANET using the shortest path between a source to destination. The author has discussed a classic optimization problem in network routing is to minimize the maximum edge congestion and the maximum path length (also known as dilation), and user selects the path selfishly [76]. In routing protocol SASR and SAAR [78] author describes the reusability of transmission media in order to enhance end to end delay and throughput of the network. The author has considered distributed opportunistic routing policy with congestion diversity (D-ORCD) [79]. D-ORCD measures draining time to opportunistically identify and route the packet along the path with an expected low overall congestion. The article proposes back-pressure algorithm which utilizes all the path including longest path even traffic is less and advocates to exploit the longest path when congestion is higher [80]. It also considers the routes based on shortest path. Another back pressure algorithm, was proposed which uses LIFO queuing discipline (called LIFO-Backpressure) and acquire the utility under O(1/V) of the optimal value for any scalar $V > 1$ [81], while upholding an average end to end delay of O([log(V)]2) for all cases of the traffic in the network. The article provides a solution for throughput optimal routing/scheduling in a multi-hop constrained queuing network using the random connectivity scenario, which has special case of input queue fabric and opportunistic multi-hop [82]. It faces the challenge to make out adequate and general function with negative expected drift. It has described the big class of throughput optimal routing policies to control the traffic along with small path for a large class of state space. The author describes an algorithm based on CSMA using adaptive feature to achieve the optimal throughput in ad hoc network while undertaking few assumptions [83] in order to combine end to end traffic control and get congestion free transmission. The work proposed was based on back-pressure mechanism [84] has been implemented in internet of things in order to control the traffic, reduce the congestion and improves the throughput of the network. The emergency packets are left in case of emergency internet of things. The model is based on arrival of packets at different level of time using shortest path from the next hop. The work proposed by author, considers hop-by-hop congestion control protocol [85] while imposing the channel access time constraint, exploiting the optimization-based structure. It uses the Lyapunov function in two scenarios, in first absent of delay, it shows that algorithm is globally stable but in other case, it illustrates hop by hop control. The article [86] uses the combination of Lyapunov function and graph partitioning technique. This has tree topologies considering the primary interference that has the provision to exchange a single bit information with the neighbor link and approximate the optimal throughput which depends upon the degree of nodes and the approximation value. In this article author considers the K-hop interference model for higher amenable implementation, where communication overhead is taken into consideration and achieve the low end to end delay in transmission.

4.3. Mathematical Formulation of Proposed Algorithm

Consider an ad hoc network represented by a graph, $G(N, E)$, where N and E represent the set of nodes and set of links respectively in network. $|N|$ denotes the cardinality of N and F represents the set of flows. Each flow $f \in F$ is further split into $|K|_f$ sub-flows and denoted as f_k =1,2,...$|K|_f$. This way here f_k represents the fraction of f; $f \in F$ and transports, $\sum_{k=1}^{K_f} f_k = 1$. An each flow f, has a source node S_f and set of destination $D_f \subset N$. Suppose t be a node $t \in D_f$ and let $R_{ij}^{f_k t}$ represents the fraction of sub-flow f_k to egress node t assigned to link $(i, j) \in E$ that i.e. $0 \leq R_{ij}^{f_k t} \leq 1$. Suppose C_{ij} (bit/sec) is the link capacity of each link $(i, j) \in E$ and assuming b_f bits/sec be the traffic request of flow $f \in F$, flowing from source S_f to D_f and if d_{ij} be the delay in each link$(i, j) \in E$. A binary variable $S_{ij}^{f_k t}$ denotes whether a link (i, j) is being used (true=1) or unused (false=0) for the sub-flow f_k to destination t which is represented as (refer to equation 4.1)

$$S_{ij}^{f_k t} = \lceil R_{ij}^{f_k t} \rceil = f(x) = \begin{cases} 0 & \text{for} \quad R_{ij}^{f_k t} = 0 \\ 1 & \text{for} \quad otherwise \end{cases} \tag{4.1}$$

This value also indicates there is connection between nodes i and j. The algorithm ensures the optimal link utilization that is given by equation (refer to equation 4.2)

$$\max_{(i,j) \in E} \gamma_{i,j} = \frac{1}{C_{ij}} \sum_{f=1}^{|F|} \sum_{k=1}^{|K_f|} b_f \left[\max_{t \in D_f} R_{ij}^{f_k t} \right] \tag{4.2}$$

and total number of hop count given by equation 4.3

$$\sum_{(i,j) \in E} \sum_{f \in F} \sum_{k \in K_f} \sum_{t \in D_f} [S_{ij}^{f_k t}] \tag{4.3}$$

and average number of hop count is expressed by equation 4.4

$$\frac{\sum_{(i,j) \in E} \sum_{f \in F} \sum_{k \in K_f} \sum_{t \in D_f} S_{ij}^{f_k t}}{\sum_{f \in F} \sum_{k=1}^{|K_f|} |D_f|} \tag{4.4}$$

and in order to assure the quality of service in network there should be maximum value of hops in network. Hence, total hop count can be expressed as (refer to equation 4.5)

$$\max_{f \in F} \max_{k \in K_f} \max_{t \in D_f} \sum_{(i,j) \in E} S_{ij}^{f_k t} \tag{4.5}$$

and for the better packet flow, there should be maximum hop count variation in respect of measuring the queue size and utility of jitter expressed by equation(4.6) and equation(4.7).

$$\max_{k \in K_f} \max_{t \in D_f} H_{ft} \tag{4.6}$$

Where

$$H_{ft} = \max_{k \in K_f} \left[\sum_{(i,j) \in E} S_{ij}^{f_k t} \right] - \min_{k \in K_f} \left[\sum_{(i,j) \in E} S_{ij}^{f_k t} \right] \tag{4.7}$$

The maximum value of hop count improves the additional delay in reaching the packet from source to destination, which can be estimated as the total delay is given by (refer equation 4.8)

$$\sum_{(i,j) \in E} \sum_{f \in F} \sum_{k \in K_f} \sum_{t \in D_f} \left[d_{ij}.S_{ij}^{f_k t} \right] \tag{4.8}$$

and the average delay in packet serving can be written as (refer equation (4.9))

$$\frac{\sum_{(i,j) \in E} \sum_{f \in F} \sum_{k \in K_f} \sum_{t \in D_f} \left[d_{ij}.S_{ij}^{f_k t} \right]}{\sum_{f \in F} \sum_{k=1}^{|K_f|} |D_f|} \tag{4.9}$$

Furthermore, delay variance (as given below) in transmission ensure the calculation of queue size to overcome the problem of the simultaneous packet transmission by nearby nodes which often leads to undesirable collision and fail to receive. This is a physical problem, which occurs before packets can be inserted into the receiver queue. The value of delay variance is represented by (refer equation (4.10))

$$\max_{f \in F} \max_{t \in T_f} \Delta_{ft} \tag{4.10}$$

Where

$$\Delta_{ft} = \max_{k \in K_f} \left[\sum_{(i,j) \in E} d_{ij}.S_{ij}^{f_k t} \right] - \min_{k \in K_f} \left[\sum_{(i,j) \in E} d_{ij}.S_{ij}^{f_k t} \right]$$

The total bandwidth required by the packet is expressed as (refer to equation (4.11))

$$\sum_{(i,j) \in E} \sum_{f \in F} \sum_{k \in K_f} b_f \left[\max_{t \in D_f} R_{ij}^{f_k t} \right] \tag{4.11}$$

And the link capacity constraint is expressed by equation (refer to equation (4.12))

$$L_{ij} = \sum_{f=1}^{|F|} \sum_{k=1}^{|K_f|} b_f \left[\max_{t \in D_f} R_{ij}^{f_k t} \right] \tag{4.12}$$

For maintaining the packet service flow continuity, there should be $L_{ij} \leq C_{ij}$ for $\forall i, j \in N$ There should always constraint on maximum sub-flow of packets between any two nodes and it can represented by inequality (refer to equation (4.13))

$$\sum_{k=1}^{|K_f|} \sum_{j \in N} S_{ij}^{f_k t} \leq N_{max}; \quad \forall f \in F, t \in D_f, i \in N \tag{4.13}$$

It is further depended upon required bandwidth b_f, which can be expressed by relation (refer to equation (4.14))

$$\sum_{k=1}^{|K_f|} \sum_{j \in N} S_{ij}^{f_k t} \leq b_f \frac{\sum_{j \in N} connection_{ij}}{\sum_{j \in N} C_{ij}}; \forall f \in F, t \in D_f, i \in N \tag{4.14}$$

4.3.1. Proposed Algorithm for Packet Serving and Example

This is shown with an example below Network shown in figure (4.1), the source and destination nodes are represented by S and D. The transmission flow between source and destination is partitioned into small segments called flow. Figure (4.2) illustrates the flow f, consists of 7-nodes ($|N| = 7$) between S_f and D_f and taking S_f=N_1 as source node with two receiving nodes D_f= N_5, N_6, N_7. Let flow f is split into 3 sub-flows namely f_1,f_2 and f_3.

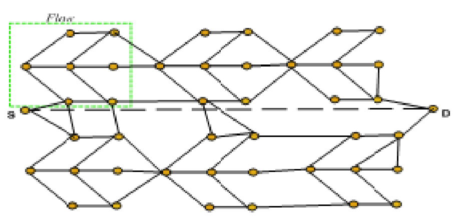


FIGURE 4.1. Shows network partitioned between S and D

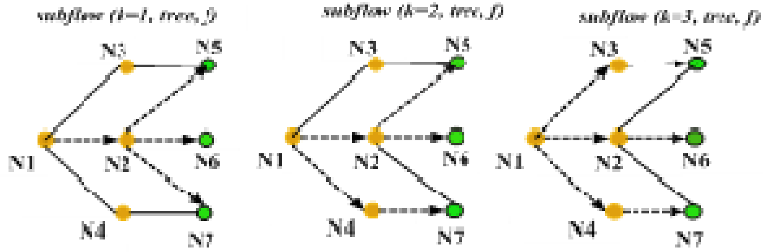


FIGURE 4.2. Depicts the multiple network partitioned for subflow transmission of packet

1. The Ist subflow transmits $(k = 1, tree, f)$ 40 % of total transmission flow through using three different paths $(pathf_1, 1, 5)= \{N_1, N_2, N_5\}$, $(pathf_2, 1, 6)= \{N_1, N_2, N_6\}$ and $(pathf_3, 1, 7)= \{N_1, N_2, N_7\}$.
2. Second subflow transmits $(k = 2, tree, f)$ the 30% of total transmission flow which consist of 3 different paths $(pathf_1, 1, 5)= \{N_1, N_2, N_5\}$,$(pathf_2, 1, 6)=\{N_1, N_2, N_6\}$ and $(pathf_3, 1, 7)=\{N_1, N_4, N_7\}$.
3. Lastly, third subflow transmits $(k = 3, tree, f)$ the 40% of total transmission flow composed of three different paths $(pathf_1, 1, 5)=\{N_1, N_3, N_5\}$,$(pathf_2, 1, 6)=\{N_1, N_2, N_6\}$ and $(pathf_3, 1, 7)=\{N_1, N_4, N_7\}$.

In order to optimize the transmission between S and D, each subflow has to be optimized. Hence, the proposed approach considered multipath routing by utilizing the nodes matrix which are found on the basis of energy of nodes [69], bandwidth of the route [67], link capacity and the optimized distance from the destination node. Moreover, packets are given to those nodes which are fit for the aforesaid conditions to reduce the wastage of path bandwidth. It all ensures the enhancement of throughput of entire network at the large. In addition to the recoil technique it also controls the congestion in the network. The algorithm namely AODV based congestion control (ACC) unfolds the steps existing in proposed work.

For the simulation, NS2.34 has been used and the parameter setting are depicted in table (4.1).

4.3.1.1. *Algorithm 9.*

Algorithm 9: Coordinated determination of recoiled off time

Result: Result would be written here

Input: initialization

$N \leftarrow Nodes$;

$R_E \leftarrow SelectedNodesOnBandwidthBasis$;

$R \leftarrow SetOfRoutes$;

$R := \{r_1, r_2, r_3...r_n\}$;

$P_N \leftarrow SetOfPotentialNodes$;

$\theta_{TBW} \leftarrow ThresholdBandwidth$;

$\theta_{TE} \leftarrow ThresholdEnergy$;

$\theta_{OD} \leftarrow ThresholdDistance$;

$\theta_{TLC} \leftarrow ThresholdLinkCapacity$;

while *(till node N exhausted)* **do**

  For each node N in transmission range of the network ;

  $n_E \leftarrow energy(N) > \theta_{TE}$;

  $n_{BW} \leftarrow bandwidth(N) > \theta_{TBN}$;

  $n_{OD} \leftarrow distance(N) > \theta_{OD}$;

  $n_{LC} \leftarrow linkcapacity(N) > \theta_{TLC}$;

$P_N \leftarrow n_E \cap n_{BW} \cap n_{OD} \cap n_{LC}$;

Given different subflows viz. $\{f_{f_1}, f_{f_2}, ... f_{f_i}\}$;

Where $SubflowF = \cup_{i=1}^{x}\{f_{f_i}\}$ and $TotalflowTF = \cup_{j=1}^{y}\{F_j\}$;

for *(each $f_i \in F$)* **do**

  $fb_i \leftarrow bandwidth(f_{f_i})$;

Sort fb in the descending order of their bandwidth along with ff so that fb_i corresponds to the bandwidth of i^{th} flow f_{f_i}.;

//Assigning the bandwidth to all flows//

$f_{f_1} \leftarrow 0.4\, of\, bandwidth$;

$remBW = 1 - 0.4\, and\, remFlow = x - 1$;

$a = \frac{remBW/2}{1-(1/2)^{remFlow}}$;

for *($j = 1$; remFlow)* **do**

  $f_{f_i} = a$;

  $a = a/2$;

End Of Algorithm 9.

TABLE 4.1. Simulation parameters for simulator

Parameter	Value	Unit
Number of nodes	150	numbers
Traffic type	CBR	—
Area Size	1500 1500	meter^2
Mobility Model	RWP	—
Transmission range	500	meter
Packet size	128, 256, 512	byte
Routing Protocols	AODV, AOMDV, ACC	protocol
Node speed	0.25	meter/ sec
Simulation Time	50	sec
Initial energy	75	joules
Queue size	50	packets

4.3.2. Computation of Theoretical Energy and Node Density

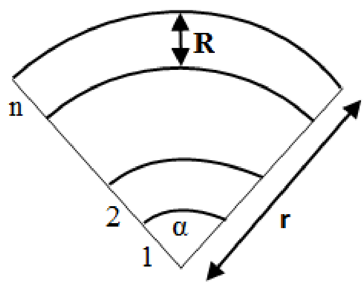


FIGURE 4.3. Shows n-ring sectors of network.

Area is divided into n ring sectors as shown in figure (4.3) with thickness R and sector angle α.

Lemma 4.3.1. *The area size and ring sector are related with the relation* $A_i = (2i-1)A_1$ *where* A_i *represents the area of* i^{th} *sector in network.*

Proof : Let there are n ring sectors namely $T_1, T_2, T_3, ..., T_n$ having corresponding area $A_1, A_2, A_3, ..., A_n$. The rings are divided into n equal size of thickness $\left(\frac{r}{n}\right)$ each. Hence,
Area of ring sector having R thickness= $\frac{\alpha}{2}.R^2$
Ares of first ring sector can be written as :
$A_1 = \frac{\alpha}{2}.\left(\frac{r}{n}\right)^2$
Similarly for subsequent sectors
$A_2 = \left[\frac{\alpha}{2}.\left(\frac{2r}{n}\right)^2\right] - (A_1) = [4A_1 - A_1] = 3A_1$
$A_3 = \left[\frac{\alpha}{2}.\left(\frac{3r}{n}\right)^2\right] - (A_1 + A_2) = [9A_1 - 4A_1] = 5A_1$
.
.
.
$A_n = \left[\frac{\alpha}{2}.\left(\frac{nr}{n}\right)^2\right] - (A_1 + A_2 + A_3 + ... + A_{n-1})$
$= [2nA_1 - A_1] = (2n-1).A_1$
Hence,
$A_i = (2i-1).A_1$

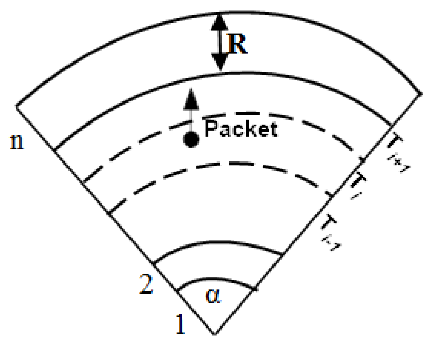


FIGURE 4.4. Shows packet transmission from ring sector T_i.

4.3.2.1. *Energy Estimation.* The node lying in area T_i handles the messages of two type which are received from or transmit to its adjacent ring sectors $(T_{i-1} and T_{i+1})$. Hence, two case may arise in order to transmit or receive the packet from adjacent ring.

Case 1: Message is sent from T_i ring sector node.

Case 2: Message is received by T_i ring sector node.

Due to random nature of message propagation in each ring sector a random variable (ξ_{ij}) has to be considered which estimates the energy theoretically (refer to equation 4.15).

$$[htbp!]\xi_{ij} = \begin{cases} cR^2 & with \;\; probability \;\; p_i \\ c(iR)^2 & with \;\; probability \;\; (1-p_i) \end{cases} \tag{4.15}$$

The energy spent in ring sector T_i is expressed by as (refer equation 4.16):

$$E(\xi_{ij}) = [cR^2 p_i - ci^2 R^2 (1-p_i)]$$

$$[htbp!]E(\xi_{ij}) = cR^2 \left[p_i - i^2(1-p_i)\right] \tag{4.16}$$

4.3.3. Proposed Algorithm for Checking Reliability of Network

The ultimate goal of network is to carry out trusty transmission and can endure link failure. The reliability of network can be expressed in terms of a new parameter called Statistical Control of network (StatCtrl) .An novel scheme is proposed to verify the reliability of network using SCUPA [73] (Statistical Control using p-chart algorithm) [110]. The network can be said to be in the condition of Statistical Control if the the number of link failure is not too excess, which can be identified by means of the SCUPA. This algorithm can work as statistical device which reveals the frequency of link failure and tells whether the network is in the state of control or not. It consists of three control lines namely central limit (CL), upper limit (UL) and lower limit (LL). The CL indicated the preferred expected level of control of network. The number of link failure are collected based on past and current link fail record and these points are plotted on graph with x-axis as different transmission instance numbered from 1 to d and y-axis as number of link failure at a particular instance. The network is considered to be in unsteady state if the points lie outside the UL and LL. The control lines CL and LL are placed above and below the grand average of statistical measure a .This grant average is plotted three times the computed sigma value, which is referred to as 3 sigma limit. The reason for considering three control lines is that in normal distribution, $a \pm 3$ covers 99.73% of link in network. For this reason, there is an very rare possibility of occurrence of link failure under normal circumstances i.e. only 0.003% if the point lies beyond $a \pm 3$. A new scheme, SCUPA is proposed to check the reliability of the network.

4.3.3.1. *Algorithm 10.* Reliability of a network ensure the system that it must perform the intended work with stipulated time in given conditions. In order to ensure the reliability an algorithm is proposed. This algorithm has been mathematically examined through mathematical principles and experimentally verified by simulation namely Statistical Control Using P-Chart Algorithm (SCUPA).

Example. The reliability of network can be verified using SCUPA scheme with the help of an example. It takes a record on link failure in each transmission and plot the graph. The table (4.2) comprehends link failure in each transmission identified by its transmission id called trans-id. There are 30 link failure in 10 transmission with total number of 100 link in the network. It is assumed that each transmission contains same number of links for simplicity.

TABLE 4.2. Link failure occurred in each transmission

Parameter	Value
1	1
2	2
3	3
4	1
5	4
6	5
7	2
8	6
9	2
10	4
Total Link failed	30

Algorithm 10: SCUPA

Input: linkfail[1...d]: link failure in each specific transmission

Output: StatCtrl

$x \leftarrow Transmission\, number$;

$y \leftarrow Link\, failure\, in\, the\, specific\, transmisssion$;

$d \leftarrow Set\, of\, routes$;

$a \leftarrow Average\, link\, failure$;

$k \leftarrow Counter\, for\, counting\, the\, number\, of\, link$;

$g \leftarrow Total\, number\, of\, links\, in\, network$;

initialization : $varCL := 0, UL := 0, LL := 0, a := 0, k := 0$;

Compute $a = \frac{\sum_{i=1}^{d} linkfail_i}{\sum_{j=1}^{d} g_j}$;

while *(k¡d)* **do**

  $k = k + 1$;

  $CL = g.a$;

  $UL = g.a + \sqrt[3]{g.a(1-a)}$;

  $LL = g.a - \sqrt[3]{g.a(1-a)}$;

  if $(LL < 0)$ **then**

    $LL = 0$;

    //As link failure can't be negative

  else

    //Plot the points with trans-id and link fail $Point\, pp = plot(x, y)$;

    $StatCtrl := \{\forall p | p \in pp, if((p > UL)$

    $\|(p < LL))\ \ 0 : 1\}$;

    if *(StatCtrl=0)* **then**

      break;

End of Algorithm 10.

Calculation for Various Parameters. Average link failed $a = (30/10).100 = 0.03$

$g = 100$

$CL = g.a = 100 * 0.03 = 3$

$UL = g.a + \sqrt[3]{g.a(1-a)} = 3 + \sqrt[3]{3(1-0.03)} = 8.12$

$LL = g.a - \sqrt[3]{g.a(1-a)} = 3 - \sqrt[3]{3(1-0.03)} = -2.12$

$= 0$(Since negative value so assigned 0)

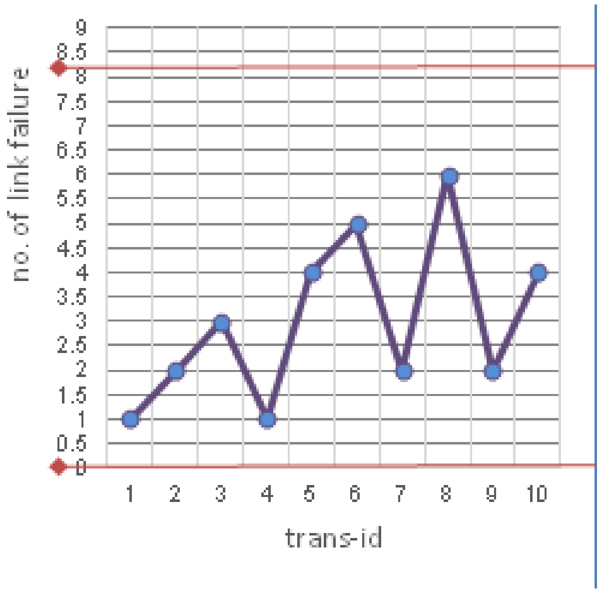


FIGURE 4.5. Shows reliability of network with number of link failure in each transmission of packets.

The following lemmas are supporting the result

Lemma 4.1. *End-to-end packet delay of routing protocol increases with the number of nodes in network in proactive and reactive protocols. It implies that if* $N_1 > N_2$, *then* $D(N_1) > D(N_2)$.

Proof : End-to-end delay or one way delay is the delay that bear by a protocol required for a packet to be serviced across the network from source node to destination node. The wired network has fixed end to end delay by virtue of unchanged topology under the given nodes. But mobility is a characteristic of mobile ad hoc network whereby end to end delay varies. Furthermore, if number of nodes in network frequently varies this affect raise to multiplier effect.

Suppose each node has probability p_r *to retransmit the RREQ packet to its destination, let the average time to send the packet to destination is* T_{avg} *and there are* m *hops to reach the destination. Hence, time required to serve the packet to its first hop* $= p_r.T_{avg}$. *The*

overall time delay in packet transmission from source to destination is denoted by T_d and is given by (refer to equation 4.17).
The first order derivative $D^{'}(N) > 0$, shows that the packet delay function increases with number of nodes. Result (refer figure (4.9), $y = 0.001x + 0.021$, is the equation of tangent of the curve. The result 0.001 is also positive. Hence, result is complying statistically also.

$$
\begin{aligned}
T_d &= 1 + p_r.T_{avg} + p_r^2 T_{avg}.T_f + p_r^3.T_{avg}T_f^2 \\
&+ .... + p_r^m.T_{avg}T_f^{(m-1)}
\end{aligned}
\tag{4.17}
$$

which reduces into equation 4.18

$$
T_d = 1 + p_r.T_{avg} \sum_{i=0}^{m-1} (p_r.T_f)^i \tag{4.18}
$$

equation takes form as (refer equation 4.19)

$$
T_d = \begin{cases} 1 + p_r.T_{avg}\left(\frac{(p_r.T_f)^m - 1}{p_r.T_f - 1}\right) & for \quad \text{any } p_r \text{ and } T_f \\ 1 + m.p_r.T_{avg} & for \quad T_f = 1 \end{cases} . \tag{4.19}
$$

Case : In case of reactive (e.g. AODV) protocol, intermediate nodes always exercise the rebroadcast the packets. Hence, $p_r = 1$, the equation get reduced into (refer equation 4.20)

$$
T_d^{react} = \begin{cases} 1 + T_{avg}\left(\frac{T_f^m - 1}{T_f - 1}\right) & for \quad \text{any } T_f \\ 1 + m.T_{avg} & for \quad T_f = 1 \end{cases} . \tag{4.20}
$$

Lemma 4.2. *Packet delivery ratio of routing protocol decreases with the number of nodes available in network in proactive and reactive protocols. It means that if $N_1 > N_2$ $PDR(N_1) < PDR(N_2)$. The first order derivatives $PDR^{'}(N) < 0$, shows that the packet delivery ratio function increases with number of nodes. Result (refer figure (4.10), $y = -0.136x + 109.8$, is the equation of tangent on packet delivery ratio curve of proposed algorithm. The result -0.136 is also negative. Hence, result is verified. In similar way the result is also verified for the lemmas for throughput and routing overhead.*

Lemma 4.3. *Throughput of routing protocol increases with the number of nodes available in network in proactive and reactive protocols. It means that if* $N_1 > N_2$ *then* $TP(N_1) > TP(N_2)$. *The first order derivatives* $TP'(N) > 0$, *shows that the throughput function monotonically increases with number of nodes. Result (refer figure (4.11),* $y = 0.672x + 94.707$, *is the equation of tangent on throughput curve of proposed algorithm. The result 0.672 is also positive. Hence, the result is verified. Similarly the result is also verified for routing overhead.*

TABLE 4.3. Show end to end delay increases with number of nodes

Total number nodes	T_f	T_{avg}	p_r	m	E2E delay
20	0.021	0.022	0.9	4	0.025
40	0.019	0.038	0.9	16	0.040
60	0.03	0.047	0.9	19	0.051
80	0.041	0.057	0.9	21	0.062
100	0.080	0.081	0.9	25	0.088
120	0.081	0.099	0.9	21	0.11
140	0.089	0.900	0.9	22	0.123

4.4. Results

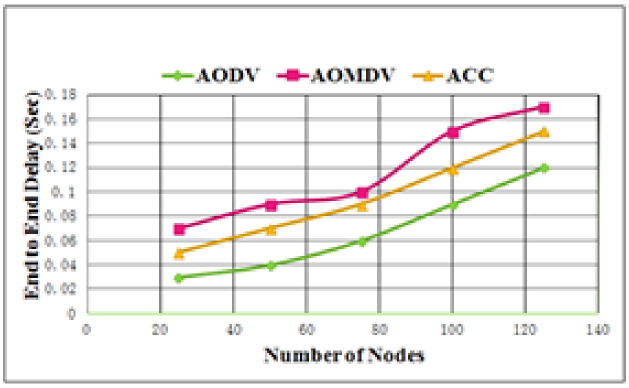


FIGURE 4.6. Illustrates the end to end delay Vs No of nodes during transmission.

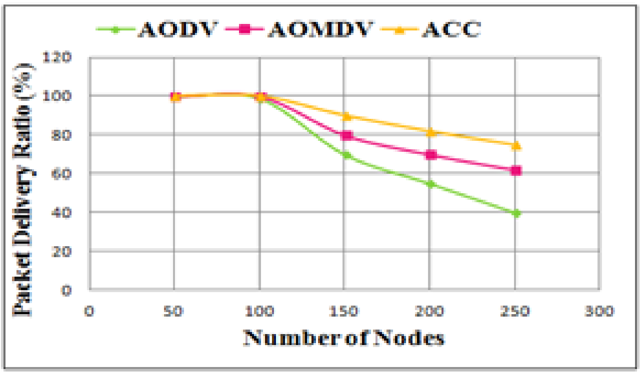


FIGURE 4.7. Shows the packet delivery ratio Vs No of nodes during packet transmission in network.

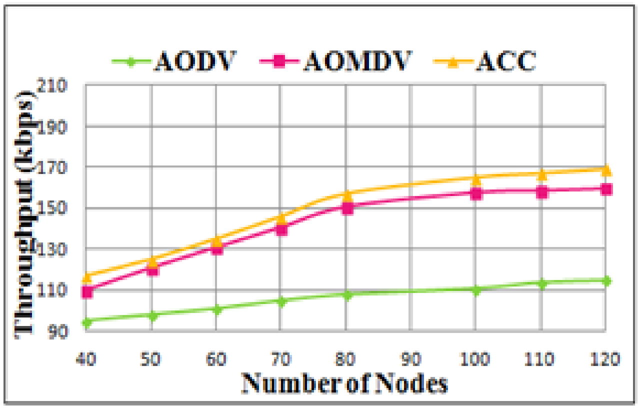


FIGURE 4.8. Depicts the throughput Vs number of nodes during packet transmission.

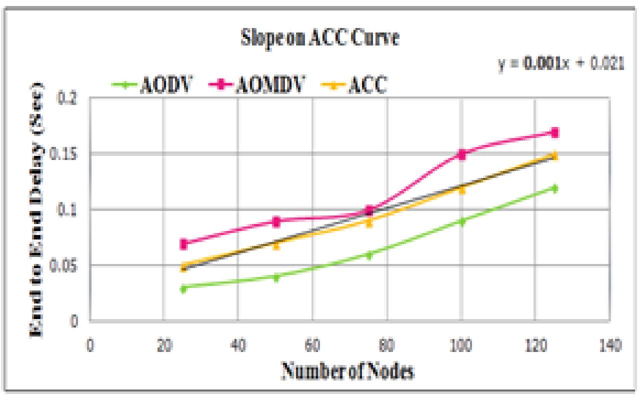


FIGURE 4.9. Illustrates the tangent on end to end curve during packet transmission in network.

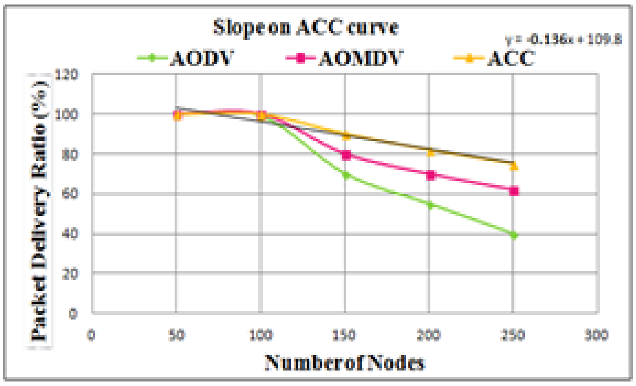


FIGURE 4.10. Shows the tangent on Packet delivery ratio curve during packet transmission in network.

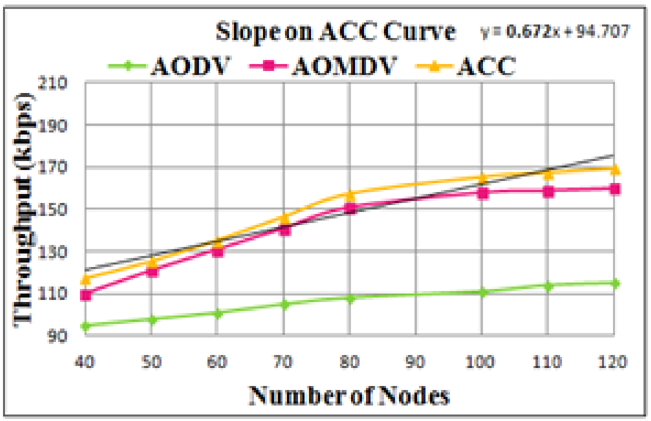


FIGURE 4.11. Depicts the tangent on throughput curve during packet transmission in network.

Figure (4.6), figure (4.7),and figure (4.8) are the demonstration of results in comparison with AODV, AOMDV and ACC, while considering the network performance parameters end-to-end delay, PDR and throughput.

4.5. Conclusion

There have been remarkable advances of research in the arena of routing protocol in MANET. But still multitree-multicast routing needs to be addressed. In this work, several multicast trees with subflow is considered and path interchange between multicast trees along with path changing scheme inside the subflow is proposed. This scheme moderates the congestion problem and enhances the various network performance parameter i.e. throughput,. end-to-end delay, routing overhead and packet delivery ratio in comparison to existing protocols viz. AODV and AOMDV. The proposed scheme reduces the congestion as it transmits the packet via different subflow of the network examined on the basis of bandwidth, link capacity, optimum distance and energy of the nodes in the path which lessen the chances of failure of link, packet loss, delay etc. and increases the likelihood of successful packet delivery to its intended node. The demonstrated result is proved by means of lemma. Also, the proposed statistical approach SCUPA aids in achieving reliable network. Figure (4.5) shows all three control points CL,UL and LL. These points are plotted from Table (4.2) with linkfail in each transmission-id. It can be obviously seen that all the points are falling inside the range of UL and LL, which indicates that the network is reliable.

In case, any control point would have been falling outside the control lines then the network would have been considered unreliable.

CHAPTER 5

MATHEMATICAL FORMULATION OF ENERGY EFFICIENT ROUTING WITH CONSTRAINT IN MOBILE ADHOC NETWORK

Energy consumption of nodes during the transmission is an important factor for efficiency and lifetime of a mobile ad hoc network. The reduction in consumption of energy can be achieved, only when its consumption at each step is known. The purpose of this work is to formulate the mathematical model of energy consumption of network on the basis links and available nodes and to formulate energy optimization function. The probability of link failure in network have been taken into consideration as constraints while formulating the objective function of estimated energy consumption as the low connectivity is one of the challenges in mobile ad hoc network.

5.1. Introduction

Energy efficient routing is an effective technique for reducing the energy consumption during the transmission in Mobile Ad hoc Network (MANET). Generally, the link failure in network leads to unsuccessful transmission which forces retransmission of packet from one node to another, which amounts to the wastage of energy of the nodes in network. Hence, energy efficient routing in ad hoc network is neither complete nor efficient without the consideration of link assessment prior to the transmission. Transmission to the healthy linked path can enhance the reliability and quality of the service. Routing protocol should be able to take appropriate action promptly to link breakdown or link failure situation. This work estimates the energy requirement for the successful transmission of packet in the network. It has considered possible consumption of energy while considering all three types of nodes available in a network.

5.2. Related Work

In order to reduce the energy consumption in transmission, the vital role is being played by the routing mechanism employed in the network. There are several scientists and researcher contributed in this area but it still demands the focus to reduce power consumption. In [87] author applied technique to reduce the number of transmission and decreases the energy consumption by using the network coding for head of the cluster and furthermore, improve the coding opportunities while employing the queue management process [112]. The work [88], expresses power saving protocol based on MAC in mobile ad hoc network. The protocol is used a technique which allows the host to sleep for a given interval of time and wake up as soon as its assigned time is over in order to minimize the power consumption. The work by author [89] on energy efficiency based on combination of nodes lifetime and distance-based power metrics and investigates some properties of power adjusted transmissions and demonstrates the power is the function of linear equation. The transmission decision is made as per the location of neighbors and the destination nodes in the network and optimizes the power between two nodes. The author discussed about the power requirement of nodes in the network by using the two techniques namely carrier-sense multiple-access/collision-avoidance (CSMA/CS) [90] and request-to-send (RTS)/clear-to-send (CTS). The work proposed in [91], focuses to minimize the energy by utilizing the combination of two concepts that are multipath routing and energy reservation mechanism. The technique is focused on reducing the energy consumption while avoiding the packet loss of wireless sensor network [92]. The work is aimed the energy consumption optimization in mobile ad hoc network for ad hoc on demand multipath distance vector (AOMDV) by employing the fitness function [93] technique in routing protocol. On the basis of this fitness function it obtained the multipath which reduces the energy consumption in the trans-mission. The work [94] proposed the cluster based scheme which improves the scalability and stability of the given network. The articulated algorithm treated the cluster of nodes the birds flock with dynamic formation. Furthermore, a mechanism based dynamic topology is proposed to reduce the congestion in the network in order to enhance the performance of the network. In this work [95], the author proposes a routing protocol, which is based on dynamic connectivity without the any intervention and maintain connectivity metric and reduces the overhead of

RREQ and RREP messages in the network. The work [96] illustrates a protocol which optimizes the transmission overhead while utilizing prediction of node mobility in combination with cluster formation. This research methodology [97] used the greedy algorithm for the formation of cluster of nodes. The theoretical analysis of decision making problem based on cooperative game analysis theory. The research work expressed [98] simulates urban scenario for the large network for the quality of services along with the scalability. The protocol uses a technique which utilizes node clustering along with the virtual backbone. The author proposed an algorithm [99] which uses genetic algorithm and cellular automata that exploits the procedure to reduce the energy and delay in the network. The author has projected [100] an algorithm that supports the self organized transmission mechanism based on node clustering in order to reduce the routing overhead. The article [101], is aimed to reduce the energy optimization of wireless sensor networks based on clustering phase and routing phase using harmony search method. The author projected a work [102] which dealt with single path and multipath routing and articulated the set of reliability for the different packets at different time of transmission. The author in this work [103], describe the research based challenges available in wireless mobile network and systems that provides logical connectivity to huge numbers of mobile network nodes co-located within a limited volume. The article [104] used an algorithm which describes the generation of cluster that maintains a metric for the potential cluster members and a node is elected as cluster head that has maximum number of potential cluster members. In order to minimize the nodes in backbone network, an associated node is assigned the responsibility for communication between two cluster heads. The work [105] is proposed to reduce the size of search space, and a new decoding scheme to generate high-quality solutions effectively. The author has introduced a technique [106] for large scale Wireless Sensor Networks (WSNs). The algorithm is used to evaluate the node which has energy supply and optimize Greedy perimeter stateless routing for wireless networks. The author proposes a routing [107] protocol which is based on position, it takes the decision of packet transmission after looking the position of router and the destination node. The decision is made as per information available about the immediate neighbors of router in the network.

5.3. Proposed Algorithm

5.3.1. Energy Consumption in Message Transmission (Based on Node Link)

Let energy consumption in message transmission of length x (bit) from node a to node b through physical link (a, b) is represented by $\delta_{a,b}(x)$, energy consumption in message receiving of length x (bit) at node b from node a is expressed by $\phi_{a,b}(x)$, I_a represents the necessary energy to run the processing unit of node a, $P_{a,b}$ be the transmission power between nodes a and node b, y_a be the energy efficiency of energy amplifier of node a; $0 \leq y_a \leq J_b$, where J_b represents the necessary energy to run processing unit of receiving node b, $r$represents the rate of data transmission of physical link between node a and node b. Hence energy consumption in message (of length x bit) transmission from node a to node b

$$\delta_{a,b} = \left(I_a + \frac{P_{a,b}}{y_a}\right)\frac{x}{r}; \quad \forall\, x \geq 0 \,\&\, \forall(a, b) \in \mathbb{E} \tag{5.1}$$

And required energy to receive message of length x, at node b

$$\delta_{a,b} = J_b \frac{x}{r}; \quad \forall\, x \geq 0 \,\&\, \forall(a, b) \in \mathbb{E} \tag{5.2}$$

The retransmission of message is not taken into consideration here.

5.3.2. Transmission Count (Expected) in Message Trans-mission

Assume T_a be the number of transmissions of a message is allowed for node a (including the first transmission), that is $T_a - 1$ retransmissions are possible for node a. ACK message is sent to node a on the arrival of data packet to node b. If ACK is lost, a new ACK will be transmitted to node a after the arrival of same data packet at node b correctly. Hence, the maximum T_a times ACK can be transmitted to the sender node as the acknowledgment of data packet at receiver node. But no ACK will be transmitted to node if ACK is lost Ta times for a data packet. Assuming the length of ACK message y (bit) and let $E\left[n_{a,b}(x)\right]$ be the number of predictable transmissions that is needed in order to successful delivery of packet of size x (bit) from node a to node b, where $1 \leq n_{a,b}(x) \leq T_a$. $E\left[m_{a,b}(y)\right]$ is the expected number of times ACK message (length y (bit)) is sent to node a by node b, where $0 \leq m_{a,b}(y) \leq T_a$. The values $E[n_{a,b}(x)]$ and $E[m_{a,b}(y)]$ is depended on the link quality and signal strength between the two nodes that a to b and b to a, the value decreases with the quality of link.

$$E\left[m_{a,b}(y)\right] = \sum_{i=0}^{T_a} i P_r\left[m_{a,b}(y) = i\right] \tag{5.3}$$

If $T_a \to \infty$ then equation would be as

$$E\left[n_{a,b}(x)\right] \to \frac{1}{P_{a,b}(x).P_{a,b}(y)} \tag{5.4}$$

$$E\left[n_{a,b}(y)\right] \to \frac{1}{P_{a,b}(y)} \tag{5.5}$$

Where $P_{a,b}(x)$, represents the probability of successful receiving of message of size x from node a to node b. The $P_{a,b}(y)$ represents the probability of successful receiving of ACK of size y bit by node a (sent by node b).

5.3.3. Energy Consumption at Each Link

Assume $\alpha_{a,b}(x)$ represents the power consumed by node a, in transmission, $\beta_{a,b}(x)$ stands for the power consumed by node b in receiving the message of size x bit from node a. The hop by hop retransmission is taking into consideration, value can be computed as :

$$\alpha_{a,b}(x) = E\left[n_{a,b}(x)\right]\delta_{a,b}(x) + E\left[m_{a,b}(y)\right]\phi_{a,b}(y) \tag{5.6}$$

And across node b, total energy consumption is also computed as

$$\beta_{a,b}(x) = E\left[n_{a,b}(x)\right]\phi_{a,b}(x) + E\left[m_{a,b}(y)\right]\delta_{a,b}(y) \tag{5.7}$$

Where, $\delta_{a,b}(x)$ be the power required by node a to transmit a message to node b of length x (bit), $\phi_{a,b}(x)$ represents the power required by node b in receiving a message of length x (bit), $\delta_{a,b}(y)$ be the power required by node b to transmit an ACK message to node a of length y (bit) and $\phi_{a,b}(y)$ be the power required by node a in receiving a ACK message of length y (bit).

5.3.4. Mathematical Formulation of Objective Function

In route, as per transmission, there exist three type of nodes, source node (transmits the packet and receives the ACK message), destination node (receives the data packet and transmits the ACK message) and intermediate node, involved in transmitting and receiving the packet and ACK message.
Lets take

$$E\left[n_{a,b}(x)\right] = E\left[n(x)\right], E\left[m_{a,b}(y)\right] = E\left[m(y)\right]$$
$$\phi_{a,b}(x) = \phi(x) \ \ and \ \ \delta_{a,b}(y) = \delta(y)$$

Hence, the source node consumes the energy as under

$$\alpha(x) = E\left[n(x)\right]\delta(x) + E\left[m(y)\right]\phi(y) \tag{5.8}$$

Energy consumption across the destination node

$$\beta(x) = E\left[n(x)\right]\phi(x) + E\left[m(y)\right]\delta(y) \tag{5.9}$$

Energy consumption by intermediate nodes

$$E\left[n(x)\right]\phi(x) + E\left[m(x)\right]\delta(x) + E\left[m(y)\right]\phi(y) + E\left[m(y)\right]\delta(y) \tag{5.10}$$

Let there be $(n-1)$ nodes in the path and intermediate nodes can be express by (n-3).The energy consumed in entire route can be obtained by using equation (5.8), (5.9) and (5.10).

$$\begin{aligned}\rho \ = \ & \Big\{E\left[n(x)\right]\delta(x) + E\left[m(y)\right]\phi(y)\Big\} + \Big\{E\left[n(x)\right]\phi(x) + E\left[m(y)\right]\delta(y)\Big\} + \\ & (n-3)\Big\{E\left[n(x)\right]\phi(x) + E\left[m(x)\right]\delta(x) + E\left[m(y)\right]\phi(y) + E\left[m(y)\right]\delta(y)\Big\}\end{aligned}$$

$$\rho = (n-2)\Big\{E\left[n(x)\right]\delta(x) + E\left[m(y)\right]\delta(y) + E\left[n(x)\right]\phi(x) + E\left[m(y)\right]\delta(y)\Big\} \tag{5.11}$$

The objective is to find out the optimal path which requires the minimum energy subjected to constraints on link failure and node failure in network. There are three decision variables: $N(=x_1), n(=x_2) and f_a(=x_3)$ have been proposed, where N represents total number node links in the network, n represents the number of node links in the route from source to destination and f_a signifies the number faulty links in network. The objective is to minimize the value of ρ such that the energy required in entire path from source node to destination should be reduced . Hence, replacing with the corresponding decision variable

$$\rho = (x_2 - 2)\left\{E\left[n(x)\right]\delta(x) + E\left[m(y)\right]\delta(y) + E\left[n(x)\right]\phi(x) + E\left[m(y)\right]\phi(y)\right\}$$

Value $E[n(x)]$ and $E[m(y)]$ are constant and replacing with constants Δ_1 and Δ_2 respectively.

Hence, expression

$$\rho = (x_2 - 2)\left\{\Delta_1\delta(x) + \Delta_2\delta(y) + \Delta_1\phi(x) + \Delta_2\phi(y)\right\}$$

$$\rho = (x_2 - 2)\left\{\Delta_1\left(\delta(x) + \phi(x)\right) + \Delta_2\left(\delta(y) + \phi(y)\right)\right\} \tag{5.12}$$

The equation(5.12) represents objective function, which needs to be optimized under the certain constraints as under:

5.3.5. Constraints

Four constraints are possible in order to optimize energy objective function.

5.3.5.1. *Constraint I.* Assume total number total number of link failure should not be greater than 10% of links existing in network. Hence,

$$\frac{10 f_a}{N} \leq 1$$

$$\frac{10 f_a}{N} - 1 \leq 0$$

$$10 f_a - N \leq 0$$

In terms of decision variables

$$g_1(x) : 10x_3 - x_1 \leq 0 \tag{5.13}$$

5.3.5.2. *Constraint II.* Let f_a be the number of link failure in network and for network survivability and stability along with the successful transmission of packets through a route, it necessary the maximum number of link failures in a route should not be more than 5%. Hence, it can be represented [110] by the following equation

$$n f_a + 3\sqrt{n f_a (1 - f_a)} \leq \frac{5n}{1000}$$

$$20f_a + 60\frac{\sqrt{f_a(1-f_a)}}{\sqrt{n}} - 1 \leq 0$$

Replacing with corresponding decision variables, we get

$$20x_3 + 60\frac{\sqrt{x_3(1-x_3)}}{\sqrt{x_2}} - 1 \leq 0$$

$$g_2(x) : 20x_3\sqrt{x_2} + 60\frac{\sqrt{x_3(1-x_3)}}{\sqrt{x_2}} - \sqrt{x_2} \leq 0 \tag{5.14}$$

5.3.5.3. *Constraint III.* This constraint expresses the minimum number of links in network.There must be at least one link in order to transmit packet to destination node. Condition can be written in terms of decision variable as

$$x_1 \geq 1$$

Hence,

$$g_3(x) : 1 - x_1 \leq 0 \tag{5.15}$$

5.3.5.4. *Constraint IV.* The following constraint is about minimum number of link required to transmit the packet to its destination. It is necessary for any route to have at least one link alive. This condition can be expressed in terms of decision variable as follows

$$x_2 \geq 1$$

we get

$$g_4(x) : 1 - x_2 \leq 0 \tag{5.16}$$

Hence, optimization of energy in routing protocol has been formulated using constraints for mobile adhoc network. It is summarized in equation(5.12)
To minimize (objective function) :

$$\rho = (x_2 - 2)\left\{\Delta_1\left(\delta(x) + \phi(x)\right) + \Delta_2\left(\delta(y) + \phi(y)\right)\right\}$$

Subjected to equations (5.13, 5.14, 5.15 and 5.16)

$$Subjected\ to\ Constraints \begin{cases} g_1(x) : 10x_3 - x_1 \leq 0 \\ g_2(x) : 20x_3\sqrt{x_2} + 60\frac{\sqrt{x_3(1-x_3)}}{\sqrt{x_2}} - \sqrt{x_2} \leq 0 \\ g_3(x) : 1 - x_1 \leq 0 \\ g_4(x) : 1 - x_2 \leq 0 \end{cases}$$

5.4. Conclusion

The purpose of this work is to formulate the energy function and its optimization viz. $\rho(x)$. The mathematical formulation of energy has been estimated theoretically subjected to some constraints like percentage of link breakdown in network and in the routes namely $g_1(x)$, $g_2(x)$, g_3(x) and $g_4(x)$.The decision variables for the number node links at network level, at route level and failure links in the route have been taken into consideration to realize the formulation. The advantage of this formulation would be helpful in minimization of retransmission of packet, improvement of network lifetime, minimization of packet drop, end to end delay and enhancement in throughput. The usefulness of this model is to estimate network failure in various way like packet drop, link breakdown, node failure and so on. The threshold value of each such parameters can be configured. The recovery process for network healing can be initiated. It can also be used as mathematical and algorithmic tool to rebuild, forecast the network failure rather than staying in failed network situation.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1. Conclusion

One of the main challenges in mobile ad hoc networks is designing energy efficient networking protocols. In this thesis, we reduced the energy requirement by utilizing four different techniques.

We focused on recoiled off technique to reduce number of transmissions(replications),without impacting the overall performance. Our proposed algorithm AOMDV-ER smartly uses varying recoiled off time based on geographic location of node. The work carried out is verified by different lemmas and critically examined by various mathematical investigation. The algorithm is tested for network performance matrix. These experimental test was based on routing overhead on different node speed, packet size, simulation. The network lifetime was also measured on different variance like node speed, packet size and different simulation time. Other parameters which considers are exhausted nodes with simulation time, Packet delivery ratio, throughput of network, energy consumption with respect to time, packet size etc.

We introduced novel scheme that synchronizes battery characteristic (relaxation time) with recoiled off time in order to rebuilt charge of battery (unavailable to available charge). This striking feature reduces energy consumption as transmission process utilizes substantial portion of battery power. The proposed work was compared with existing algorithms and evaluated performance on the basis of different important parameters.

Furthermore, we investigated and introduced efficient algorithm to predict link broken, node failure and route maintenance thereby, to reduce the congestion in network. This approach is based on network partition, split transmission of flow into sub-flows. Each subflow was examined separately and perform path interchange between multicast tree to reduce congestion problem and enhance the network performance parameters i.e throughput, end-to-end delay, routing overhead and packet delivery ratio. Also proposed statical approach SCUPA which aid in achieving reliable network. This SCUPA mechanism is based on failing range of network, hence, it considers different control points namely central limit, upper limit and lower limit.

Finally we proposed energy requirement in different scenarios of network. Algorithm formulates energy requirement function subjected to all possible constraints like percentage of link failure, minimum number of nodes in route and in entire network in order to have successful transmission of packet from source to destination. The decision variables have been taken into consideration for different parameters. The advantage of this formulation helps in minimizing number of retransmission of packets, enhancement of network lifetime, trimming down packet drop and end-to-end delay and improvement in throughput of transmission.

6.2. Future Work

Ad hoc networking is a boiling concept in personal communications World wide research is going on in this area and many issues still have to be addressed. We focused on concepts like unipath and multipath routing protocols with respect to their performance in the mobile Ad hoc network. Multipath routing is a step towards achieving a network with better Quality of Service. However there are many more issues related to routing that could be subjected to further research studies. The present research work can be extended to design and develop new routing protocols to meet the following additional desirable features.

Robust Scenario: A routing protocol must work with robust scenarios where mobility is high, nodes are dense, area is large and the amount of traffic is more.

Probabilistic Route Maintenance: A more research in the field like probabilistic route maintenance is required to identify the probability of route failure before the occurrences of route failures.

Quality of service (QoS) : Ad hoc routing protocols must meet the desired requirements of QoS to achieve lower end-to-end delay, high throughput improved delivery ratio, reduced routing overhead and more energy efficiency.

Security : A vital issue that has to be addressed is the security in Ad hoc networks. Applications like Military and Confidential Meetings require high degree of security against enemies and active /passive eavesdropping attackers. A new protocol must have authentication headers and necessary key management to distribute keys to the members of Ad hoc networks.

Routing Overhead: Routing messages will utilize most of the precious bandwidth of Ad hoc networks; a new protocol has to be devised to reduce the routing overhead still further compared to AOMDV.

Energy Aware Routing : Since mobile nodes are working on small portable batteries in most of the applications, developing an energy aware routing protocol, which maximizes the life of batteries, is of paramount importance.

Newer operational demands on Ad hoc networks are going to bring in new trends and directions in the research field towards designing robust protocols, and Mobile Wireless Communication keeps on evolving forever making the research an endless paradigm.

APPENDIX-A

The appendix, we provide is a supplemental material, which contains the information to main thesis

6.3. Routing in Mobile Adhoc Network

The absence of fixed infrastructure in a MANET poses several types of challenges. The biggest challenge among them is routing. Routing is the process of selecting paths in a network along which to send data packets. An ad hoc routing protocol is a convention, or standard, that controls how nodes decide which way to route packets between computing devices in a mobile ad-hoc network. In ad hoc networks, nodes do not start out familiar with the topology of their networks; instead, they have to discover it. The basic idea is that a new node may announce its presence and should listen for announcements broadcast by its neighbors. Each node learns about nearby nodes and how to reach them, and may announce that it can reach them too. The routing process usually directs forwarding on the basis of routing tables which maintain a record of the routes to various network destinations. Thus, constructing routing tables, which are held in the router's memory, is very important for efficient routing.

6.4. Routing Protocols for Mobile Adhoc Network

The growth of laptops and 802.11/Wi-Fi wireless networking has made MANETs a popular research topic since the 1990s. Many academic work evaluate protocols and abilities assuming varying degrees of mobility within a bounded space, usually with all nodes within a few hops of each other and usually with nodes sending data at a constant rate. Different protocols are then evaluated based on the packet drop rate, average routing load, average end-to-end-delay, and other measures. The proposed solutions for routing protocols could be grouped in three categories: proactive (or table-driven), reactive (or on-demand), and hybrid protocols. Even the reactive protocols have become the main stream for MANET routing. In this chapter, we introduce some popular routing protocols in each of the three categories and for IPv6 networks

6.5. Classification of Routing Protocols

6.5.1. Proactive Routing Protocols

Every proactive routing protocol usually needs to maintain accurate information in their routing tables. It attempts to continuously evaluate all of the routes within a network. This means the protocol maintains fresh lists of destinations and their routes by periodically distributing routing tables throughout the network. So that when a packet needs to be forwarded, a route is already known and can be used immediately. Once the routing tables are setup, then data (packets) transmissions will be as fast and easy as in the traditional wired networks. Unfortunately, it is a big overhead to maintain routing tables in the mobile ad hoc network environment. Therefore, the proactive routing protocols have the following common disadvantages: 1. Respective amount of data for maintaining routing information. 2. Slow reaction on restructuring network and failures of individual nodes. Proactive routing protocols became less popular after more and more reactive routing protocols were introduced. In this section, we introduce three popular proactive routing protocols DSDV, WRP and OLSR. Besides the three popular protocols, there are many other proactive routing protocols for MNAET, such as CGSR, HSR, MMRP and so on.

6.5.2. Reactive Routing Protocols

In bandwidth-starved and power-starved environments, it is interesting to keep the network silent when there is no traffic to be routed. Reactive routing protocols do not maintain routes, but build them on demand. A reactive protocol finds a route on demand by flooding the network with Route Request packets. These protocols have the following advantages: 1. No big overhead for global routing table maintenance as in proactive protocols. 2. Quick reaction for network restructure and node failure. Even reactive protocols have become the main stream for MANET routing, they still have the following main disadvantages: 1. High latency time in route finding. 2. Excessive flooding can lead to network clogging. There are many reactive routing protocols for MANET. We only introduce three popular (AODV, DSR and DYMO) and one new (ODCR) protocols in this section.

6.5.2.1. *Advanced On Demand Distance Vector Routing Protocol :* Ad hoc On-Demand Distance Vector (AODV) Routing is a routing protocol for mobile ad hoc networks (MANETs) and other wireless ad-hoc networks. It is jointly developed in Nokia Research Center, University of California, Santa Barbara and University of Cincinnati by C. Perkins, E. Belding-Royer and S. Das. AODV is capable of both unicast and multicast routing. It is a reactive routing protocol, meaning that it establishes a route to a destination only on demand. In contrast, the most common routing protocols of the Internet are proactive, meaning they find routing paths independently of the usage of the paths. AODV is, as the name indicates, a distance-vector routing protocol. AODV avoids the counting-toinfinity problem of other distance-vector protocols by using sequence numbers on route updates, a technique pioneered by DSDV. In AODV, the network is silent until a connection is needed. At that point the network node that needs a connection broadcasts a request for connection. Other AODV nodes forward this message, and record the node that they heard it from, creating an explosion of temporary routes back to the needy node. When a node receives such a message and already has a route to the desired node, it sends a message backwards through a temporary route to the requesting node. The needy node then begins using the route that has the least number of hops through other nodes. Unused entries in the routing tables are recycled after a time. When a link fails, a routing error is passed back to a transmitting node, and the process repeats. Much of the complexity of the protocol is to lower the number of messages to conserve the capacity of the network. For example, each request for a route has a sequence number. Nodes use this sequence number so that they do not repeat route requests that they have already passed on. Another such feature is that the route requests have a ”time to live” number that limits how many times they can be retransmitted. The third feature is that if a route request fails, another route request may not be sent until twice as much time has passed as the timeout of the previous route request.

Technical Description : The AODV Routing protocol uses an on-demand approach for finding routes, that is, a route is established only when it is required by a source node for transmitting data packets. It employs destination sequence numbers to identify the most recent path. The major difference between AODV and Dynamic Source Routing (DSR) is that DSR uses source routing in which a data packet carries the complete path to be traversed; however, in AODV, the source node and the intermediate nodes store the next-hop information corresponding to each flow for data packet transmission. In an on-demand routing protocol, the source node floods the RouteRequest packet in the network when a route is not available for the desired destination. It may obtain multiple routes to different destinations from a single RouteRequest. The major difference between AODV and other on-demand routing protocols is that it uses a destination sequence number (DestSeqNum) to determine an up-to- date path to the destination. A node updates its path information only if the DestSeqNum of the current packet received is greater than the last DestSeqNum stored at the node. A RouteRequest carries the source identifier (SrcID), the destination identifier (DestID), the source sequence number (SrcSeqNum), the destination sequence number (DestSeqNum), the broadcast identifier (BcastID), and the time to live (TTL) field. DestSeqNum indicates the freshness of the route that is accepted by the source. When an intermediate node receives a RouteRequest, it either forwards it or prepares a RouteReply if it has a valid route to the destination. The validity of a route at the intermediate node is determined by comparing the sequence number at the intermediate node with the destination sequence number in the RouteRequest packet. If a RouteRequest is received multiple times, which is indicated by the BcastID-SrcID pair, the duplicate copies are discarded. All intermediate nodes having valid routes to the destination, or the destination node itself, are allowed to send RouteReply packets to the source. Every intermediate node, while forwarding a RouteRequest, enters the previous node address and its BcastID. A timer is used to delete this entry in case a RouteReply is not received before the timer expires. This helps in storing an active path at the intermediate node as AODV does not employ source routing of data packets. When a node receives a RouteReply packet, information about the previous node from which the packet was received is also stored in order to forward the data packet to this next node as the next hop toward the destination.

Advantages of AODV :. The main advantage of this protocol is that routes are established on demand and destination sequence numbers are used to find the latest route to the destination. The connection setup delay is lower. It creates no extra traffic for communication along existing links. Also, distance vector routing is simple, and doesn't require much memory or calculation.

Disadvantages of AODV :. AODV requires more time to establish a connection, and the initial communication to establish a route is heavier than some other approaches. Also, intermediate nodes can lead to inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number, thereby having stale entries. Also multiple RouteReply packets in response to a single RouteRequest packet can lead to heavy control overhead. Another disadvantage of AODV is that the periodic beaconing leads to unnecessary bandwidth consumption

6.5.3. Hybrid Routing Protocols

This type of protocols combines the advantages of proactive and reactive routings. The routing is initially established with some proactively prospected routes and then serves the demand from additionally activated nodes through reactive flooding. The choice for one or the other method requires predetermination for typical cases. The main disadvantages of such algorithms are: 1. Advantage depends on amount of nodes activated. 2. Reaction to traffic demand depends on gradient of traffic volume

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