DESIGN, DEVELOPMENT AND EVALUATION OF EFFICIENT ROUTING ALGORITHMS FOR MOBILE AD HOC NETWORKS

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By

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DESIGN, DEVELOPMENT AND EVALUATION OF EFFICIENT ROUTING ALGORITHMS FOR MOBILE AD HOC NETWORKS

Ph.D. Thesis in the field of Computer Science

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Dedicated to

My Parents

Mr. K Gopinathan Nair

&

Mrs. V S Vimala Kumari

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Certificate

This is to certify that the thesis entitled ***"Design, Development and Evaluation of Efficient Routing Algorithms for Mobile Ad hoc Networks"*** *is a bonafide record of the research carried out by* ***Mrs. Preetha K G*** *under my supervision and guidance at the Department of Computer Science, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, Cochin University of Science and Technology and has not been included in any other thesis submitted previously for the award of any degree..*

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Declaration

I, Preetha K G hereby declare that the work presented in the thesis entitled "Design, Development and Evaluation of Efficient Routing Algorithms for Mobile Ad hoc Networks" is submitted to Cochin University of Science and Technology is based on the original research work done by me under the supervision of Dr. A Unnikrishnan, Scientist H (Retired), NPOL, DRDO, Kochi, Kochi and has not been included in any other thesis submitted previously for the award of any degree.

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Preface

Over the last decade, advances in wireless technology and hand-held computing devices have brought revolution in the area of mobile communication. The increasing mobility of humans across the globe generated demand for infrastructure-less and quickly deployable mobile networks. Such networks are referred to as Mobile Ad hoc Networks (MANET). In general, Ad hoc networks are suited for use in situations where infrastructure is unavailable or to deploy one is not cost effective, to cater for an impending requirement. MANETs qualifies best, when the application demands quick network configuration and faces difficulty to set up the infrastructure for communication. In MANET, there is no central controller to regulate the events and every individual node participates in the network administration. Node mobility is not predictable in MANET, so that the topology keeps changing dynamically, thereby making the decision of routes also dynamic. The frequent movement of nodes and the deteriorating energy levels in nodes undermine the sustained availability of routes. Literature is abuzz with an opulent collection of solutions and techniques to tackle the problems of routing in MANETs.

Ever since its inception in the 70s, the MANET has grown in coverage and diversity of applications. The Ad hoc structure of the network, thanks to the mobility leads to randomness in the behaviour of the network in respect of packet delivery and turnaround time. Accordingly, the areas pertaining to route identification, data security, data replication and reliable data delivery have always attracted the attention of researchers all over the world. It is well known that the routing in MANET often poses very intricate problems due to the highly mobile nature of the nodes. The high mobility leads to frequent disruption in route, when the intermediate node informs the incidents via special packets to the source.

The lack of infrastructure ensures that MANET is free from total failure due to disasters and natural calamities. The self-organizing and self-maintaining capability makes the MANET a well acknowledged candidate, in situations where the network is required to be set up and operated quickly. Mobile nodes have limited memory, low power consumption and light weight and are easy to maintain. The nodes can be equipped with different hardware and software capabilities, enlarging the flexible options available in the construction of network. Accordingly, the MANET holds promise to be the proper choice in the context of disaster management and military operations, which necessitate quick actions. The administrative decisions including routing, error control and security are distributed among the nodes and the chances of single point failure are very low. Even if there is no direct link between sources to destination, then the source can reach the destination via wireless multi-hop links. Since each node in the network is highly mobile, the node movement is unpredictable, and each node has the freedom to enter and leave the network at any time. The network is thus easily scalable. Any node with adequate equipment and wireless technology can access the open medium of wireless channel at any moment. As a result, MANET is the right choice for any time-anywhere networking.

The establishment of routes, with limited control overhead and re-establishment of route quickly after a route failure are mandatory requirements of good routing algorithms. While reviewing routing protocols, it was observed that algorithms for routing in MANET required further explorative development. Routing of data in MANET involves three major steps (i) Route establishment (ii) Route maintenance, and (iii) route re-establishment in the event of a failure. A major step in the route establishment is the flooding of route request packets (RREQ). In order to assuage the problems of flooding, the present work concentrates on the establishment of alternate approaches in the route discovery process, using restricted flooding. The new approaches are developed and demonstrated on the presumption that in on demand algorithms, each node forwards the message to its neighbours for route establishment, based on the chances of detecting the destination node and node reliability. The proposed alternative has resulted in the reduction of control overhead. Frequent failure of the nodes on account of the high mobility is a bane in MANETs and, any route failure reported makes it mandatory for the source node to find an alternate route. In order to alleviate the problem of frequent node failure, the thesis proposes a new approach to establish route through domination nodes maintain the long-lived route in the network, so that it could ensure the stable routing. The high connectivity available in the dominating set are effectively utilized to establish dependable routes. While this approach is shown to have resulted in the improvement of packet delivery ratio (PDR) and control overhead, further improvements could be achieved by developing a decision function based on residual energy of the node and the packet transmission through the nodes in the dominating set. With a view to evolve a routing strategy accommodating the dynamic nature of MANET, the establishment of consistent routes based on belief propagation strategy is effectively utilized in the present work to predict the longevity of the links, thus achieving improved performance. Incorporating the residual energy of nodes in developing the decision function led to further improvement of PDR and control overhead.

The algorithms are demonstrated on network of varying complexity and evaluated for different durations. The performance metrics are also computed through independent Monte Carlo runs in order to assess the comparative performance of the proposed algorithms with other well established algorithms.

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Abbreviations

ABR	Associativity Based Routing
AODV	Ad hoc On- demand Distance Vector
BER	Bit Error Rate
BP	Belief Propagation
BR	Bit Rate
CDS	Connected Dominating Set
CEDAR	Core Extraction Distributed Ad hoc Routing
CGSR	Cluster- head Gateway Switch Routing
CSMA	Carrier Sense Multiple Access
DARPA	Defence Advanced Research Projects Agency
DBR	Dominating Set Based Routing
DID	Destination ID
DS	Dominating Set
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
GPS	Global Positioning System
GSCBP	Gaussian Sum Cubature Belief Propagation
GSR	Global State Routing
HSR	Hierarchical State Routing
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISO	International Standard Organisation

LAR	Location Aided Routing
LPR	Link Prediction Routing
MANET	Mobile Ad hoc Network
MCDS	Minimum Connected Dominating Set
MODEM	Modulator and Demodulator
MP	Markov Process
NS2	Network Simulator Version 2
OLSR	Optimised Link State Routing
OSI	Open Systems Interconnection
PAR	Power Aware Routing
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PRNET	Packet Radio Network
RABR	Route Lifetime Assessment Based Routing
RDBR	Reliable Dominating Set Based Routing
RLPR	Reliable Link Prediction Routing
RREP	Route Reply Packet
RREQ	Route Request Packet
RRER	Route Error Packet
SID	Source ID
STAR	Source Tree Adaptive Routing
TCP	Transmission Control Protocol
TNDR	Threshold Neighbourhood Distance Ratio
TORA	Temporarily Ordered Algorithm

TTL	Time to Live
UGSN	Underground Sensor Network
UWSN	Underwater Sensor Network
VANET	Vehicular Ad hoc Networks
WMN	Wireless Mesh Networks
WRP	Wireless Routing Protocol
WSN	Wireless Sensor Networks
ZRP	Zone Routing Protocol

Chapter 1

INTRODUCTION

1.1 Background & Motivations

A noteworthy feature of the evolution of species, as Charles Darwin postulated, is the increasing urge to communicate among those who live around, as the generations evolved. The need to express the emotions could have been the motivating factor to start communications. From hand guster to spoken words and then to written messages, communication grew with the evolutions. As the present century dawned, electronic messaging stated showing promise thanks to Mathematical wizards like JC Maxwell [1] and subsequently to practical developers like JC Bose [2], Alexander Grahambel [3] and G Marconi [4]. The last decade witnessed the healthy blend of Computers and Communication, which helped world to push further the limits of speed and density in communication. Digital Communication became the order of the day and voice, words, text and video - all forms of communication started going together, making the world short in terms of access, if not physical. The astonishing stride in the electronic device technology and packaging made the communicating devices literally handy. As in the case of motor car syndrome, faster communication with more facilities was the minimum that anyone could ask for. Handling many channels originating from a mixture of fixed and mobile sources, with no compromise on bit rate (BR) and bit error rate (BER), all became easy to integrate, with embedded computers calling for the shots. While acknowledging the developments in the antenna technology, especially smart antennas, one cannot but reduce the visible influence of the embedded technology in the development of the modern communication systems.

A glance over the history of communication would be in order, to appreciate the present strides towards networked communication. In the Stone Age era, people relied on signals which helped in conveying the thoughts or ideas to a larger group. It is said that the history of new age communication started here. The tribes in Africa, Latin America and Asia made use of smoke signals and drums to alert /indicate something important, in the form of a warning. Waving flags was another mode of communication, where the colour of the flag and the sequence of waving the same conveyed the message. Communication over longer distances became possible, when Pigeons were used as carriers. However, all these modes of communication remained as a point to point message passing. History also chronicles the usage of beacons for Communication. In the Scottish borders, a system of beacon fires gave warning signals about the incursions by the English, where a network of beacons atop the Hume and Egger stone castles and Soltra Edge were operational.

Modern communication history starts from the earlier telephone networks, meant for voice communication though, the telegraph was arguably one of the most effective tools of communication as a precursor to the telephone. The wired system was difficult to set up and maintain during operation and naturally the coverage was restricted to limited areas only. Further developments in telephone like carrier communication and wireless communications pushed the ranges further, which then became the pivotal factor in the two world wars. Gradually, the earlier mode of analogue signalling gave way to much more accurate and efficient digital communication systems, mobilising the introduction of mobile telephony. Remote access to computers was soon made possible, facilitating the access to remotely located computer systems. Computer networks evolved as a collection of autonomous computers inter connected by communication medium. As early as 1940, George Stibitz [5] had sent commands to the Complex Number Computer in New York over telegraph lines. While the manually managed mechanical telephone exchanges struggled to provide channel wise interconnection, automated connection establishment from any point to any point still remained a dream.

The healthy marriage of computer and communication threw open a host of the possibilities of communication among computers. The commercial airline system, SABRE developed by IBM in the early 60s stands out as the earliest initiative in networking computers. Linking the computers together and laying down the rules to talk to each other launched a new scheme for communication viz. networked communication among computers. The US defence department introduced a research project called ARPANET in 1969 for connecting the different types of computers for resource sharing. High speed digital channels were soon developed that fuelled further growth in the development of communication networks.

The computer networks of earlier designs utilized the existing telephone lines, which were laid out and widely operational at that point of time. MODEMs (Modulator and Demodulator) incorporating the state of art designs in data communication were used extensively to communicate over telephone lines. Though the wireless technology was used to transmit digital data over long distances, the data transfer had to be limited to circuit switching, where by the route remain locked between the sender and the receiver. In order to ensure multiplexed data transmission from different channels, the packet switching was introduced by an

English scientist, Donald Davies. Slicing the message into equal sized packets and delivering the packets along available routes revolutionized the concept of data transfer ensuring high throughput and effective utilization of available bandwidth, promising message integrity. Towards this end protocols evolved in order to rationalize the exchange of packets. Interoperability of different devices are solved by developing a common standard in the networking area by International Standard Organization (ISO). The protocols and standards are called Open Systems Interconnection (OSI) standards [6]. Though emails and files were transmitted successfully the coverage was limited to short distance. Worldwide connectivity still remained a dream.

The evolution of internet, initially defined to describe internetworking [7] led to standardization of protocols. Widely spread protocols used in internet communication viz. Internet Protocol (IP) and Transmission Control Protocol (TCP) were introduced in 1974 [8]. The resulting TCP/IP protocols were incorporated into the ARPANET in 80s.

Based on the realization of the physical layer, computer networks are classified into wired and wireless networks [9] (Fig. 1.1). While the wired networks use physical cables like coaxial cable, twisted pair cable and fibre optic cables, the wireless connection is realised through RF links operating from the MHz to

GHz frequency range. The first professional wireless network ALOHAnet developed in 1969 uses the UHF frequency range.

The invention and increased usage of portable and advanced computing devices like laptops, personal digital assistant (PDA), tablets and various designs of mobile phones introduce mobility as a major component to be addressed in wireless data transfer. The term ‘mobile’ has helped to turn the dream of networking at any place and at any time into reality. While all mobile devices uses wireless connectivity for data transfer, the practical realization further falls into two categories viz. infrastructure based and infrastructure independent.

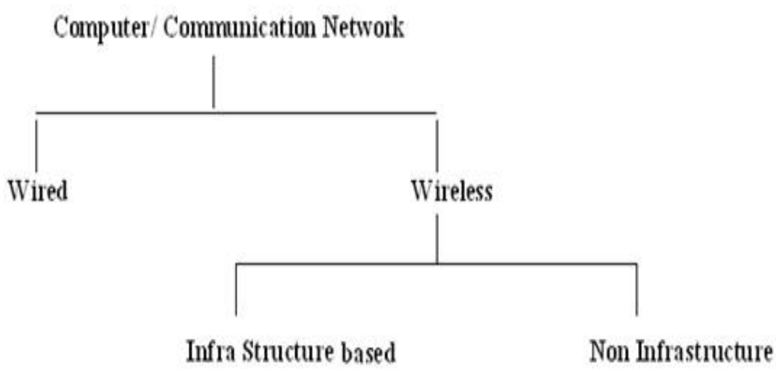


Fig. 1.1: Classification of Communication Network.

1.1.1 Infra-Structure Based Network

Infrastructure based networks requires an access point to which mobile devices establish connectivity as illustrated in Fig.1.2. The access point is responsible for coordinating the activities like providing connectivity, routing, selection of bandwidth and secure data transfer [10]. Cellular networks and wireless LAN thus fall under the category of infrastructure based network. These networks also come under the category of single hop networks, where the device can gain access only through access point. However, the access point imposes some restrictions on the mobility of the devices connected.

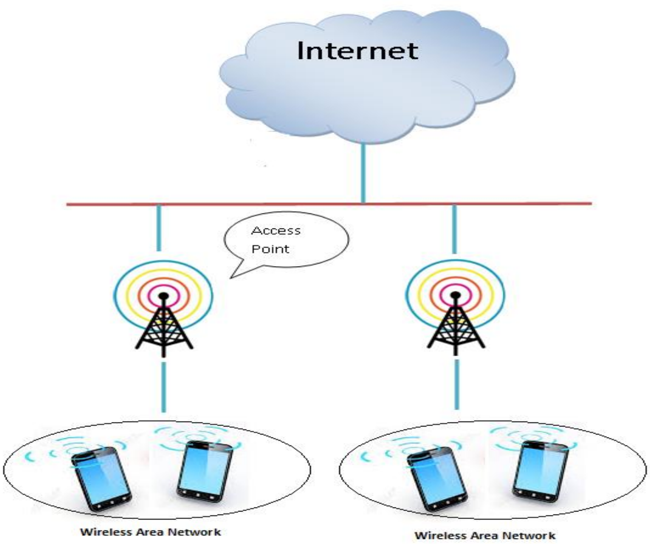


Fig. 1.2: Infrastructure Based Network.

1.1.2 Non Infra- Structure Network

In the absence of an infrastructure supporting, the network is established and configured whenever it is required. Mobile Ad hoc Network (MANET), describing a network instantaneously configured for a specific task is a typical example of this class of networks. The term ‘Ad-hoc’ is a Latin word meaning ‘for this’ or ‘for this only’ [11]. Two kinds of Ad hoc networks exist, Static Ad hoc networks and Mobile Ad hoc networks. While in static networks, the devices are fixed with the moving capability disabled, in the case of Mobile Ad hoc networks (MANET) the devices are highly mobile and free to move. The devices in the network are self-organizing and self-configuring to form a multi hop network. Historically, the term MANET is used in military research during early 70's and 80's, as a tactical network, meant to improve battlefield communications/survivability. MANETs maintain a dynamic interconnection among the mobile users, thereby providing the facility to communicate at any place and at any time. With no assigned central coordinator/router in MANET, all nodes are considered as source or router and the control of the network is distributed among nodes. Defence Advanced Research Projects Agency (DARPA) developed Packet Radio Network (PRNET) in 1972 [12] is an early attempt in the realization of mobile ad hoc networking. The distributed architecture of PRNET consists of network of broadcast radios with minimal central control. Aloha and Carrier Sense Multiple Access (CSMA) channel access protocols are used to support the dynamic sharing of the broadcast radio channel. The implementation uses multi hop technology and store & forward technique for communication within a very large geographic area. A typical MANET is illustrated in Fig.1.3.

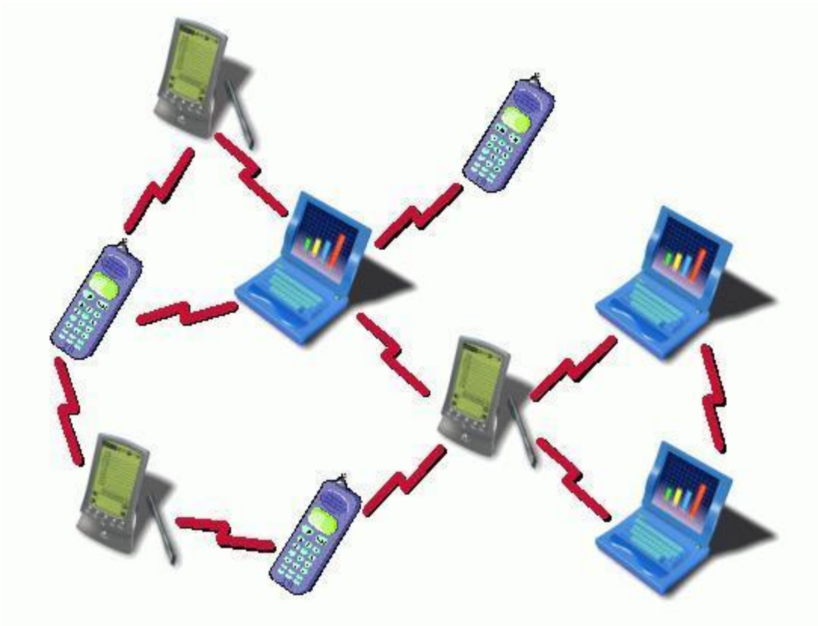


Fig.1.3: Typical MANET

(Courtesy: http://www.eexploria.com/manet-mobile-ad-hoc-network-characteristics-and-features/).

1.1.3 Types of MANET

There are three different types of MANETs in operational at present. They are Vehicular Ad hoc Networks (VANET), Wireless Sensor Networks (WSN) and Wireless Mesh Networks (WMN). VANET is a mobile ad hoc network in which the nodes are moving vehicles. The network is established between moving vehicles, which communicate for handling emergency situations. A typical scenario of VANET is given in Fig. 1.4, where the ambulance could be able to acquire priority at the junction through multi hop communication.

WSN consists of small, lightweight and portable sensor nodes, deployed densely over a large area in order to assess the situation. The main application areas of sensor networks are seismic and atmospheric changes, agriculture, animal tracking, health care, security, surveillance, transportation, energy control systems etc. The web of sensors deployed could be a hybrid mix of mobile and static in nature. A typical scenario is depicted in Fig. 1.5.

WMN is a type of ad hoc networks which contains a collection of mobile nodes capable of communicating each other. Mesh topology provides more than one path to the destination. It is a high speed, low cost and self-organizing network. Typical examples include

1) the US military WMN meant to connect their computers in field operations.

2) electric meters deployed in residences, which communicate each other and transfer their readings from one to another and finally reach at the central office for billing without human interaction.

Fig.1.6 shows the example of mesh network.

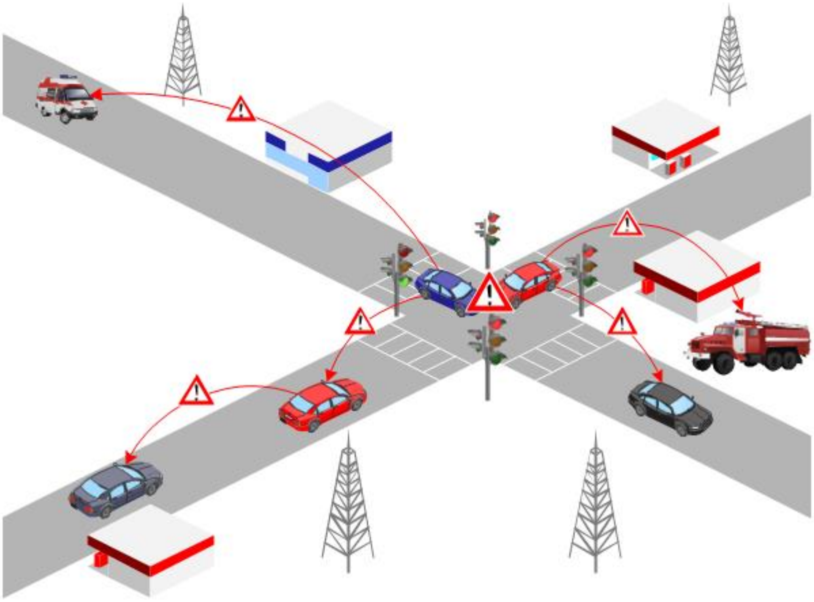


Fig.1.4: Example of VANET

(Courtesy: http://www.conceptdraw.com /examples/vehicular-networking).

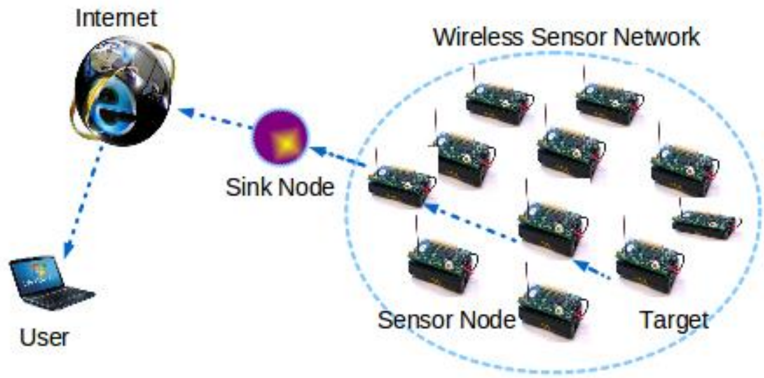


Fig. 1.5: Example Wireless Sensor Network (Courtesy: https://www.quora.com/What-is-wireless-sensor-network-WSN-technology).

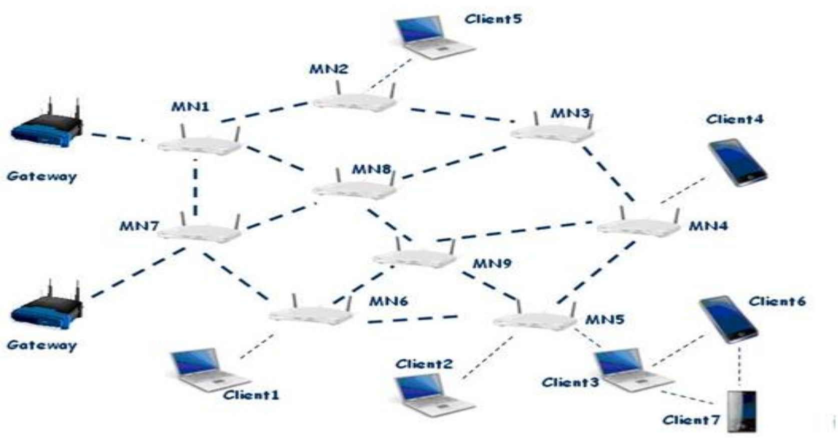


Fig. 1.6: Example Wireless Mesh Network (Courtesy:http://www.cnri.dit.ie/research.mesh.security.html).

1.2 Scope and Relevance of Research

Ever since its inception in the 70s, the MANET has grown in coverage and diversity of applications. The Ad hoc structure of the network, thanks to the mobility leads to randomness in the behaviour of the network in respect of packet delivery and turnaround time. Accordingly, the areas pertaining to route identification, data security, data replication and reliable data delivery have always attracted the attention of researchers all over the world. In order to get a better appreciation of the research challengers a brief overview of the unique characteristics of MANET and its applications are in order, which is presented in the section to follow.

1.2.1 MANET- Unique Characteristics

As was seen in the previous sections the MANET stands to possess many unique characteristics which makes it flexible and at the same time robust also. The lack of infrastructure ensures that MANET is free from failure due to disasters and natural calamities. The self-organizing and self-maintaining capability makes the MANET a well acknowledged candidate, in situations where the network is required to be set up and operated quickly. Mobile nodes have limited memory, low power conception and light weight and are easy to maintain. The nodes can be equipped with different hardware and software capabilities, enlarging the flexible options available in the construction of network. Accordingly the MANET holds promise to be the proper choice in the context of disaster management and military operations, which necessitate quick actions. There is no centralized administrative mechanism and each device or nodes in the network interchangeably plays the role of router and source. The administrative decisions including routing, error control and security are distributed among the nodes and the chances of single point failure are very low. Even if there is no direct link between sources to destination, then it can communicate via wireless muti-hop links. Since each node in the network is highly mobile, the node movement is unpredictable, each node has the freedom to enter and leave the network at any time. The network is thus easily scalable. Any node with adequate equipment and wireless technology can access the open medium of wireless channel at any moment. As a result MANET is the right choice for any time-anywhere networking.

1.2.2 Applications

Over the last many years the MANET design has matured to provide concrete solutions in a variety of application areas. Some typical instances of application areas are addressed below.

Military Applications: MANET is the right choice when it comes to setting up a military base quickly for operation. The communication infrastructure and the network of sensors grab the troupe movement in real time. Since the operation scenario demands high mobility of the platforms carrying the sensors, the MANET technology furnishes the effective and easy to implement solutions.

Commercial Use: Quick connection between various handheld devices like laptop, cell phone, PDA etc. is possible. The present day smart phone owes a lot to the developers of MANET, thus making it possible for the smart phones to handle voice, text and video in the same channel. The infrastructure less property can be use for connecting the devices at anytime, anywhere.

Collaborative Computing: Devices used for different applications can also connect together and communicate each other for a special purpose. The possibility of establishing connection over a wide area, makes also possible for the MANET to perform distributed computations like collaborative signal processing and distributed tracking. After the use, the network can be disconnected.

Rescue & Emergency Situations: During the emergency, the network is established quickly and does the needful. For example, in case of any accident occurs, the network is established, the situation of the patient is analysed and inform the nearby hospital immediately. Then the hospital can prepare to accept the patient and give maximum care.

Health Care: MANET can be useful for connecting the doctors and patients both stationary and travelling. The doctors can easily track the status of each patient, who is being rushed to hospitals from accident sites. The hospitals and rescue vehicles like ambulance, which are in network can better gear up for handling emergency situation.

Education: The network can be put to maximum use in education. University libraries can be interconnected by using this temporary network in order to support distance education to rural areas and moving vehicles like trains. Lecture classes and tutorials can be offered and listened from different points of MANET with wide coverage. World becomes closer by conducting quick conferences at short notice.

Research: MANET throws open a treasure of opportunities in research. The sensor network and vehicular network, which form the variations of ad hoc networks, can open up large avenues of research in seismic studies, atmospheric sciences, ocean modelling and object tracking. In fact the branch of multi sensor data fusion, which has ramifications to many other branches like stochastic signal processing, information theory and theory of evidences, is a very promising spin off from the MANET evolution.

1.3 Research Challenges in MANET

Table 1.1 brings out the major characteristics of the MANET vis-a-vis the resulting issues, turning the spotlight on some of the research challenges, required to be addressed. In spite of the rising interest, the MANET imposes serious challenges and inadequacies in communication due to unlimited mobility of nodes, dynamic topology and limited connectivity caused by the limited transmission range of signal from a node. Major challenges are portrayed in Fig. 1.7. Nodes in the network can freely move so the topology change is random and unpredictable. Due to the frequent short lived disconnections, path failures are very frequent in MANET. Dynamic topology leads to the chances of collision, transmission error, and packet loss. Performance and throughput of the network is largely influenced by these factors.

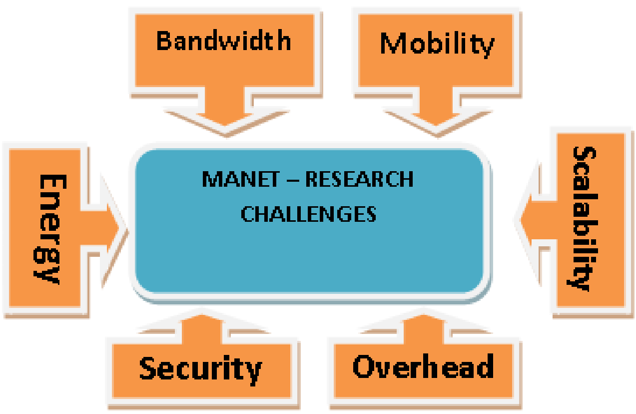


Fig. 1.7: Major Challenges in MANET.

Characteristics	Issues
Mobility- Any time anywhere Networking	Dynamic Topology changes- network partition and data loss
Mobile nodes are small light weight devices	Less memory, Less power
Lack of centralized administration- self configuring	Network management has to be distributed- Routing and security issues
Open Medium- Wireless links shared by all users	Security, Reliability, Efficiency, Stability and Capacity of wireless links are less. Fading path loss, blockage, limited bandwidth and interference,
Autonomous in Behaviour- multi hop routing	Increase network overhead

Table1.1: Characteristic Features and Resulting Issues.

1.3.1 Bandwidth

Bandwidth of the wireless media is very limited and it is shared by many users, so number collisions, contentions and chances of errors are more in MANET. Special characteristics of wireless media like fading, multipath propagation, interference, noise etc. induces more irritations in communication. Data rate of the wireless medium is also less compared to wired medium [13]. Efficient utilization of bandwidth is a major challenge in MANET.

1.3.2 Energy/Power

Another important constraint is energy/ power. All the nodes in the network are wireless and they are running on battery power. All nodes are considered either source or router and are mandated to be active most of the time. The absence of a central administrator distributes the responsibilities to the nodes. Even if a node does not want to send the message, it has to participate in the routing as a forwarder, forcing the node to spend some additional energy. There is an extra toll of energy, if some computational capability is enforced in each device to execute intelligent operations also. The resulting drain of energy could become prohibitive at times. Efficient optimization of power in deciding the utilisation of the network thus turns out to be a major challenge in MANET.

1.3.3 Mobility

Mobility of the nodes leads to frequent failure of links, which in turn can reflect on the network performance significantly. The fact that this movement is unexpected and unpredictable, adds to the woes and worries of maintaining reliable connections in the network. When the intermediate nodes move randomly, the route from the source to destination breaks and sometimes the destination is partitioned into another network. As a result, the multi-hop routing, which is the hall mark of MANETs, fails to give the promised packet delivery. This could also lead to many messages passing actions, for determining the route to the destination.

1.3.4 Overhead

MANET research is aimed at developing the algorithms and protocols for communication. Routing algorithms are broadly classified into table driven or on demand [14]. While table driven strategy uses the stored routing information from routing table, the on demand algorithms arrive at the routes as and when required. The research findings and practical realizations show that on demand routing algorithms are more suitable than the table driven algorithms for MANETs. But on demand routing strategy necessitates the transmission of large number of control packets to establish the route. Obviously these control packets can induce more overhead in the network. When the devices move from one location to another, they should retain their contact to neighbours. Similar update is solicited when the participating nodes want to welcome a newly arrived node to the network. The node discovery process also necessitates the exchange of many control packets. In short, addressing and configuration management of the network is a daunting tasks and raises major important challenges in design of routing algorithms in MANET.

1.3.5 Scalability

Network size varies from application to application. It has been shown that the throughput per node comes down with the increase in the number of omnidirectional antennas used for transmission [15]. Limitations in the available bandwidth and also the radiation pattern of the antenna could hamper scalability. Control overhead also could increase when the number of node goes up which in turn may affect the scalability. All these issues have serious implications on the design of routing protocols vis-à-vis scalability of the network.

1.3.6 Security and Reliability

Reliability of the routes established is absolutely imperative for sustained operation of MANET. Reliability of the wireless communication is based on the transmitted power, node proximity and node energy. One of the major issues bringing down the reliability is the packet loss, which occurs because of short lived routes, hidden and exposed terminal problems, collisions, link breakage and interferences. Due to the dynamic nature of the network, the possibility of stale routes getting accumulated is also very high. Consequently, the route saved in the cache may not be valid in all cases. Selfish and malicious behaviour of the nodes, when some nodes drop the packets intentionally to save their precious resources, which can also reduce the reliability of the data.

Since wireless medium is shared by all nodes, the security issues are more in MANET than in wired network. Development of the routing algorithms with guaranteed performance thus turn out to be the hot research topic in the area of MANET.

1.4 Identified Objective

The review of the challenges in the previous section brings clearly the requirement of well designed, robust and effective routing algorithms. The establishment of such routes, with limited control over head and re-establishment of route quickly after a route failure are imperative in the case of good routing algorithms. Towards this end, the following objective have been identified as part of the present research work.

- To conduct a detailed literature survey to take stock of the current state of the art routing techniques and algorithms in the field of mobile ad hoc networks.
- To conduct a detailed study of the existing routing protocols and to evaluate the performance issues of existing protocols.
- To evaluate the performance of existing protocols using network simulator over a variety of complex wireless network models and configurations. Simulate various protocols using these models in Network Simulator (NS2) and compare the performance against some well-established performance parameters.

While reviewing routing protocols, it was observed that algorithms for routing in MANET required further explorative development.

- To devise, develop and demonstrate new algorithms to

  (i) reduce the control overhead in on demand routing algorithms for mobile ad hoc networks.

  (ii) refine the routing strategy by using efficient dominating set.

  (iii) device a method for predicting the future status of the network, which can be used for further performance improvement in routing protocols.

  (iv) finally evaluate and compare the performance of routing algorithms, through Monte Carlo simulations.

Towards this end the thesis is organised as in Section 1.5.

1.5 Layout of the Thesis

Chapter 2 presents the review of the literature relevant to the topic addressed in the thesis.

Chapter 3 gives a detailed study on the table driven, on- demand and hybrid routing protocols. Performance comparison is demonstrated using simulation.

Chapter 4 delineates a method to reduce the control overhead caused by RREQ flooding, by using fuzzy decision function on success rate and residual energy. Performance improvement is verified using simulation study.

Chapter 5 focuses on the concept dominating set in graph theory and the same is used for developing routing protocols for performance improvement, demonstrated through simulation.

Chapter 6 examines the structure of the network and devices an algorithm for finding the routes based on belief propagation, thus predicting the existence of routes. The improvement in reliable and robust computational routes is demonstrated.

Chapter 7 assess and compare the performance of routing algorithms proposed and developed.

Chapter 8 recapitulates the research work and make recommendations for future work.

Chapter 2

LITERATURE REVIEW

The development in MANET dates back to 1990, when Charles Perkins, SUN Microsystems USA and Chai Keong Toh, Cambridge University independently started working on the key issues in dynamic addressing and routing protocols. Since then the literature is swamped with a plethora of opulent material reported by a large number of researchers. The present chapter highlights some of the research contributions, relevant to the area of routing in MANET, which is addressed in the work reported.

2.1 Routing in MANET

Organized research in Ad hoc network started for military purposes. Subsequently from the late 90s, the benefits of MANET started spreading outside the battle field, thanks to the wider awareness of radio technology. Since then MANET has become popular among the research community. The research work on MANET starts in 1996 by IETF [16] (Internet Engineering Task

Force), which reported the summary of the discussions of the working group, deliberating the design and performance issues of MANET. A series of research reports, addressing the formative aspects like terminology, applicability, protocols and performance issues, soon found place in the literature regularly. Soon the research community became aware of the exciting applications of MANET, ranging from communication to commerce [17].

The unique features of MANET bring out great opportunity in data communications, at the same time highlighting some serious challenges as well [18]. It is well known that the mobility of the nodes in MANET adds to the randomness in the behaviour of the network, which in turn can affect the routes established [19]. Accordingly the design of MANET turns out to be very critical. As reported in [20], the self-organized and autonomous nature of MANET assigns equal responsibility to receive and forward the data to every single node. There is no router or central administrator to control the activities and all the nodes must contribute their resources for data delivery from source to destination. In dynamic networks the nodes are highly mobile and wireless links are disrupted frequently [21]. The development of efficient routing algorithm poses a serious challenge to the researchers in MANET. As a result, conventional routing algorithms which are used in wired networks are not suitable and ineffective in these types of networks. Remarkably enough, the challenges paved the way for the development of routing protocols specific to MANET [22]. Seamless connectivity became pivotal to all those routing protocols.

2.2 Design Issues of Routing Protocols

The routing protocol proposed for MANET always considers the dynamic nature and frequency of topology changes. The following design issues have a profound impact on the design of routing protocols, which has been extensively reviewed in [23].

- **Distributed Operation**: Due to the absence of a coordinator, the routing decision must be distributed all over the network. So the routing does not rely on a particular node, and hence the network is free from single point failure.
- **Loop-free Operation**: While selecting the routes, all routing protocols should be loop free in order to avoid wastage of bandwidth.
- **Demand-based Operation**: In the light of the limited resources available with each node and also the dynamic nature of the network, it becomes imperative that the route finding task undertaken by each node should impose only minimum burden to the node. On-demand approach to the establishment of route is the right choice to alleviate the problem of extra load on each node.

- **Secured Operation**: Because of the wireless environment, the network is susceptible to intrusion, when security issues have added significance to be addressed in the design of protocols.
- **Sleep Period Operation**: Mobile nodes are running on battery. Limited battery capacity and processing capability have to be addressed in the context of reducing power consumption. The node goes into sleep mode, when not in operation. Nodes in the MANET often exhibit "malicious behaviour" of not transmitting any data to support routing, in order to save power. Design of routing protocols have to accommodate this aspect, so as to ensure the continuous availability of establish routes.
- **Unlimited Mobility**: Random movement of the nodes leads to link failure while excessive transmission lead to failure of nodes. A routing protocol which can guarantee continuous route, with minimum reestablishment time, would be a major boon in ensuring sustained operation of the network.
- **Heterogeneous Devices**: MANET nodes can have heterogeneous characteristics, in respect of architecture and operating systems. The resulting system response across various nodes can lead to lethargy on the part of the nodes to process the real time interrupts which could result in bottlenecks in the network.

- **Delay Tolerant Operation**: The tremendous amount of connectivity, possibly directly and through multi hop can result in number of feasible path. Choosing the right path ensuring minimum round trip delay and route establishment time is a major challenge. The choice of route has a bearing on bandwidth, latency and stability.

2.3 Review of Reported Work in Routing

Due to the high mobility and dynamic nature, routing is a critical task in MANET. The nodes move randomly and consequently links are made and broken arbitrarily. The resulting problems in deciding the choice of routes suggests itself that wired routing protocols are not suitable. Naturally the research community started focusing their attention towards the development of routing protocols specifically for MANETs. These protocols addresses various facets like wireless link quality, power limitation, mobility of nodes, multi user interference and capability to respond rapidly to the topological changes. The routing protocols for MANET are broadly classified into four basic categories [23], as shown in Fig. 2.1.

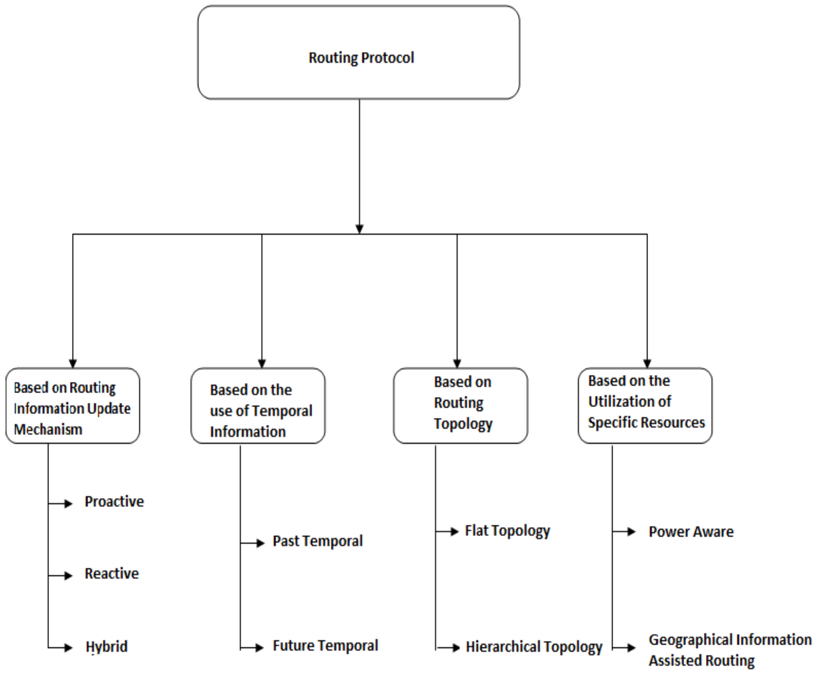


Fig. 2.1: Classification of Routing Protocols for MANET.

- **Based on Routing Information Update Mechanism:** In this category the routing protocols are divided into Proactive (Table Driven), Reactive (On Demand) and Hybrid. Proactive routing protocols maintain up to date information of the routes in routing table, whereas reactive routing protocol determine the route while it is needed. Hybrid routing protocol combines with the advantages of both proactive and reactive routing protocols. However with increase in size of network, hybrid protocols are seen to behave like proactive protocols [23,]. Typical examples falling into this category are Destination Sequenced Distance Vector (DSDV), Ad hoc On- demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Temporarily Ordered Algorithm (TORA).

- **Based on the Use of Temporal Information:** This category contains mainly two types of protocols. First one uses past information for finding the route and the second one predicts the future status based on the location information and power availability, to find the route. The protocols focusing on temporal information adds robustness to the network operation. Global State Routing (GSR) [24], Route Lifetime Assessment Based Routing (RABR) [25] and Load Balanced Routing [26] stands out as a crowning examples in this category.
- **Based on Routing Topology:** This category divides the routing protocols into flat topology and hierarchical topology. In the flat topology routing protocol, global addressing scheme is used whereas hierarchical routing protocol maintains the logical hierarchy between nodes while deciding the address. Example protocols developed under this category are Hierarchical State Routing (HSR) [27], Associativity Based Routing (ABR) [28] and Fisheye State Routing (FSR) [29].
- **Based on the Utilization of Specific Resources:** Two main types of routing protocols are developed under this. These are Power

Aware and Geographical Information Assisted routing. In the power aware routing the major concern is the consumption of battery power. In the geographical assisted routing, the location of each node is traced with the help of GPS. Example protocols are Power Aware Routing (PAR) [30] and Location Aided Routing (LAR) [31].

A look at the major developments reported in the literature on the protocols falling into the above classification could reveal the research initiative, so as to ignite new ideas in the development of protocols. Since the present work concentrates on the category "Based on the Use of Temporal Information", review of literature to follow has been limited to this category.

2.3.1 Table Driven/Proactive Routing Protocols

Introduced in 1994, the Destination Sequenced Distance Vector (DSDV) routing protocol is the first complete routing protocol for MANET, which evolved as an extension of the Bell man Ford Distance Vector routing protocol [32]. The algorithm mainly targeted the rectification of the routing loop problem. Freshness of the route is ensured by the use of a sequence number, associated with each entry in the routing table. In DSDV, the routing table is created by each node when the network is configured. The routing table is periodically exchanged between neighbours as in the case of distance vector routing protocol. The protocol is thus table driven/proactive and therefore quasi static.

The DSDV has attracted the attention of the researchers and many problems and improvement are discussed at length in literature. Paper [33] has reported the problem of multiplicity of the updates of the routing tables of similar nature in response to the message from neighbouring nodes. To alleviate this problem, [34] uses the concept of weighted settling time. If the update message received is for a known destination with a new sequence number, updates are not carried out immediately; but deferred until the weighted settling time to update. Stale routes are frequently reported in DSDV because of permanent nature of the routing table and the dynamic behaviour. The Efficient DSDV (Eff-DSDV) algorithm [35] overcomes the problem of stale routes by looking for the existence of the alternate route from host S to destination T, by sending one-hop ROUTE-REQUEST and ROUTE-ACK messages.

One of the main issue in DSDV algorithm is the excessive overhead. The ARM-DSDV [36] algorithm uses two controls to reduce the overhead. This approach maintains mobility metric, which dynamically adjusts the routing update period, and the route demand matric to regulate the content of routing updates. The updates are sent regularly only for the most recently used routes and sparsely for the rest.

Excessive broadcast which forms a major feature of DSDV algorithm results in the phenomena called broadcast storm, leading to network congestion. The Randomized-DSDV [37] algorithm eliminates the broad cast storm by randomizes the routing interval as per the routing probability distribution.

The authors of [38] studies the behaviour of DSDV with the power control algorithm CLUSTERPOW and demonstrates the reduction of the routing overhead. Paper [39] handles the link breakage by resorting to a route finding dynamically in the nearby locality, in response to a route break. The route reconstruction is attempted locally and the area is progressively increased dynamically, if route could not be established in a given area in a single hop.

Wireless Routing Protocol (WRP) [40] proposes four different tables namely Distance table, Routing table, Link-cost table and Message retransmission list table to maintain more accurate information. The tables separately store shortest distance, route information, link cost and message retransmission information. WRR approach can effectively improve the count-to-infinity problem in distance vector routing. Compared to DSDV, WRP has faster convergence and fewer table updates. But it needs more memory to store multiple tables.

The Cluster- head Gateway Switch Routing (CGSR) protocol [41] is a hierarchical protocol. The nodes are grouped into clusters and one node is elected as cluster head. Cluster head is responsible for creating and maintain the routing table for the network and coordinate the communication process, which reduces the number of routing table exchange and thus reducing the overhead. However, the frequent selection of cluster head and single point failure degrade the performance significantly. Also the node acts as cluster head, which needs more resources.

Optimized Link State Routing (OLSR) [42] protocol uses the concept called multi point relays to reduce the duplicated retransmission during flooding process. Some amount of control messages are also used to get the topological information to find the optimal path. Source Tree Adaptive Routing (STAR), another protocol falling in to the category of table driven protocols [43], maintains a partial topology map of their network. The router transmits the link state updates to its neighbours for those links along the path leading to the destination. The literature reports that STAR is the most efficient table driven routing protocol.

Though a number of attempts to use the table driven protocols in MANET are reported in the literature, the limited adaptability of dynamic changes and excessive overhead due to the exchange of routing tables have prompted the researcher to look for alternative approaches. All table driven routing protocols exhibit same degree of complexity among themselves during link failures and are not suitable for highly dynamic networks.

2.3.2 On- Demand/Reactive Routing Protocols

Very soon, the research community was convinced that the table driven protocol is not very effective for MANET, on account of its unpredictable behaviour [44]. In contrast to table driven algorithms, on demand routing protocols do not maintain the up to date routing information; but creates the routing table only when there is a demand. The first on demand routing algorithm Ad hoc on demand distance vector (AODV) was proposed in 1997 [44]. In AODV, the route establishment and route maintenance are carried out based on the flooding of a series of control packets viz. route request (RREQ), route reply (RREP) and route error (RERR), whenever there is a demand to establish the route. The literature also portrays a good number of problems and improvements on AODV.

Neighbour discovery in AODV is initiated by HELLO messages; however periodic broadcast of HELLO messages causes extra overhead [45]. The author [45] also reports that the AODV is not the apt choice for interactive and real time applications since the route has to be established before the transmission begins. The idea suggested in [46] elucidate a novel approach to constrain route request broadcast based on node mobility. In this approach one selects the neighbourhood nodes for broadcasting RREQ, based on their mobility rate and recent involvement in routing, so that blind flooding of the route request in the network can be avoided.

A reverse AODV routing protocol (RAODV) is reported in [47] to provide solutions to the missing RREP packet at source node, due to the unexpected node movement. The RAODV protocol discovers routes on demand using a reverse route discovery procedure. After receiving RREQ, destination node floods R-RREQ instead of RREP to find the source node. On receipt of R-RREQ packet source node starts the data transmission. The extra control overhead for flooding R-RREQ packet is certainly a limitation to this approach. In [48] the authors proposed an enhanced AODV routing protocol for re-establishing a new shortest routing path at regular interval without waiting for a route break to be reported. The method reported in [49], increases the life time of the path by selecting the neighbouring node having energy greater than the given threshold energy. The resulting approach also ensures that nodes involved in one communication session are not involved in other communication sessions, in order to save the energy. Noting that single path routing in MANET induces extra overhead at the time of route repair and route re-establishment, Hrishabha et.al. [50] proposes a multipath routing scheme, which permits to initiate multiple paths between single source and destination.

In order to alleviate the problem of limited path information in AODV, Dynamic Source Routing protocol (DSR) [51] was introduced. Source routing encompasses techniques, in which the sender attaches the complete sequence of nodes, in the packet's header, through which the packet are to be forwarded [52]. The intermediate nodes in route are aware of the entire path, which can help in easy reconstruction in the event of a failure. Route discovery phase of DSR floods the RREQ packets in the entire network. Ko and Vaidya [53] have proposed an optimization to route discovery, known as Location-Aided Routing (LAR), that uses knowledge of the physical location of the target node from Global Positioning System (GPS), to narrow down the area of the network over which the RREQ packets must be propagated. An alternative approach is proposed in [54] which creates the clusters in the network so that subset of nodes participate in the RREQ forwarding process. Consequently there is predominant reduction in the overhead on bandwidth by curtailing the flooding of packets.

In [55] Nasipuri et.al. proposes to establish a number of disjoint routes as an extension to the multi path routing, discussed above. The route cash in the source node keeps all routes. When the primary route breaks, the switching to the alternate is immediate. An energy efficient strategy for RREQ flooding is proposed in [56], in which the nodes transmit RREQ, if it meets a threshold based on residual battery, received signal strength and speed. The congestion and energy consumption are thus reduced. Another energy aware DSR reported in [57] accumulated the total energy consumption across all nodes in a given path and chooses the path with minimum accumulated energy consumption. The net result is an enhancement in packet delivery and throughput.

Another on demand algorithm which has appeared in the literature uses link reversal algorithm for erasing the path, quite different from the approaches outlined above in the AODV and DSR protocols. In the Temporarily Ordered Algorithm (TORA) [58], the path is established by sending the Query/ Update packets. When the query packets reached at any intermediate node then the node records the height of the node to destination. The height of the destination node is zero and each node update the height according to the availability and attached to the packet. Any link break is detected and reported to the source node by sending clear packet. However it has been observed that the optimal path discovery is difficult in this method [58].

2.3.3 Hybrid Routing Protocols

The literature also very vociferous about the third classification of routing protocol viz. hybrid protocol. The hybrid protocol combines the advantages of both proactive and reactive routing protocols. The basic approach is to envisage the network as zones and follow the proactive protocols inside the zone and reactive protocols outside. Among the many protocols available in this category, Core Extraction Distributed Ad hoc Routing (CEDAR) protocol [59] and Zone Routing Protocol (ZRP) [60] are most widely used. CEDAR is based on the core nodes, which are administrative nodes in the network. Here a path containing core nodes is established from the source to the destination. From among the path generated, the one with the highest bandwidth is selected for communication. The mobility of the core node influences the routing performances. In ZRP also, the nodes are grouped into zones and utilizes proactive routing protocol within the zone and reactive routing protocol outside the zone. As the size of the zone radius, the ZRP has the tendency to become more proactive. Accordingly the choice of the zone size is very critical in ensuring a promised performance.

2.4 Conclusion

The previous sections in this chapter have brought out the major landmarks in the research on routing protocols. Table driven protocol exhibits more overhead and congestion due to the excessive routing table exchange between the nodes. But the route establishment delay is very low, since the route to all destination is readily available in the routing table. Because of the stored information, the stale routes formation is common in table driven routing protocols. Subsequent research on routing protocols for MANET has brought out that this kind of proactive protocols are not suitable in highly dynamic networks. On the other hand, the On-demand routing protocols postulates the route discovery process only as and when required. Even though there is some time delay for determining the route before transmission, the absence of the periodic routing table exchange reduces the overhead significantly. Hybrid protocols, which have been developed incorporating the features of both proactive and reactive protocols, works well in small networks. As the network size increases, the protocol behaves like table driven protocol.

In order to channelize the directions of further research work to be taken up in the area of routing protocols, the major protocols discussed above are simulated on Network Simulator Version 2 (NS2), in the chapter to follow. The consolidation of the result across a number of parameters has helped to get proper insight into the behaviour of the each of the protocols, thereby helping to derive the new directions in the research.

Chapter 3

EVALUATION OF EXISTING ROUTING ALGORITHMS IN MANET

As was indicated in the last chapter, the MANET routing algorithms fall broadly into three classes viz. Table driven, On-demand and Hybrid. Over the last 20 years, a good number of routing algorithms have been reported in the literature [61]. The most representative algorithms belonging to these categorizations are DSDV, AODV and DSR. A detailed analysis of these algorithms on networks of varying complexity, size and duration of operations would help to bring out the limitations of these algorithms, thereby paving way for further investigations.

3.1 Review of Existing Routing Algorithms

Routing of data in MANET involves three major steps (i) Route establishment (ii) Route maintenance, and (iii) Route re-establishment in the event of a failure. The routing process as outlined above is extremely complex in view of the mobile nature of MANET without any central regulating agency and limited resources of the participating nodes. Falling into the categories of table driven and on demand algorithms the typical routing protocols are DSDV, AODV and DSR, which are examined in detail in the section to follow.

3.1.1 Destination Sequenced Distance Vector (DSDV) Protocol

DSDV routing protocol is the first complete routing protocol for MANET developed in 1995, which is purely the extension of Distance Vector routing protocol, used in wired network [32]. In DSDV, route is established by exchanging the routing table, which is periodically updated. For each node keeps a routing table which contains the distance to all the nodes in a network. Based on the shortest distance, the connecting node is selected from the routing table and the graph of connected nodes result in the route. During the periodic update, the routing table gets exchanged, but information is updated only if the sequence number in the update is more than what is currently stored. This process rationalizes the route update and prevents the routing table from possible repeat of earlier values. The example given below elucidate the technique discussed above.

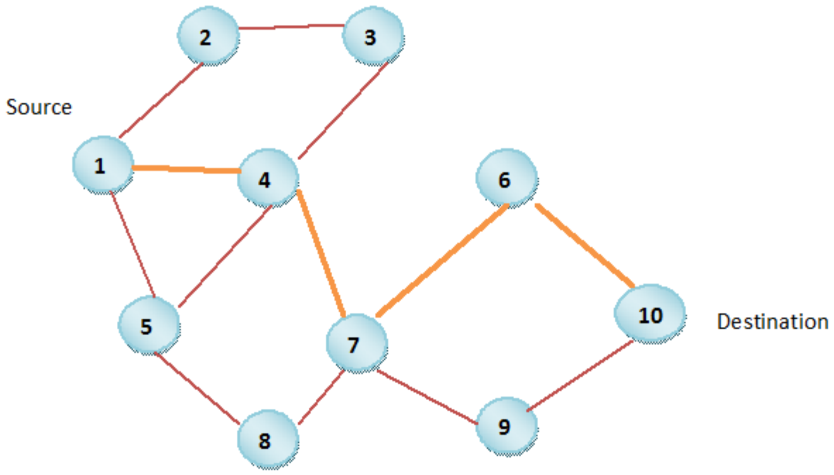


Fig. 3.1: DSDV- A Sample Scenario.

Node 1 is the source and node 10 is the destination in Fig. 3.1. When the network is configured, all the information is exchanged between the nodes. Suppose node 1 wants to send some message to node 10, then the route information is readily available in the routing table and it can easily find the shortest route.

Referring Table 3.1 A, the neighbours of source node1= {2, 4, 5}. Distances to the destination node 10 through nodes {2, 4, 5} as read from Table 3.2 B, C and D are <5, 3, 4> respectively. Since the route through node 4 has a shortest distance of 3, node 4 is taken as the next neighbour of node 1.

Destination	Distance	Next Node	Seq No.
2	1	2	40
3	2	2	35
4	1	4	42
5	1	5	34
6	3	4	56
7	2	4	54
8	2	5	32
9	9	4	67
10	4	4	60

A: Routing table of 1; Adjacent nodes of 1: {2,3,4}

Destination	Distance	Next Node	Seq No.
1	1	1	45
3	1	3	34
4	2	1	23
5	2	1	56
6	4	3	48
7	3	1	68
8	3	1	38
9	4	3	20
10	5	3	86

B: Routing table of 2; Distance to 10: 5

Destination	Distance	Next Node	Seq No.
1	1	1	42
2	2	1	32
3	1	3	24
5	1	5	26
6	3	7	38
7	1	7	48
8	2	7	66
9	2	7	58
10	3	7	52

C: Routing table of 4; Distance to 10: 3

Destination	Distance	Next Node	Seq No.
1	1	1	38
2	2	1	46
3	2	4	40
4	1	4	32
6	3	4	18
7	2	8	26
8	1	8	22
9	3	8	78
10	4	8	64

D: Routing table of 5; Distance to 10: 4

Table 3.1: Routing Table Prompting the Selection of Neighbours.

The advantage of this protocol is that the routing information is readily available at each node, thereby minimizing the route establishment delay. The exchange of routing table, carried out periodically to account for the dynamic changes in the network, induces more overhead. Thus DSDV may not be the right choice in MANET.

3.1.2 Ad hoc On- Demand Distance Vector (AODV) Protocol

In the AODV protocol, which is proposed in 1997 [44], the route establishment is initiated by the source node, by sending the route request (RREQ) packets and it contains source id (SID), destination id (DID), destination sequence number (DestSeqNum), broadcast id (BcastID), and time to live (TTL). Any intermediate node getting the RREQ packet, either sends a route reply packet (RREP) to source node, if it has any information about destination or forward to its neighbours. The destination node returns RREP which is propagated through the shortest path. If any intermediate node detects the route break, it creates the route error packet (RERR) and inform the source node and starts the route re-establishment process all over again.

The entire process of route establishment is illustrated in Figures 3.2, 3.3 and 3.4. In Fig. 3.2 the source node initiates the route discovery process by flooding the RREQ packet. All the nodes respond to RREQ flooding till the destination is reached.

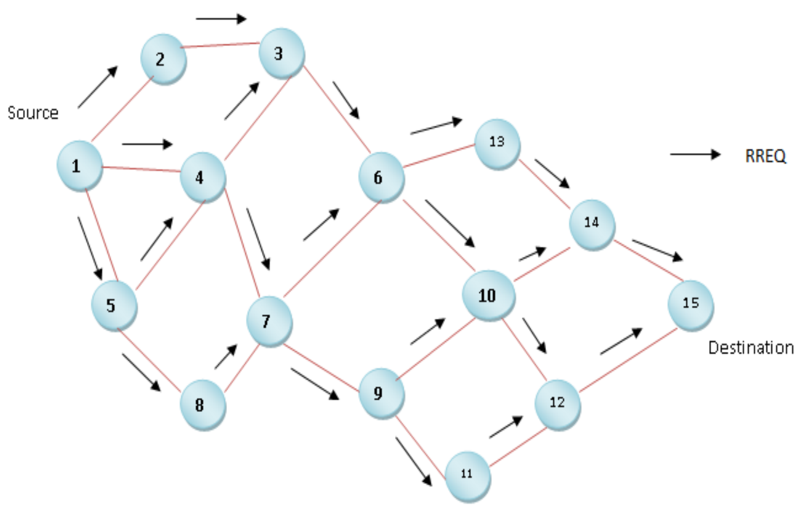


Fig. 3.2: Route Establishment in AODV- Flooding of RREQ Packets.

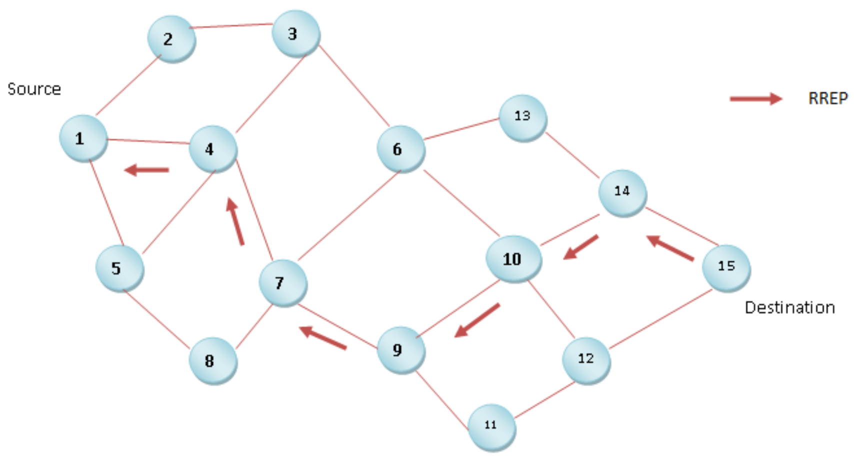


Fig. 3.3: Route Confirmation in AODV- Transmission of RREP Packets.

In Fig.3.3 the destination node selects the shortest path and sends the RREP packet through the shortest path, thereby confirming the route.

Node 1 starts transmitting data through {1,4,7,9,10,14,15} as shown in Fig. 3.4.

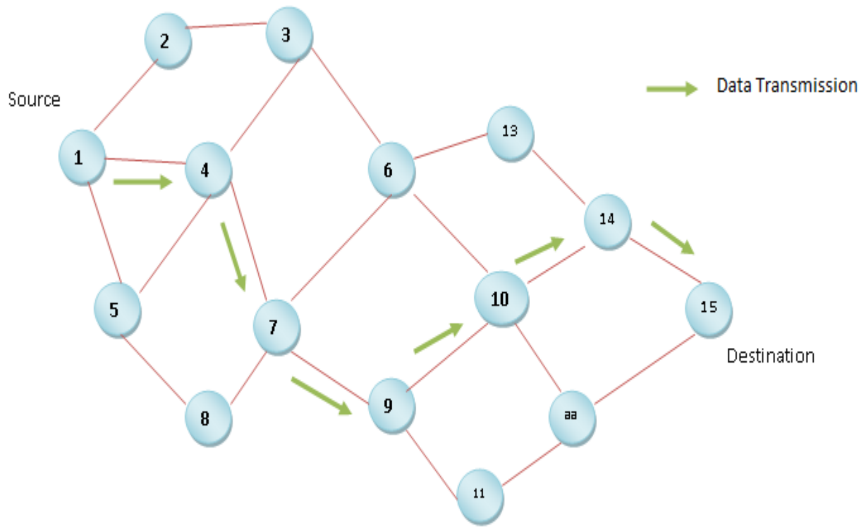


Fig. 3.4: Data Transmission in AODV.

Once the route is established, the source node can continuously send data through the established path until any path break occurs. Referring to Fig. 3.5 the break of link between nodes 10 and 14 is detected by node 10, which returns the RERR packet to the source node. The source node then reinitiates the route establishment.

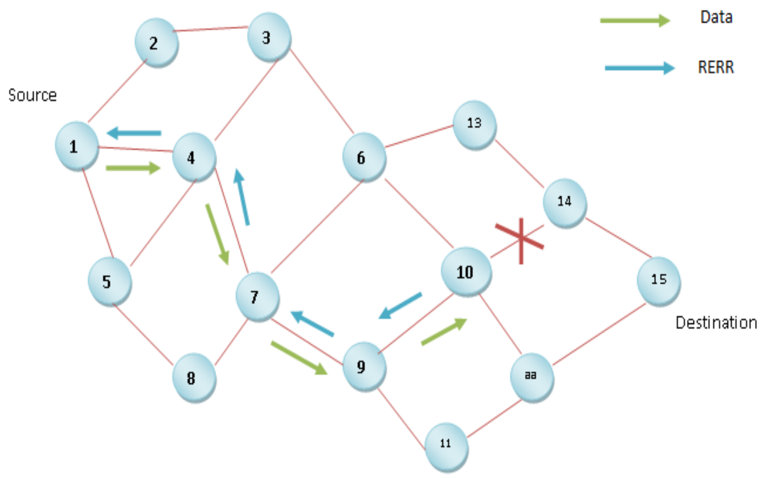


Fig. 3.5: Reporting of Route Failure through RERR Packets.

It is interesting to note that the AODV adapts to the instantaneous changes in the dynamic nature of the MANET.

3.1.3 Dynamic Source Routing (DSR) Protocol

Packet transmission in MANET uses both payload and extra information for assisting route identification. While in AODV the extra information is limited to neighbours only, in the DSR protocol full path information is attached [62, 63]. Route establishment and maintenance process in DSR are similar to the AODV protocol. The source node looks for the complete route information in the cache before it starts flooding RREQ. To explicate further, the process of finding the routes, the RREQ floods the information as shown in Fig. 3.6. It can be seen that the information trail in expands from <1,4> to <1,4,7,9,10,14>, as the RREQ approaches the destination node. The return message RREP carries the complete path information <14,10,9,7,4,1> (Fig. 3.7). There after the source node starts data transmission through the constructed path. The route re-establishment after failure is similar to AODV.

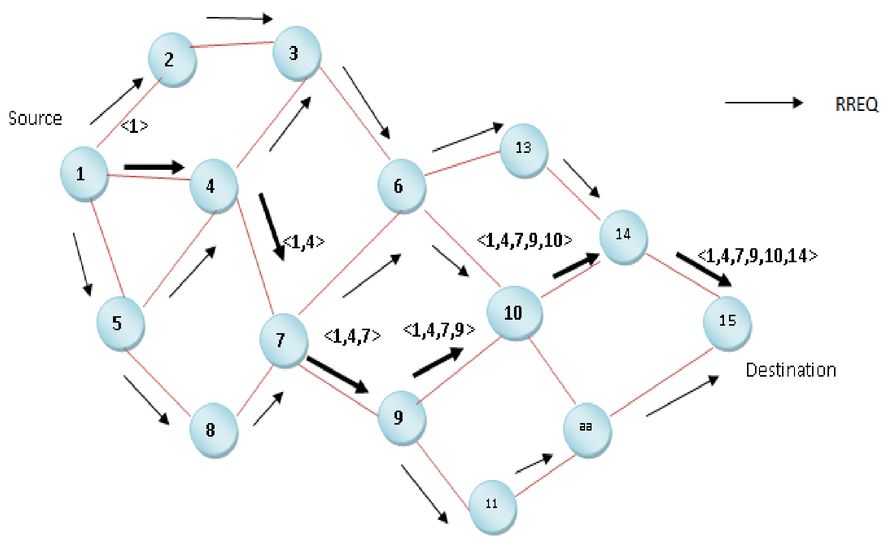


Fig. 3.6: Route Establishment in DSR- RREQ Flooding.

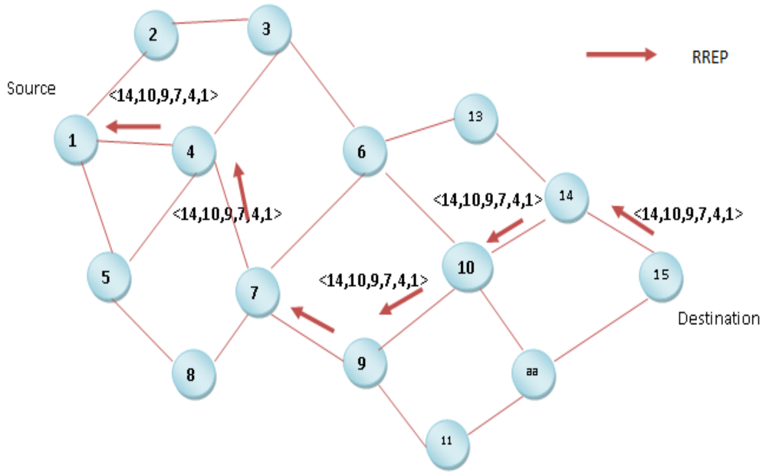


Fig. 3.7: Route Confirmation in DSR- Transmission of RREP Packets.

It can be seen that the availability of complete route information can help to speed up the data routing time. At the same time the requirement to store the entire path for large network increases the burden of storage within the nodes which have limited resources.

Table 3.2 summarises the comparison of the salient features of DSDV, AODV and DSR. From the table, it is clear that the AODV and DSR supports the scalability of the MANET, better than DSDV.

Properties	DSDV	AODV	DSR
Type	**Table Driven**	**On Demand**	**On Demand**
Distributed	Yes	Yes	Yes
Route Discovery	Routing table	Through Control Messages	Through Control Messages
Route Maintenance	Routing table exchange	Through Control Messages	Through Control Messages
Route Acquisition Delay	Low	High	High
Reuse of Routing Information	Yes	No	No
Source Routing	No	No	Yes
Bandwidth Usage	Very High due to the exchange of routing table	Less	Less
Hello Message	Yes	Yes	No
Suitable for large Network	No	Yes	Yes

Table 3.2: Features of DSDV, AODV and DSR Routing Protocols.

3.2 Metrics Relevant to the Performance Evaluation

A notable requirement of all routing protocols is the fail free delivery of packets to the destination, with good resilience to node failure and mobility. Before any attempt is made to find improvements in the execution of the routing protocols in MANET, a detailed evaluation of the above three representative protocols would be in order. Towards this, the following metrics highlighting the network performance are evaluated through elaborate simulation of the network.

- **Packet Delivery Ratio (PDR):** The ratio of the number of packets send from the source node to the number of packets received by the destination node is called PDR. A very low value of PDR, calculated over a period of time, indicates the network is susceptible to frequent failures in the links and also this sluggish nature of the protocols to respond to the link failures.

$$PDR = \frac{\sum Total\ Number\ of\ Packets\ Recieved}{\sum Total\ Number\ of\ Packets\ Sent} * 100 \qquad (3.1)$$

- **Packet Drop:** It is the measure of the number of packets dropped by the nodes for a given time. High packet drops indicative of events like insufficient energy; buffer overflow and limited processing power.

$$Packet\ Drop = \sum Total\ Number\ of\ Packets\ Sent - \sum Total\ Number\ of\ Packets\ Recieved \qquad (3.2)$$

- **Control Overhead:** It is defined as the total number of control packets divided by the total number of packets transmitted. The high value of control overhead reveals the clumsy nature of establishing routes.

$$Overhead = \frac{Total\ Number\ of\ Control\ Packets\ \ Sent}{Total\ Packets\ Sent} \quad (3.3)$$

- **Throughput:** The efficiency of the network is assessed in terms of the throughput. It is the average number of packets successfully delivered to the destination per unit time. High value of throughput indicates the fail free operation of the network.
- **End to end Delay:** It is the average time taken for a packet to travel from source to destination. The contributing factors to the delay could be due to processing, queuing, transmission and excessive amount of retransmission.

3.3 Performance Comparison of DSDV, AODV and DSR

Performance of AODV, DSR and DSDV protocols are implemented in NS2 simulator with varying number of nodes. The parameters used for simulation is listed in Table 3.3. Mac layer protocols for the simulation have been implemented using IEEE 802.15.4.

Parameters	Value
Number of Nodes	10,15,25,50,100
Simulation Area	500X500
Packet Size	512 bytes
Simulation Time	500 seconds

Table 3.3: Simulation Parameters.

Performance of AODV, DSR and DSDV protocols are evaluated based on the metrics discussed in the Sec.3.2. In the simulation scenario 10 to 100 nodes spanning an area of 500X500 m^2 are created with movement decided by random initial placement and velocity. Independent runs are carried out for different number of nodes over a duration of 500 s. Fig. 3.8 to 3.12 represent the typical results, obtained from trace file using scripts to format the results corresponding to PDR, packet drop, throughput, end to end delay and overhead.

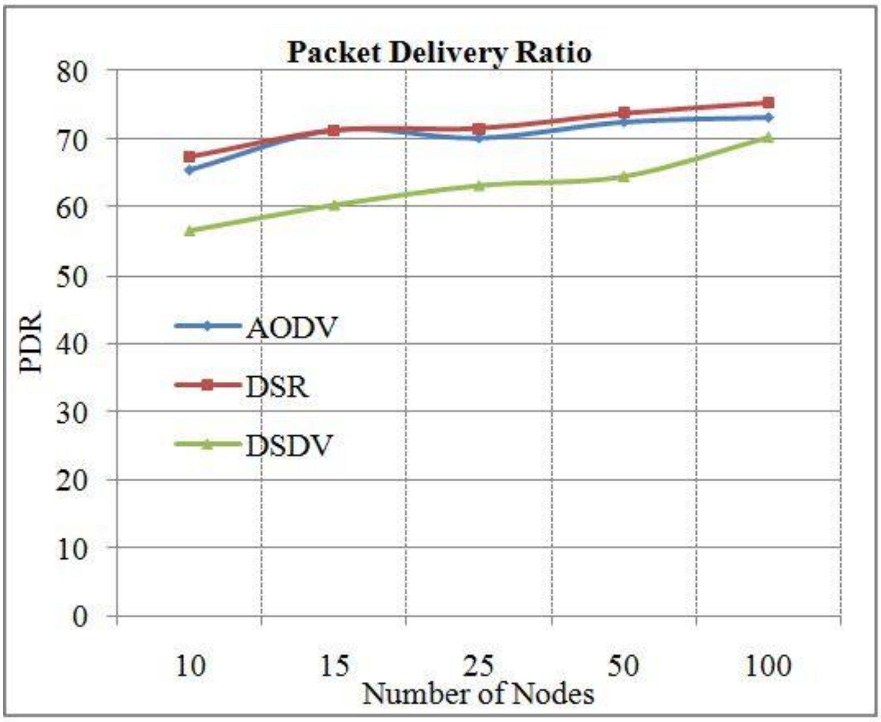


Fig. 3.8: Comparison among AODV, DSR and DSDV Protocols based on PDR. PDR of AODV and DSR is almost the same; DSDV has lowest PDR among all the three.

The simulation results demonstrate that DSDV protocol has the lowest PDR (Fig. 3.8), revealing the inflexibility of the protocol to frequent link failures because of the mobility in MANET. For the same parameter, DSR and AODV exhibits better performance basically because of the adaptation to the dynamic change in topology.

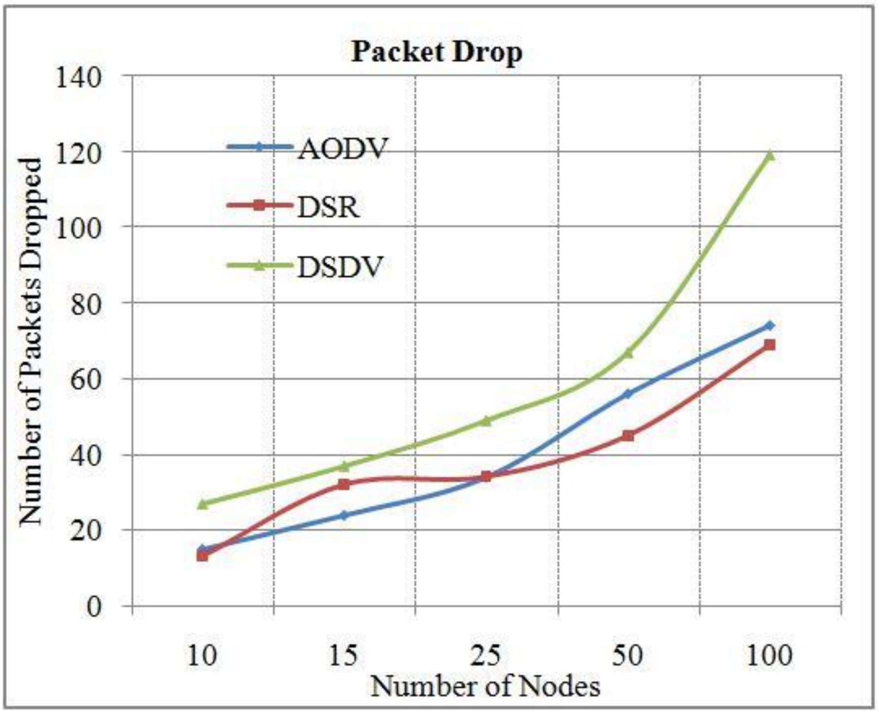


Fig. 3.9: Comparison between AODV, DSR and DSDV Protocols based on Packet Drop. Number of packets dropped in DSDV is more than AODV and DSR.

The number of packets dropped in DSDV is high for larger number of nodes spanning the same area (Fig. 3.9). The packet drop occurs due to the stale entry in the routing table and the inherent delay in arriving at a stable routing table. Packet drop is better in the case of both DSR and AODV primarily because of the instantaneous formation of the routes in the event of a failure and the resulting utilization of the large number of nodes promising stable routes.

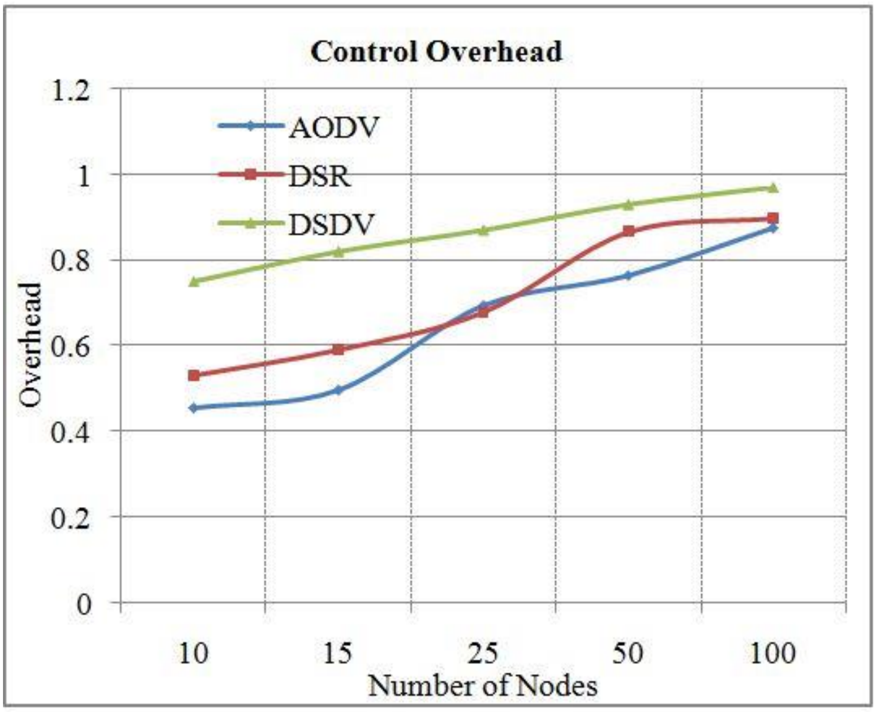


Fig. 3.10: Comparison between AODV, DSR and DSDV Protocols based on Control Overhead. Overhead is more in DSDV due to the routing table exchange.

From the Fig. 3.10 it is evident that control overhead is very high in DSDV. Being a table driven protocol, the DSDV utilized large amount of time in the nodes to update routing tables and circulation of excessive amount of control packets, which incapacitates the network. The limited amount of control packets used in AODV and DSR for route establishment promotes better performance.

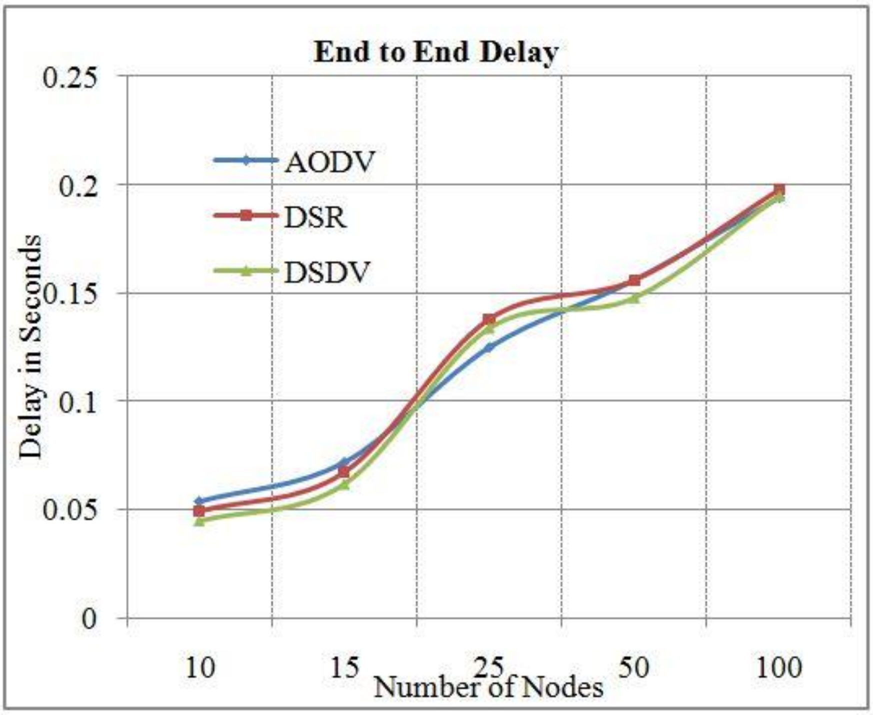


Fig. 3.11: Comparison between AODV, DSR and DSDV Protocol based on end to end Delay. Delay is comparable with all the three protocols.

The end to end delay is approximately same for all the three protocols as in Fig.3.11. In DSDV protocol routes to every destination is readily available in the routing table. The delay in the establishment of route in AODV and DSR mostly compares with the process of finding routes in DSDV, thus justifying the comparable performance of all the three algorithms in respect of delay.

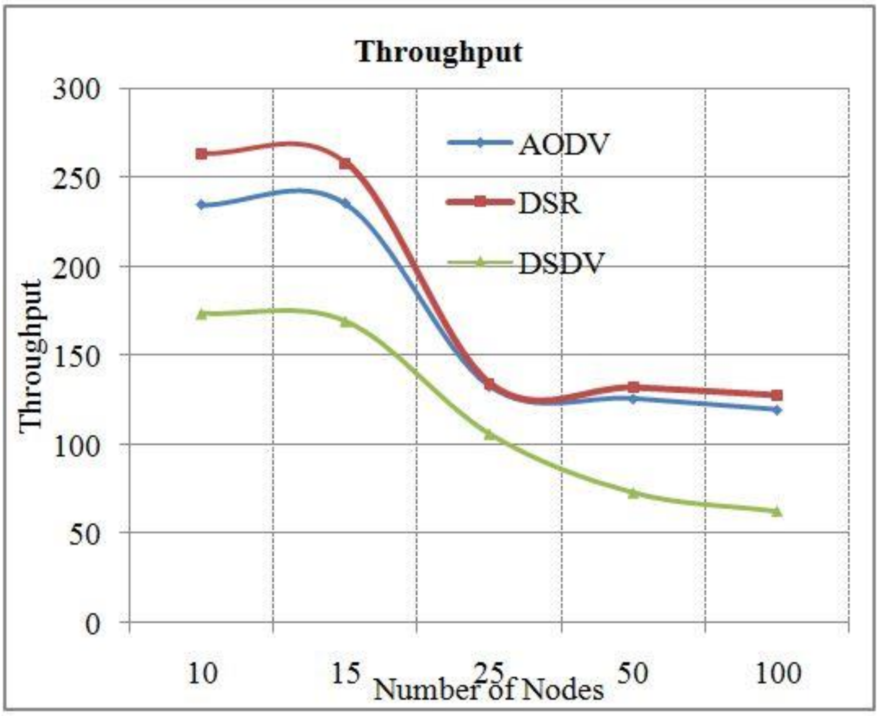


Fig. 3.12: Comparison between AODV, DSR and DSDV Protocols based on Throughput. DSDV performs worse against AODV and DSR for larger number of nodes.

Fig. 3.12 gives a comparison of three protocols against the throughput. The DSDV demonstrate the lowest throughput compared to AODV and DSR. The excessive amount of packet exchange in DSDV accounts for the degraded performance. In general it can be seen that the metrics like delay and throughput deteriorates because of the increase in the number of hops, even though more number of nodes can assure stable path.

The comprehensive view of the comparison is depicted in the Table 3.4.

Parameters	**Protocols**		
	DSDV	**AODV**	**DSR**
PDR	Low	High	High
Packet Drop	High	Low	Low
End to End Delay	Low (Load is low) High (Load is High)	Low	Low
Throughput	Low	High	High
Control Overhead	High	Low	Low

Table 3.4: Performance Comparison Table of DSDV, AODV and DSR Protocols.

3.4 Conclusion

The present chapter has examined three well known protocols in MANET through elaborate simulation of network with different number of nodes. The comparison in terms of established metrics reveal that

(i) Compared to DSDV, the AODV and DSR algorithms show pronounced improvement in performance

(ii) The adaptive nature of the on demand algorithms influences the better performance

However, the on demand algorithms also show some obvious limitations like large end to end delay and control overhead which are seen to increase as the network size increases. The excessive amount of packet flooding to establish the route in on demand algorithms could be one of the reasons impeding the performance. Centered on this concern, the chapter to follow therefore discusses the improvement in the on demand routing protocols.

Chapter 4

REDUCTION OF CONTROL OVERHEAD IN ON DEMAND ROUTING ALGORITHMS- AN ALTERNATE APPROACH

It is well known that flooding of control packets is the simple, effective and well sought out mechanism for route establishment in an On- demand routing algorithm [64]. However it is also interesting to note that flooding works at the cost of network resources and induces congestion, contention and overhead in the network. In order to assuage the problems of flooding, the present chapter concentrates on the establishment of alternate approaches in the route discovery process, using restricted flooding. The new approaches are built on the presumption that in on demand algorithms, each node forwards the message to its neighbours for route establishment, based on the chances of detecting the destination node and node reliability.

4.1 Introduction

Since well-timed dissemination of data is the mandate of MANETs, establishing the route with minimum overhead then turns out to be most critical. A major challenge that affects the timeliness of the data delivery is the unlimited mobility and the resultant frequent failures due to link breakage. Routes also fail because of the failure of the nodes participating in the routing process. The route establishment process, therefore lobs a major challenge in MANETs which has attracted the attention of researchers and as a result the literature is flooded with a number of investigations to readily establish the route on demand [65]. These approaches, however are observed to have the limitations of excessive overhead in route establishment, thus necessitating the exploration for alternate approaches. Nevertheless flooding still qualifies to be a basic and simple approach for route establishment in the On-demand routing algorithms [66]. Accordingly, the present chapter makes an effort to reduce the overhead in AODV and DSR, based on the history of earlier attempts and the reliability of nodes participating in the routing could bring down the routing overhead.

4.1.1 Flooding- A Sample Scenario

In all On-demand routing algorithms, the first step is to compute the route from source to destination using a set of control messages. Control messages are flooded through the network, which imposes definite amount of control overhead in the network. Route establishment depends largely on the flooding of control packets, which in turn increases the overhead of the network. When the network grows bigger the overhead could seriously impair the performance. In On-demand algorithms like AODV and DSR, the route discovery is initiated from the source node by generating the route request packet (RREQ) [67]. The typical case is illustrated in Fig. 4.1, where almost all the nodes are entertaining the RREQ messages received as part of flooding. The source node sends the RREQ to its neighbor nodes and neighbor nodes in turn floods to its neighbors, thereby leading to enormous overhead. Some restricted flooding mechanisms have been reported [68, 69] to alleviate the problem of increased overhead; but still the overhead due to control packet remains objectionably high in large networks.

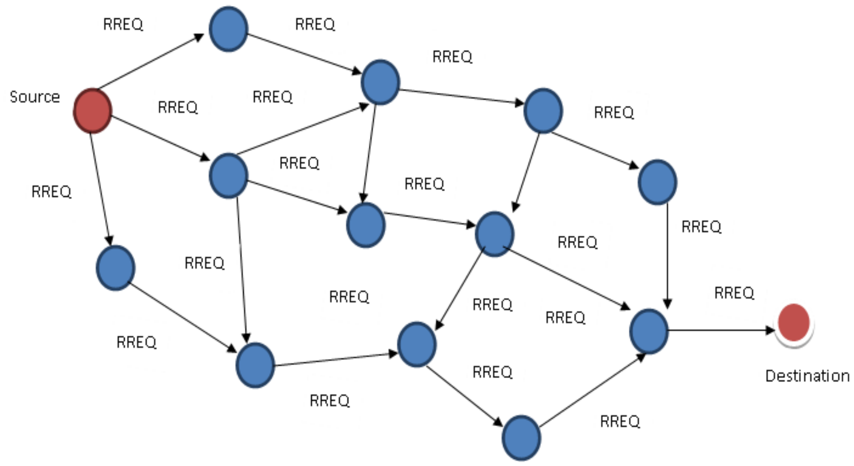


Fig. 4.1: Flooding, a Sample Scenario.

As is obvious from Fig. 4.2, the uncontrolled flooding leads to nodes, which are now here on the possible route shown inside the closed area, are also participating in the flooding process. These nodes inside the closed area will not contribute to the possible route. Because of the unnecessary and unproductive message flooding, the valuable and limited resources like node energy, bandwidth and battery power of each node are wasted. The process of route discovery thus introduces additional burden on the network.

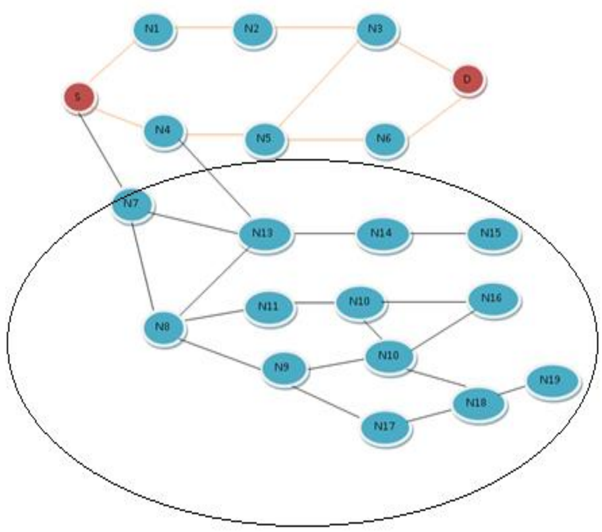


Fig. 4.2: A Typical Network Showing the Flooding Overhead; though there are only three paths from S to D, the flooding is wide spread.

4.2 Related Research

It has been reported that the blind flooding causes the broadcast storm problem [70, 71] that congests the entire network. Congestion increases the energy consumption and average latency, thereby degrades the performance of the network. Several schemes are proposed to alleviate the problems due to this unwanted flooding of control messages. There exist two common mechanisms used to suppress the propagation of route search overhead- query quenching and expanding ring search [72]. In the first method, on receiving RREQ packet the intermediate node will respond, only if it has the information about the destination. So the message flooding can stop at the intermediate node. However, this method does not guarantee the optimal route. In the second method, at each attempt searching scope is increased by some factor. After a maximum threshold of the scope only, the RREQ message is flooded. The drawback of this method is the increase in routing latency.

The following methods also have been reported in the literature to restrict flooding:

- Probability based [72] - Each node broadcast the message that is received for the first time with some fixed probability P. The nodes having relatively higher values of P alone will transmit the RREQ.

- Counter Based [72] - Each node broadcast the message only if it has not seen more than c times.
- Distance based [72] -Each node broadcasts the message only if the physical distance between the nodes is less than some prescribed value d. Distance can be measured by monitoring the signal strength.
- Location based [72] - A message is broadcast only if the bounding area around the node is less than a. The protocols limit the search for a route to the request zone. Request zone is determined based on the expected location of the destination node at the time of route discovery. The size of the request zone is proportional to the average speed of movement, the last location of the destination recorded.
- Cluster based [73] - Nodes are grouped into clusters; only cluster heads broadcast the control message.
- Avoiding malicious flooding - In the approach reported in [73], the flooding of packets in the network by malicious nodes, who do not obey any limits, is reduced by limiting hyper activism. Each of the receiver nodes has an upper limit of the RREQ it can receive. When a RREQ request reaches a node, it first checks the RREQ_RATELIMIT. If it exceeds the limit, then it avoids all the requests generated from the sending node, which is suspected to be malicious, for the current interval.

In the restricted flooding [74], the sequence number is used to avoid repeated flooding of same packet. In [75] when a node receives the RREQ packet, the node computes a term called the fuzzy cost and accumulate to the previous cost. The destination route collects the fuzzy cost of all the routes and selects path of least cost [76]. Alternately in [77], when a node receives a RREQ packet, it checks out its own battery power and decides whether to forward or drop the packet. The authors in [78] proposed a method in which the RREQ packet forwarding is based on the speed of mobile node and the received signal strength. Based on the multi-point relay mechanism, an optimal path selection technique for flooding is reported in [79].

In all the above approaches, the RREQ packets are discarded, thereby reducing the chance of establishing a connection.

On the other hand, it is proposed [80] to reduce the RREQ flooding by estimating the geometrical distance and topological distance towards the destination. Since the mobility of the nodes in the MANET is unpredictable, this approach does not guarantee the correct direction towards the destination always. In [81], authors tried to reduce the HELLO packet for neighbour discovery. But this approach does not reduce the flooding overhead.

Majority of existing schemes above concentrates on the routing efficiency rather than route discovery. It is interesting to note that the route discovery starts ab initio every time whenever a route break is detected. However the availability of past history of those routes which responded to the RREQ safely promises subsequent flooding on these established path, rather than wasting resources in blind flooding. The effective utilization of the history is elucidated below.

4.3 Reduction of Control Overhead based on the Past History

The proposed method attempts to minimize the control packets by restricted flooding. The flooding process is controlled based on the success of the previous trials. A node receives the RREQ packet and is forwarded to the most prominent node, decided on the basis of the success in the previous attempt. The method relies on the assumption that there is a higher chance of success of chosen node in the remaining trials also.

The proposed algorithm depends on the previous behaviour of a node to get the destination, through an outgoing link, calculating the probability to reach the destination, in terms of connectivity index/success rate (μ_k).

$$\mu_k = \frac{\text{Number of Success Obtained}}{\text{Number of Attempts Made}} \tag{4.1}$$

For each attempt, each node updates the μ_k for each outgoing link using Equation 4.2.

$$\mu_k \leftarrow \mu_k\alpha + (1-\alpha)\mu_{k-1},\ 0 < \alpha < 1 \qquad (4.2)$$

μ_k on each outgoing link is considered to be small value. The first few flooding cover the entire network. Subsequently μ_k is calculated in each attempt by all nodes as given by equations 4.1 and 4.2. If μ_k at any node is greater than a predetermined threshold, is considered as eligible to be explored for connectivity. It can be seen that the build-up of μ_k depends up on α. Accordingly, the first few route requests are made on all the outgoing links. Subsequently, the most favoured links alone are chosen corresponding to the higher values of μ_k.

The proposed algorithm uses two dimensional array for storing the past history of nodes. For a network having n nodes, the space complexity will be dependent on n and the instantaneous connectivity. However in the worst case space required for storing history could be n^2 with full connectivity. Similarly the decision on packet flooding takes place in all the nodes, though the actual flooding takes place only through nodes which has got higher success rate in the routing process. Thus the time taken for routing will be a function of n (number of nodes) and the best performing nodes which is obviously less than n.

The method discussed above ensures the reduction of RREQ flooding in the network. By updating the connectivity index table, each node is aware of the connection potential of the requested destination. With this awareness, the node blocks the unwanted forwarding of RREQ control messages generated by the source node. The proposed algorithm also has minimal computational complexity, which is bounded by the number of RREQs flooded.

4.3.1 Simulation Results

The proposed modification of RREQ flooding is implemented in NS2 simulator for a fixed number of nodes, with varying time of execution. The parameters used for simulation is listed in the Table 4.1. The RREQ flooding process in AODV and DSR is modified and the performance is evaluated, in respect of control overhead.

Parameters	Options/Values Chosen
Number of nodes	50
Simulation area	500X500 m^2
Packet size	512 bytes
Simulation time	100,200,300,400,500 seconds
Mac Protocol	IEEE 802.15.4
Routing Protocols	AODV, DSR

Table 4.1 Simulation Parameters.

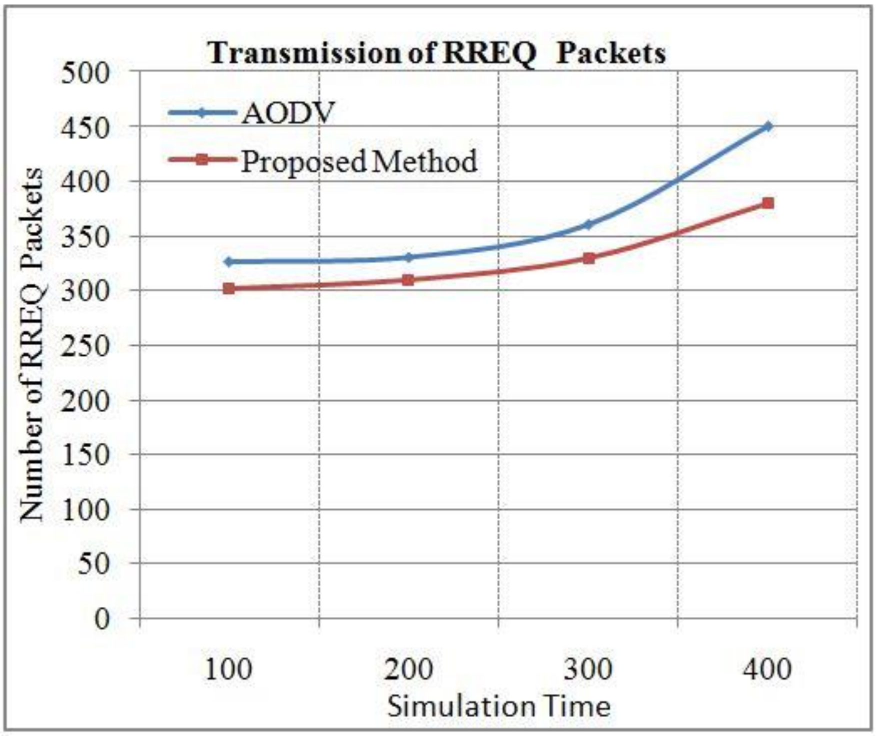


Fig. 4.3: Comparison of AODV and Modified AODV in terms of RREQ Packet Transmission.

Fig. 4.3 and Fig. 4.4 shows the transmission of RREQ packets in the proposed method against AODV and DSR. The number of RREQ packets transmitted gets reduced in the restricted flooding mechanism proposed. As the time elapses, it can be seen that the number of RREQ packets transmitted is less in modified AODV, where the repository of route information available with the node cache restricts the RREQ flooding, thereby keeping the number of packet transmitted are bounded. Compared to the both approaches above, the proposed approach restricts the transmission of RREQ packets based on the history accumulated, thereby limiting the increase in packets transmitted to the lowest of the three approaches.

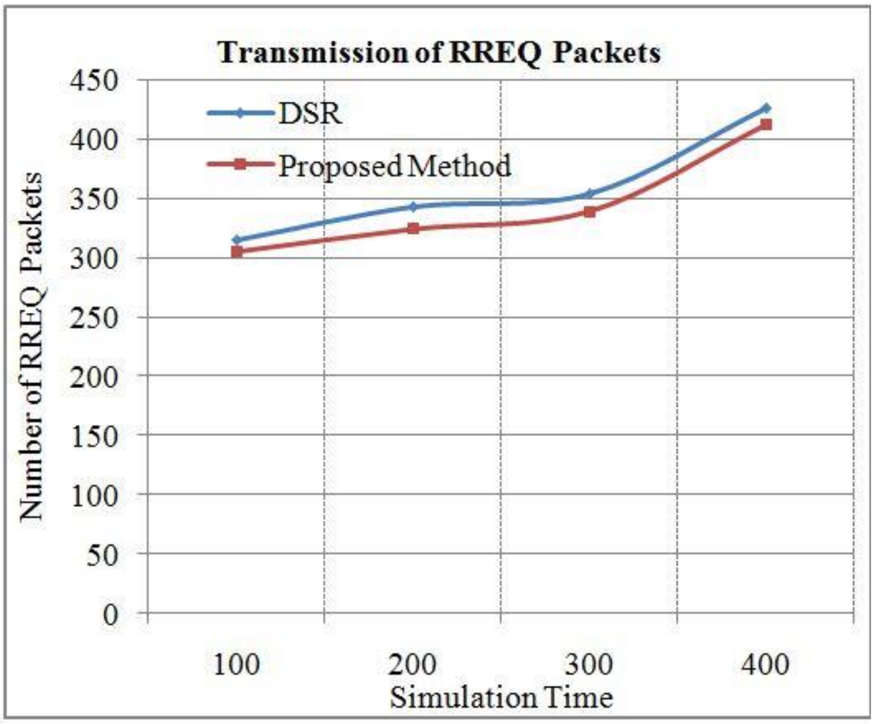


Fig.4.4: Comparison DSR and Modified DSR in terms of RREQ Packet Transmission.

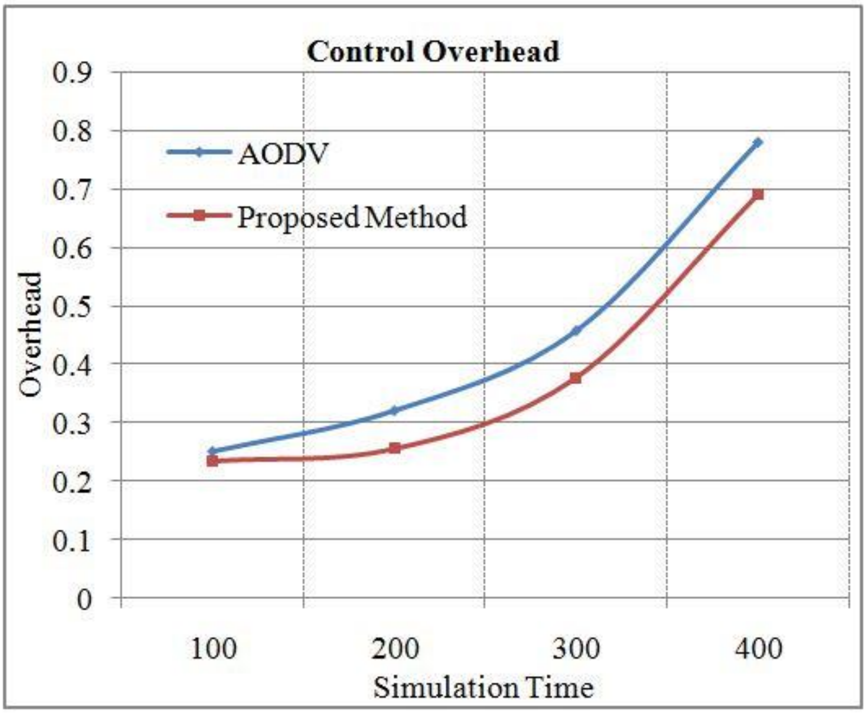


Fig. 4.5: Comparison of AODV and the Modified AODV in terms of Control Overhead.

The control overhead is an indication of the effort required for route establishment and maintenance. As shown in Fig. 4.5 and Fig. 4.6, in the proposed method, profound reduction in the control overhead is noticed, as against both AODV and DSR. Here again the reduced transmission of control packets underscores the impact of the history of flooding influencing the packet transmission for control.

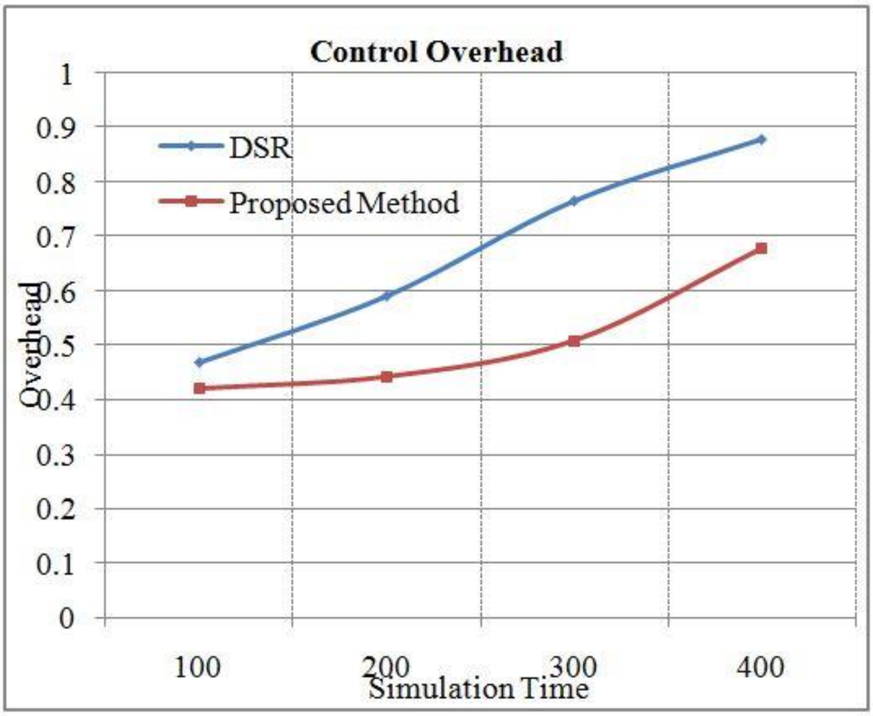


Fig.4.6: Comparison of DSR and the Modified DSR in terms of Control Overhead

Though the proposed approach selects the node which uses the history of μ_k to schedule the flow of RREQ, all the nodes on the route participate in the flooding process spending their energy. Therefore the nodes with limited energy also attempts to participate in the flooding process though they may not be able to complete the process of route establishment. Selection of the nodes based on sufficient residual power can make the route durable. In view of the uncertainty in μ_k as well as the residual power, a decision on the choice of the nodes to be selected for participation in the route establishment process, is taken on the basis of a fuzzy function computed on μ_k and residual energy. The section to follow discusses the decision of the node to be selected as above, utilizing a fuzzy function of μ_k and residual power.

4.4 Reduction of Control Overhead using Fuzzy Function of Success Rate and Remaining Energy in AODV and DSR

Referring to Fig. 4.7, the choice of a neighbour of a given node to be included in the routing is dependent on the following parameters.

(i) The success rate of links originating from a given node in the delivery of packets over a period of time influences the choice of a neighbour node.

(ii) Remaining energy in a node ensures the longer durability of the established route.

The proposed method takes the decision to forward the RREQ packet to a neighbouring node, based on two fuzzy variables, X1 to denote μ_k and X2 to denote remaining energy of the node. The fact that both X1 and X2 have overlapping content in the definition of the attributes like high, low, medium etc. of the variables, suggests itself the choice of fuzzy sets in describing the attributes. The combined decision on these two parameters is thereafter arrived a fuzzy rule based inference system.

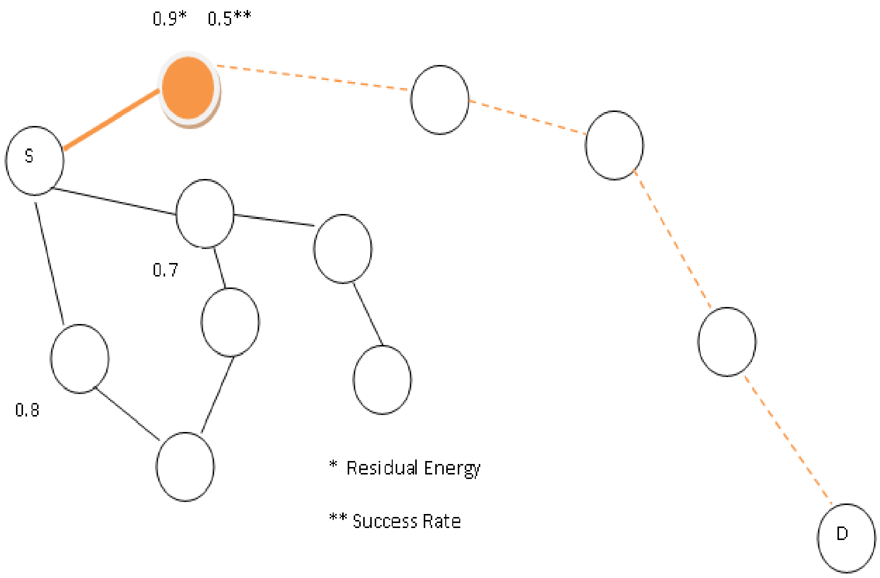


Fig.4.7: Illustration of the Selection of Reliable Neighbour Nodes for Flooding.

The fuzzy function of the two variable X1 and X2 is computed as explained below.

The fuzzy membership function of the fuzzy variable X1 is given by

$$\mu(x1) = e^{-(x1 - c_i)^2/2}. \tag{4.3}$$

where x1 corresponds to the crisp value of μ_k, success rate and c_i denotes the centre of the fuzzy function. (x1 is used to denote crisp value of μ_k in the definition in order to avoid the conflict with the membership function μ of the fuzzy set. Fig. 4.8 represents the fuzzy membership function.

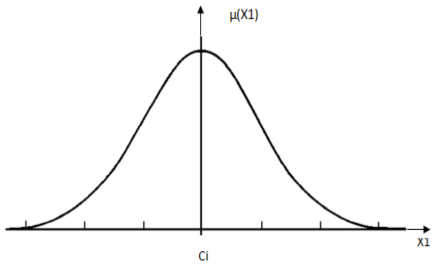


Fig. 4.8: Fuzzy Membership Function.

The variable x1 is spanning over the range 0.05 to 1 and is considered as the support for the definition of fuzzy set. The fuzzy variable X1 assumes the five values centred on c_i as listed in Table 4.2 below.

Fuzzy Functions of X1	**$0<c_i<1$**
Very Low	0.05
Low	0.25
Medium	0.5
High	0.75
Very High	1

Table 4.2: Definition of Fuzzy Function.

Similarly, the remaining energy X2 in the neighbouring node, also spanning over a range of 0.05 to 1 is also represented as a fuzzy function, defined over similar support as in Table 4.2.

The decision to choose a neighbour node for sending route request packet RREQ is computed as a fuzzy function of X1 and X2, using the rule base given in Table 4.3. A typical rule could be formulated as

If X1is Low and X2 is Very Low output is Very Low.

X1 \ X2	Very Low	Low	Medium	High	Very High
Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
Low	Very Low	Low	Low	Low	Low
Medium	Very Low	Low	Medium	Medium	High
High	Very Low	Low	Medium	High	Very High
Very High	Very Low	Low	High	Very High	Very High

Table 4.3: Rule Base.

Given the crisp values of X1 and X2, corresponding to a typical instance of time, all the rules are fired and combined to produce a final inference using the crisp value Y given by

$$Y = \frac{\sum_{i=1}^{5}\sum_{j=1}^{5} \mu_i(X1)\mu_j(X2)c_{ij}}{\sum_{i=1}^{5}\sum_{j=1}^{5} \mu_i(X1)\mu_j(X2)}\ , i,j = 1\ to\ 5 \quad (4.4)$$

where c_{ij} corresponds to the center of the fuzzy variable indicating the inference in the rule base at the position <i,j> (Table 4.2). Those neighboring nodes for which the crisp value Y exceeds a threshold alone are chosen for routing the RREQ message. Accordingly it can be seen that the neighboring nodes in the less reliable path and with less remaining energy will not participate in the flooding process. The formal Algorithm is illustrated in Fig. 4.9.

```
On receiving RREQ packet at node n do
    {
        if (new RREQ) // with new sequence number
        for all k neighboring nodes do the following
        {
            Compute μ(x1) = e^{-(x1 - c_i)^2/2}, i = 1 to 5
             // x1 corresponds to success rate
            Compute μ(x2) = e^{-(x2 - c_i)^2/2}, i = 1 to 5
            // x2 corresponds to remaining energy
          Compute Y = (Σ_{i=1}^{5} Σ_{j=1}^{5} μ_i(X1) μ_j(X2) c_ij) / (Σ_{i=1}^{5} Σ_{j=1}^{5} μ_i(X1) μ_j(X2)), i = 1 to 5
        }
            If (Y>Threshold)
            then forward RREQ packet through node k
            else discard RREQ
    }
```

Fig. 4.9. The Algorithm to Decide the Nodes to be selected to Transmit RREQ.

4.4.1 Simulation Results

The proposed approach is implemented in NS2 for networks with fixed number of nodes and varying simulation time. The performance of the proposed algorithm, in terms of number of route request packets (RREQ) transmitted and control overhead are evaluated and compared with the existing protocols viz. AODV and DSR. The simulation parameters chosen are described in Table 4.1.

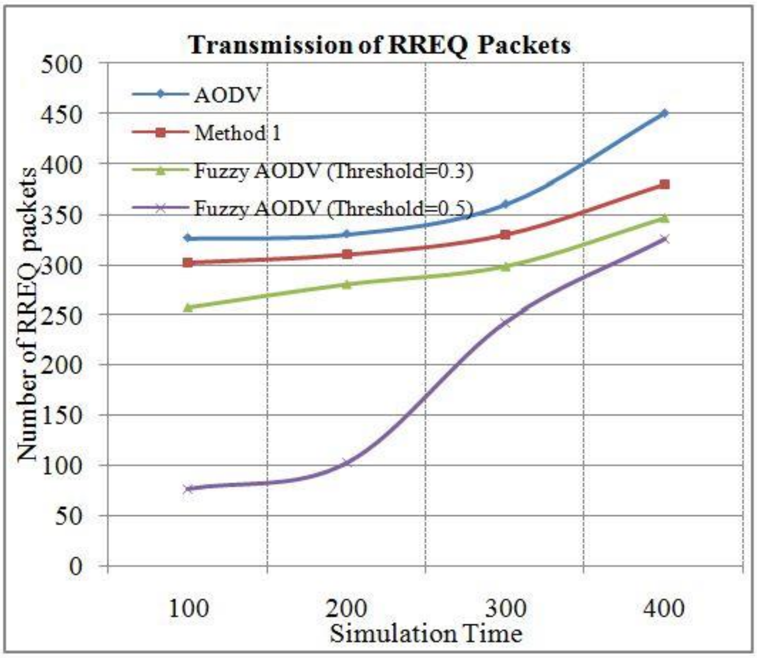


Fig. 4.10: Comparison of AODV with the Fuzzy Extension of AODV in terms of Route of RREQ Packets for Different Threshold Settings for Y. The number of RREQ packets transferred comes down appreciably with increase in threshold. Method 1 refers to Sec 4.3.

Fig.4.10 illustrates how the number of RREQ packets transmitted vary with the elapse of time for the proposed algorithm, in comparison with AODV. The parabolic nature of the increase in RREQ, for the AODV may be contrasted with the stabilizing tendency of the Fuzzy extension of AODV. Similar improvement of the proposed algorithm in comparison with the DSR is also worth noting (Fig.4.11).

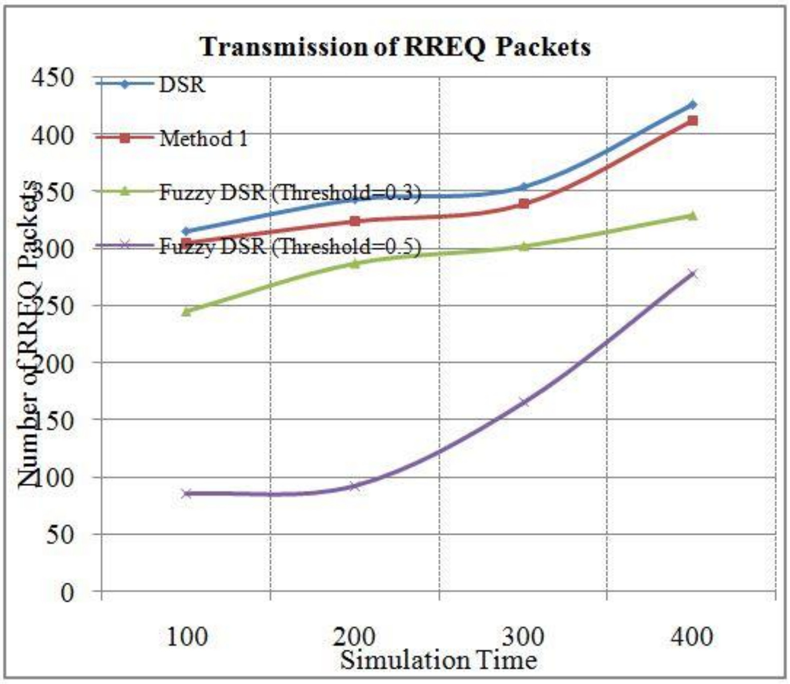


Fig.4.11: Comparison of DSR with the Fuzzy Extension of DSR in terms of RREQ Packets for Different Threshold Settings for Y. The number of RREQ packets transferred comes down appreciably with increase in threshold in the proposed algorithm. Method 1 refers to Sec 4.3.

It is interesting to note that the selection of threshold for Y has pronounced impact on the reduction of RREQ. As the threshold value is made liberal, the RREQ flooding is more. However, since the proposed algorithm works on the history of the established routes, the chances of missing the routes at the cost of reduced number of RREQ are less. On the other hand, since the decision combines the effects of success rate and power availability of the node, the route establishment algorithm is conservative.

The control overhead accounts for the extra amount of packets required to be transmitted as part of the protocol. The route establishment in MANET being a frequent process, can contribute to the overhead substantially. Fig. 4.12 and 4.13 exemplify the variation in the control overhead as a function of time. It is clear that the control overhead is appreciably low for the proposed modification to both the DSR and AODV algorithms. It is also worthwhile to note that the control overhead is stable with the proposed modification over a longer duration of time, though subsequently the overhead increases but at a rate much lower than the AODV and DSR implemented without modification.

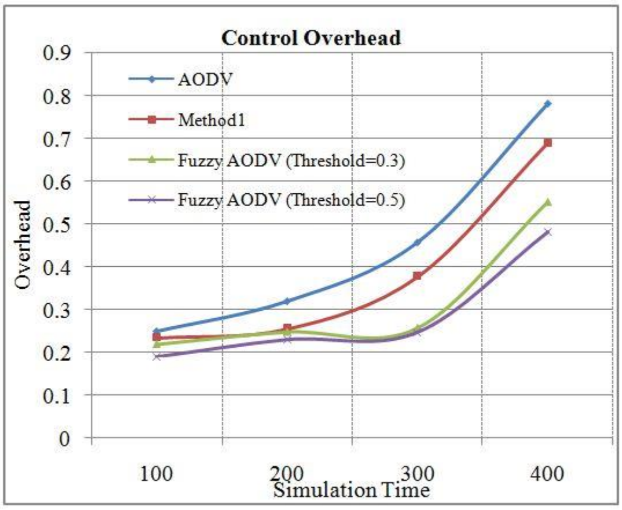


Fig.4.12: Comparison of AODV and Fuzzy Extension of AODV in terms of Control Overhead for Different Threshold Settings for Y.

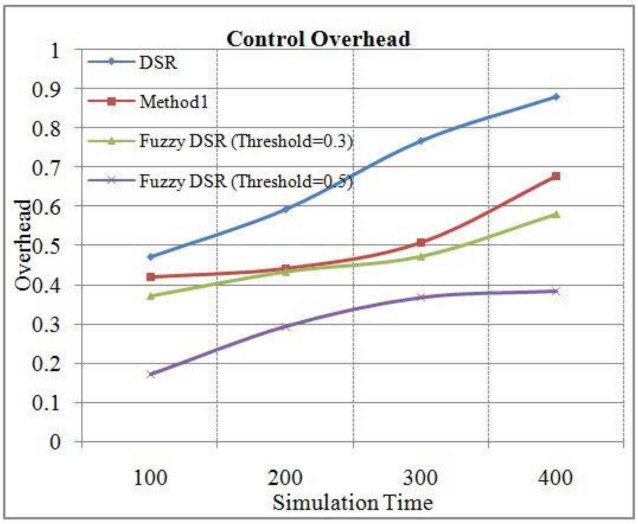


Fig. 4.13: Comparison of DSR and Fuzzy Extension of DSR in terms of Control Overhead for Different Threshold Settings for Y.

Independent Monte Carlo runs of the modified algorithm for both AODV and DSR have brought out that the average performance of control overhead comes with a relatively low value of the variance, thereby confirming the credence of the proposed algorithm. The detailed results of Monte Carlo runs for different simulation timings are summarized in Table 4.5 and 4.6. The influence of the threshold in the average value of the overhead is visible in the table.

Protocol	**Overhead**	**Simulation Time in (s)**			
		100	200	300	400
AODV	Mean	0.250	0.320	0.457	0.780
	Variance	0.084	0.084	0.122	0.179
Method1	Mean	0.234	0.255	0.377	0.690
	Variance	0.082	0.081	0.091	0.099
Fuzzy AODV (Threshold=.3)	**Mean**	**0.219**	**0.248**	**0.257**	**0.551**
	Variance	**0.082**	**0.08**	**0.070**	**0.087**
Fuzzy AODV (Threshold=.5)	**Mean**	**0.190**	**0.230**	**0.247**	**0.480**
	Variance	**0.08**	**0.08**	**0.067**	**0.076**

Table 4.4: Mean and Variance of Control Overhead in AODV out of 1000 Independent Runs. Method 1 refers to Sec 4.3.

Protocol	Overhead	Simulation Time in (s)			
		100	200	300	400
AODV	Mean	0.470	0.5929	0.767	0.880
	Variance	0.081	0.104	0.122	0.199
Method1	Mean	0.42	0.442	0.508	0.677
	Variance	0.080	0.08	0.08	0.131
Fuzzy DSR (Threshold=.3)	**Mean**	**0.371**	**0.432**	**0.471**	**0.579**
	Variance	**0.081**	**0.079**	**0.079**	**0.099**
Fuzzy DSR (Threshold=.5)	**Mean**	**0.170**	**0.293**	**0.367**	**0.383**
	Variance	**0.08**	**0.061**	**0.076**	**0.089**

Table 4.5: Mean and Variance of Control Overhead in DSR out of 1000 Independent Runs. Method 1 refers to Sec 4.3.

4.5 Conclusion

The chapter has examined the possible uncontrolled increase in the route request packets (RREQ) transmitted, which can mitigate the performance of the MANET. In an attempt to save the restricted resources like bandwidth and battery power, a modification to both AODV and DSR algorithms is proposed and the resulting reduction in RREQ flooding and control overhead is verified through simulation.

Two methods are proposed to decide on the choice of a neighbour to forward the RREQ packets based on

i) the history of success rate.

ii) a fuzzy function computed on success rate and residual energy of neighbouring nodes.

The above choice ensures that unnecessary flooding of RREQ is avoided and only healthy nodes participate in the routing process. The simulation results bring out the appreciable reduction in both the number of RREQ transmitted and control overhead, also underscored by the low values of variance in the Monte Carlo runs carried out for each instance of the elapse of time. The reduced flooding also saves the energy in the resources of the network, since the decision to flood RREQ is judiciously taken on the basis of success rate and residual power.

Chapter 5

ENHANCING THE ROUTING PERFORMANCE OF MANET, USING DOMINATING SET

While the previous chapter demonstrated some possible improvements in the execution of AODV and DSR algorithms, the present chapter proposes an algorithm to increase the stability of the route established by directing the route through dominating nodes. Domination nodes in any graph have the maximum connectivity. The selection of the domination node is based on the parameters like residual energy and the packet delivery ratio in the previous trials. This approach maintains the long lived route in the network, so that it could ensure the stable routing. It is also interesting to observe that the proposed method results in bringing down the re-route establishment.

5.1 Introduction

Frequent failure of the nodes on account of the high mobility is a bane in MANETs and any route failure reported makes it mandatory for the source node to find an alternate route. One of the promising approaches to get stable route is to ensure that the route is established through the dominating set. The definition of dominating set, as the set of nodes having maximum connectivity, stems out of graph theory [82]. A review of the basic concepts of graph theory therefore would be in order.

5.1.1 Connected Graph

A connected graph is a graph in which there is a path between every pair of vertices [83]. The MANET is considered as a connected undirected graph G = (V, E), where V represents set of wireless nodes and E represents the edge which form the connection between nodes. In the context of MANET, the edge between two nodes {u ,v} confirms that u and v are in the range and nodes u and v can transmit and receive messages mutually. Consider a wireless network topology in Fig. 5.1. The circle indicates the transmission range and the corresponding undirected connected graph is shown in Fig. 5.2.

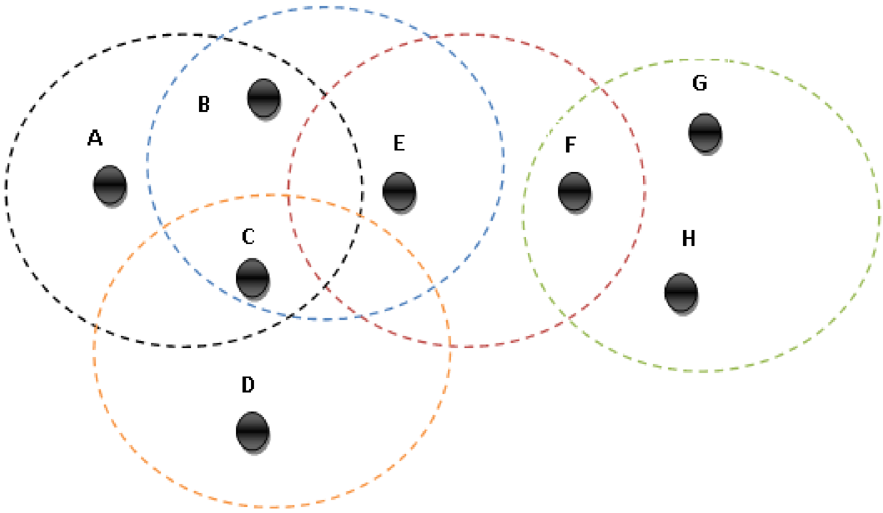


Fig. 5.1: A Typical MANET Topology; the Dotted Circles Indicate the Transmission Range.

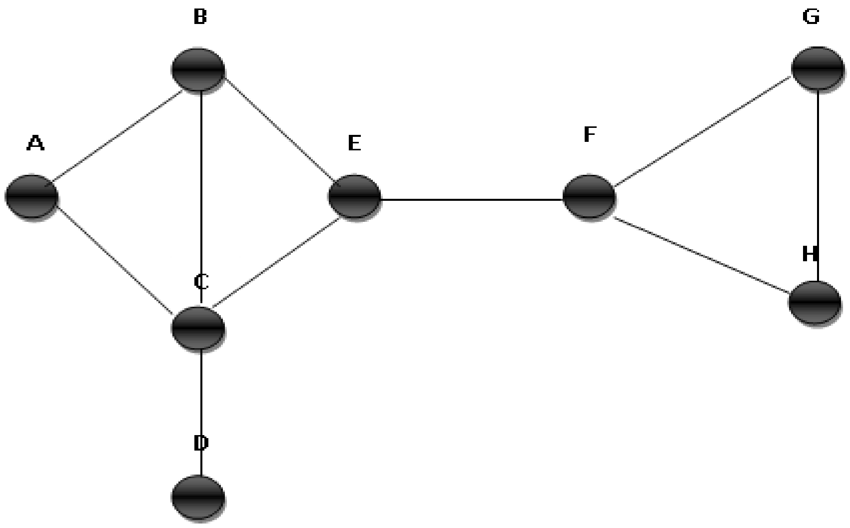


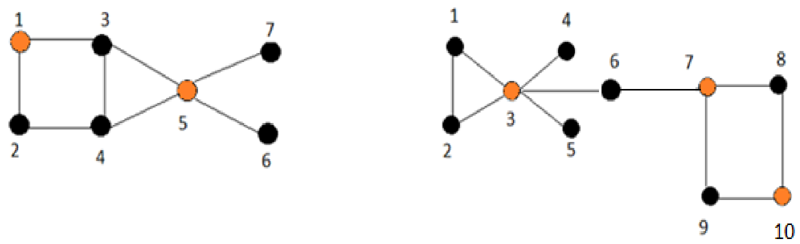
Fig. 5.2: Graphical Representation of Fig. 5.1.

5.1.2 Dominating Set

A. Domination Node and Dominating Set

Dominating Set (DS) for a graph G=(V,E) is defined as D ⊆ V, such that every v ∈ V and ∉ D is adjacent to at least one member of D [84]. A set D of vertices of G is a dominating set of G if every vertices of G is dominated by at least one vertex of D. Equivalently: a set D of vertices of G is a dominating set if every vertex in V(G) – D is adjacent to at least one vertex in D. The domination number γ(G) is the number of vertices in a smallest dominating set for G.

To illustrate the dominating sets, consider the graph of Fig. 5.3 a and 5.3 b. The dominating set for Fig. 5.3 (a) is given by D={1,5},{2,5}, while the one for Fig. 5.3 (b) is {3,7,10},{3,8,10},{3,8,9}.



(a): Typical DS: {5,1} (b): Typical DS: {3,7,10}

Fig. 5.3: Illustration of the Formation of Dominating Set.

B. Connected Dominating Set

A dominating set D is a Connected Dominating Set (CDS) [84] of a graph G= (V, E), with two properties such that

(i) D is a Dominating set in G and

(ii) D induces a connected sub graph on G.

There exists a path from every node in D from every other node in D.

C. Minimum Connected Dominating Set

Minimum Connected Dominating Set (MCDS) [84] is a CDS, with minimum number of nodes. The minimum cardinality among the dominating sets of G is called the domination number of G and denoted by $\gamma(G)$. A dominating set of minimum cardinality $\gamma(G)$ is referred to as a minimum connected dominating set.

The problem of finding the Minimum Connected Dominating Set (MCDS) is considered as the NP complete problem [85].

5.2 Related Research in Route Discovery using Dominating Set

A review of the related literature shows that the concept of Dominating set was introduced in 1970's and the advances in research in this area has increased drastically during 1980's.

In 2002, network researchers adapted and applied this concept into routing. The authors explain the algorithm and application of dominating set in [86]. The paper basically concentrate on the extended dominating set based routing in wireless Ad hoc network with the unidirectional link. In this, the algorithm finds the domination node (or core node [87]), based on the network topology. A marking process is used for finding the dominating set and the marking process is verified through simulation study. Jie Wu extended their concept in [87] and proposed a distributed algorithm [88] for determining dominating set based on the geographical distances. For finding MCDS (or small connected dominating set), this algorithm works very well in dynamic networks. The approach is distributed and only local information as a number of message exchange are required among the neighbouring nodes. When the transmission range of the mobile nodes is not too large, this algorithm generates the MCDS, efficiently. Otherwise the algorithm does not guarantee to generate the MCDS.

An efficient algorithm was formulated in [87, 88] for determining the dominating set and these sets are updated when the topology dynamically changes. The authors claimed that the proposed algorithm simplifies the routing process with CDS. But the efficiency of the algorithm depends on the size of the network. This will work perfectly for small network and with the number of nodes increased, the algorithm becomes slow. Yamin Li et al. presented an algorithm [89] for determining almost CDS of small size on Ad hoc wireless networks. The efficiency of the algorithm depends on the overhead in constructing the dominating set and the size of the dominating set. They claimed that the size of the forwarding set will be very small compared to the initial set. But the authors did not consider the node mobility and packet collision, when determining the dominating set. A MAC –layer timer based protocol is presented in paper [90]. In this protocol, a timer is initiated based on the number of uncovered neighbours. Whether to join the dominating set or not is decided when the timer expires. The authors proved that the result of the algorithm produces the MCDS and the number of nodes in the set is 35%-60% less than the result of the other algorithms.

While examining the improvement in the routing of packets in mobile ad hoc networks, it is seen that the results of [91] based on CDS bring out the reduction in the request packet in AODV protocol. Here the algorithm distributes the route request packets using DS neighbour elimination. They claimed that this method saved 70% traffic on route request packets in AODV. But there is no improvement in the packet delivery ratio and throughput of the network. The same idea is also used in paper [92] and in this, the domination node is calculated based on the rate of change of displacement and signal strength of the nodes. Steiner tree is used to determine the CDS. An algorithm is proposed for determining the stable CDS in [93]. In the proposed algorithm three re-marking processes are used based on danger links, the average received power strength and node identifier. The simulation proved the efficiency of the algorithm. But the approach did not consider the transmission power of the node and the unidirectional links.

A Strategic Location-based CDS is constructed for mobile Ad hoc networks in [94]. The CDS is selected based on density and velocity. The authors claimed that the life time of the CDS is increased, so that the complexity of re-computing is very less. A power aware MCDS is computed using the neighbourhood information in [95]. Due to topological changes, MCDS should be constructed frequently, which may be computationally complex. A local repair algorithm is used for constructing the new MCDS, which will drastically reduce the time complexity as well as the network overhead. The computation of power aware dominating set reported in [96] generates the MCDS based on the energy levels of nodes. In normal case the nodes in the dominating set consume more energy than the other nodes. In order to reduce the energy consumption of these nodes, alternate set of nodes should be chosen to form MCDS. This approach enhances the lifetime of each node in the network. But the frequent computation of the new dominating set could be excessively costly.

A distributed algorithm is proposed in [97] to construct energy efficient stable multi point rely based CDS to extend the life time of nodes in the Ad hoc network, based on energy and velocity of nodes. It is claimed that the algorithm can result in 25% improvement in node's life time and 60% reduction in route request packets. However, this method is only compared against the AODV algorithm and no attempt made to compare with other existing On-demand algorithms. An evolutionary approach using genetic algorithm for constructing the MCDS is proposed in [98]. The genetic algorithm considers the energy of each node in the network and minimizes the number of nodes in CDS as much as possible. An algorithm proposed in [99] finds the CDS based on node degree and energy level of each host. This scheme always ensures that the overall energy consumption of the network is balanced. This also improves the life span of the nodes in the network. Natarajan Meghanathan et al. proposed an algorithm [100] for determining the CDS, using the parameter Threshold Neighbourhood Distance Ratio (TNDR). The algorithm builds a list of node according to the decreasing order of the number of uncovered strong neighbours until all nodes in the network are covered. This method has longer life time than the density based CDS.

Establishing a reliable route in MANET still remains perplexing, to encourage the exploration of alternate approaches in finding routes through dominating set.

5.3 Computation of Dominating Set

In MANET determination of the domination set is distributed among the nodes. The dominating set is constructed by including all the nodes of maximum connectivity. Since it is required that the dominating set should contain nodes which are reachable, isolated nodes with lower connectivity are also included in the dominating set.

The algorithm described in Fig. 5.5 establishes the dominating set by computing the adjacency matrix and collecting the nodes corresponding to the maximum connected node, from the row sum. To form the adjacency matrix, initially 1- hop neighbor information is used and then expanded to 2-hop and 3-hop gradually. The row-sum of each row in the matrix is computed to find the maximum connected node and appended the maximum connected node to the dominating set. This can be continued till all the nodes are connected.

The algorithm has three main steps.

(i) Find the neighbour list by using HELLO messages.

(ii) Find the adjacency matrix

(iii) Find the dominating set from the row sum of the adjacency matrix. Referring to Fig. 5.4 node 1 and 4 have a connectivity of 3. Since {1,4} are connected to all other nodes dominating set is {1,4}. Proceeding in the same way {5,4},{2,4} also constitute domination sets.

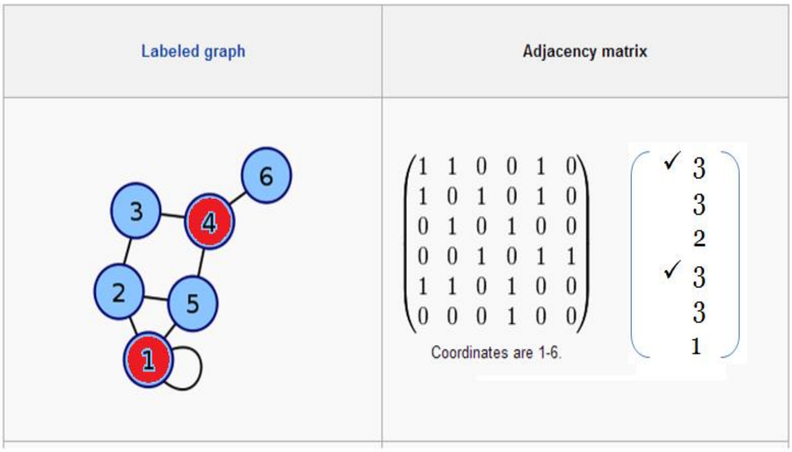


Fig. 5.4: Computation of Dominating Set.

```
For each node (X) compute the following
{
    For all neighbouring node Y
    {
     // Create Adjacency Matrix ADJ
    adj [X][Y]=1  // Y is a neighbour of X
    adj [X][Y]=0 //  Y is not a neighbour of X
    }
// Computation of  domination set 'dom set'
    While (ADJ ! NULL)
     {
          for (each i)
          {
          for (each j)
          Row_sum[i] = Row_sum[i] + Adj [i, j]
          }
          Select i, such that Row_sum[i] is maximum
          Append this to "dom set"
          For (each j)
          {
          Adj[i][j] = 0
          Adj[j][i] = 0
          }
    }
    If any node is not connected to the nodes in the 'dom set' then add
that node to dom set.
}
```

Fig. 5.5: Algorithm for Establishing the Dominating Set.

5.3.1 Route Discovery through Dominating Set

After computing the dominating set, the present algorithm, Dominating Set Based Routing (DBR), establishes the route to the destination through the domination nodes only. Referring to Fig. 5.6, the dominating set is {N3,N6,N10}, N1 the source and N10 the destination node. In the initial route discovery process, each node tries to connect the domination node from the source node. Even if the shortest path exists, the route to destination is always through the domination nodes. When the route failure occurs, then the corresponding domination node attempts the possible routes through the nodes connected to the domination node. If link N6-N8 is broken, then the node N6 can easily set up the connection through N7, failing which N6 will flood the route failure report to the other domination nodes. So this method is ready to lend a hand for finding the alternate route easily.

In the proposed method, the local repair is initiated by the domination node when the route break is detected and the reroute establishment delay and the control overhead can be reduced. For this, minimum dominating set is determined before transmission.

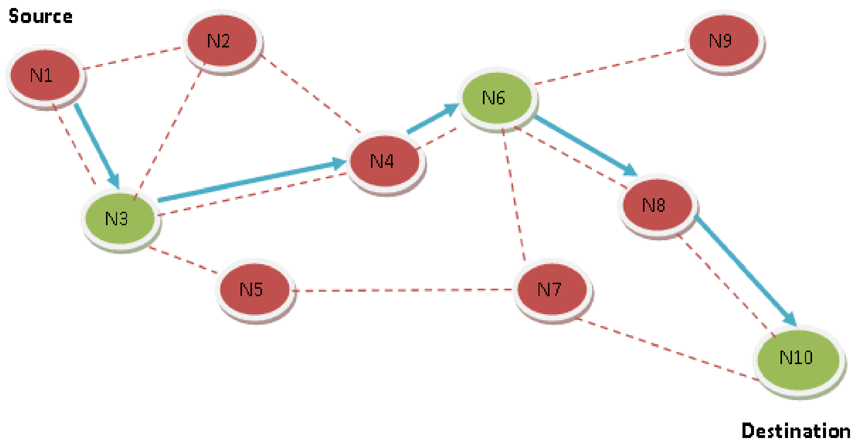


Fig. 5.6: Route Discovery through Domination Nodes.

5.3.2 Simulation Results

The proposed algorithm DBR is implemented in NS2 simulator with the parameters listed in Table 5.1.

Parameters	Value
Mac Protocols	IEEE 802.15.4
Number of Nodes	10,15,25,50,100
Simulation Area	500X500
Packet Size	512 bytes
Simulation Time	400 seconds
Initial Energy	Random Assignment

Table 5.1: Simulation Parameters.

Fig. 5.7 and 5.8 show the comparison of the performance of DBR with AODV and DSR in terms of packet delivery ratio and packet drop for different number of nodes. There is significant improvement in PDR in DBR compared to AODV and DSR, since DBR discovers the alternate route through the dominating set ensuring best connectivity. The packet drop also decreases in DBR and rapidly increases in AODV and DSR, with the increase in number of nodes to the tune of 40%. The reduction in the routing overhead for DBR is of the order of 50% compared to AODV and DSR as shown in Fig 5.9.

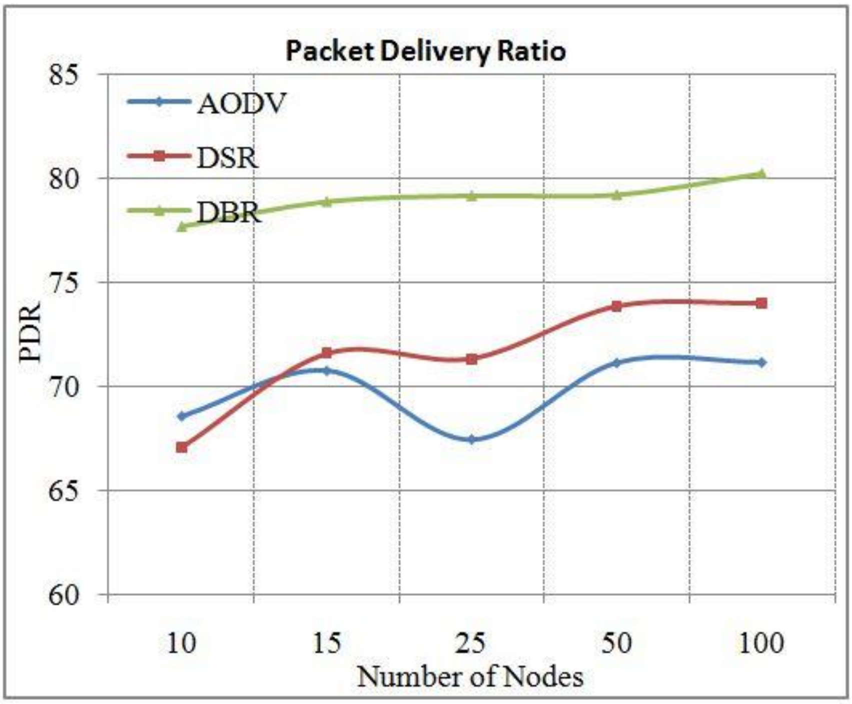


Fig. 5.7: Packet Delivery Ratio v/s Number of Nodes.

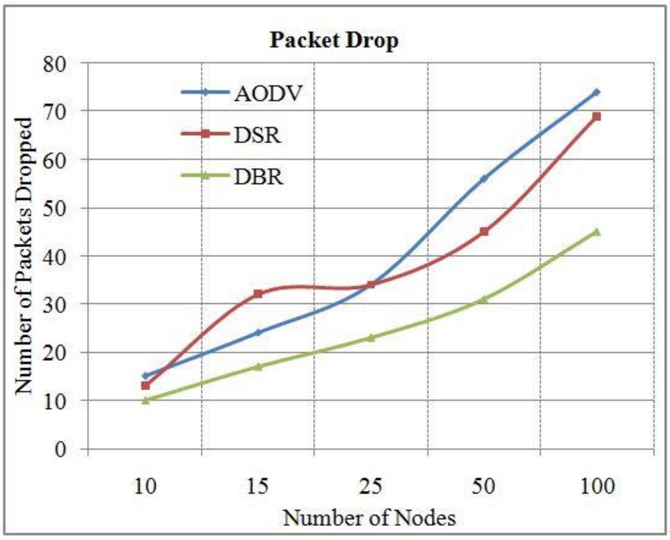


Fig. 5.8: Number of Packets Dropped during Transmission v/s Number of Nodes.

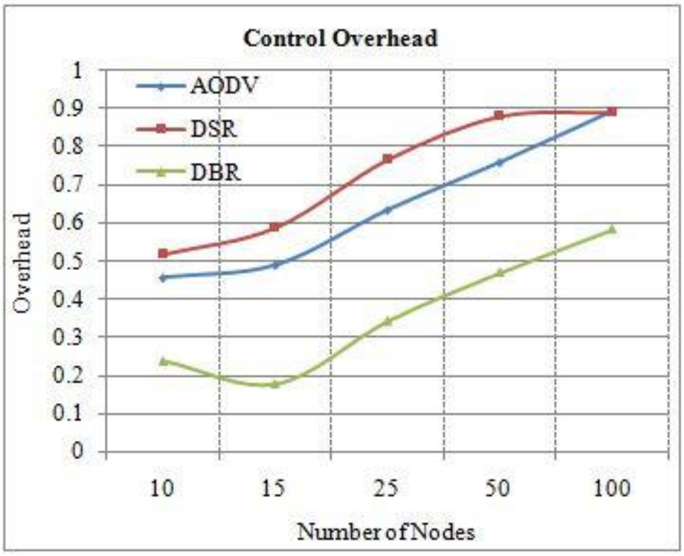


Fig. 5.9: Routing Overhead v/s Number of Nodes; Overhead is consistently low for DBR.

The selection of the domination nodes in DBR is random, thereby making many other alternatives possible. Since the domination node bears the brunt of majority of the transmissions it is imperative, that the domination node should be highly reliable. This suggests the possibility of selecting the reliable set from among the dominating set, based on the residual power and previous performance of the node measured in terms of PDR.

5.4 Reliable Dominating Set based Routing

The concept of DBR is extended to make the routing reliable, viz. Reliable Dominating Set Based Routing (RDBR), by selecting the domination nodes in the network based on the connectivity, residual energy and packet delivery ratio (PDR) through each node in the dominating set. While the main aim of the network is to improve the PDR, there could be some nodes which do not forward the packet for conserving its own resources. These nodes are called malicious nodes [101]. However, the algorithm proposed concentrates on finding the node which is least malicious, considering the PDR as an indicator of good behaviour. In order to achieve this, after each successful delivery of the packet, the nodes update the PDR of its neighbouring nodes.

The present work proposes a method to compute the Reliable Dominating Set (rDS) from a set of Dominating Set (DS) given by {D1, D2...........Dn}. The approach is illustrated in Fig.5.10.

It may be noted that the DS is initially formed depending on the maximum neighbourhood connectivity. Then the proposed algorithm refines the DS using

(i) residual energy of the nodes in the dominating set

(ii) the packet delivery ratio of the previous trials of each node in the set.

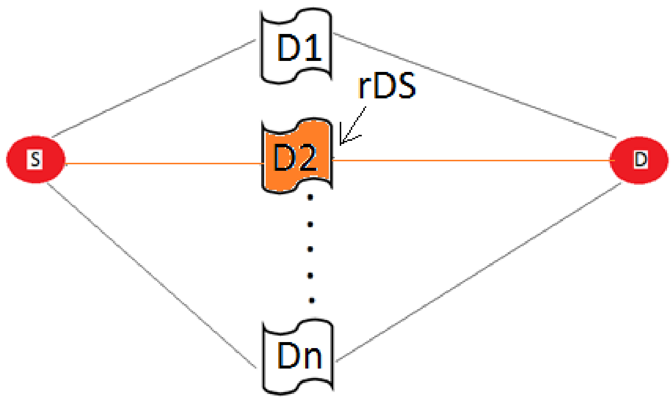


Fig. 5.10: Selection of rDS from the Given Set of DS.

The formal computational scheme of the proposed approach is given in Fig. 5.11. The Adjacency Matrix is generated by the source node based on connectivity. From the adjacency matrix, the dominating set is created using the algorithm described in 5.5, by computing the row sums of the matrix. The rDS is selected based on the PDR in the previous trials and residual energy of the nodes in the set, as detailed in Sec 5.4.1. The route is established through rDs from source to destination.

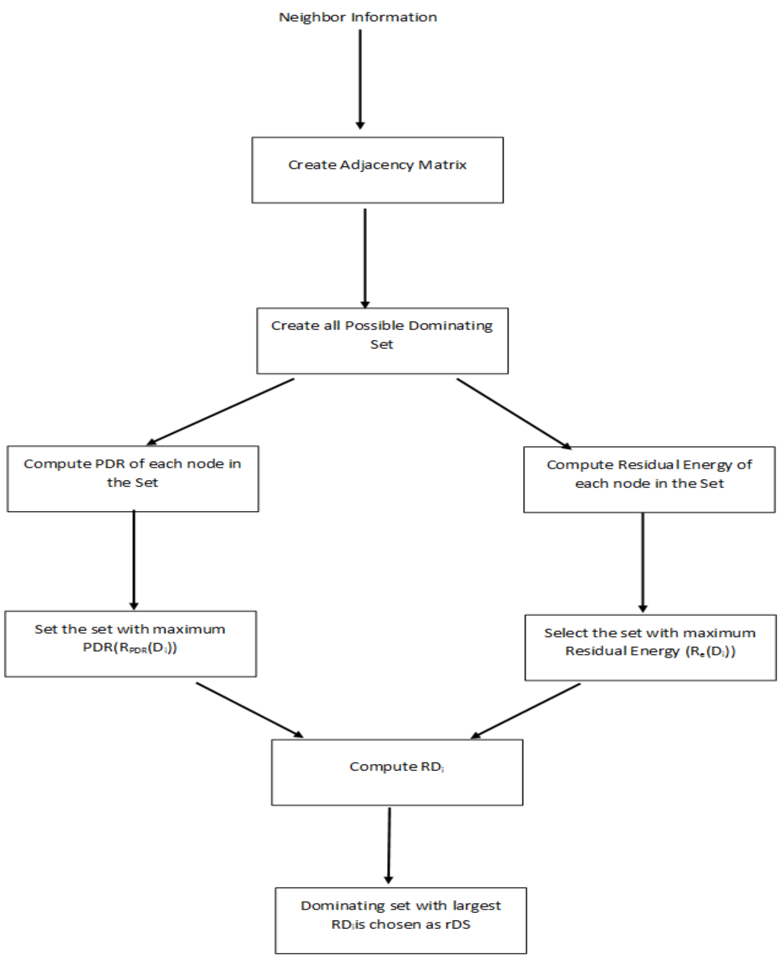


Fig. 5.11: Computational Scheme of rDS.

5.4.1 Computation of Node Reliability

A. Based on Residual Energy

Residual energy can be computed by subtracting the energy consumption at any time from the initial energy of the node. For any $x_k \in D_i$, $R_k(x_k)$ denotes the residual energy.

Reliability of the dominating set based on residual energy (Re(Di))of DS = {D1, D2 …Dn} is

$$R_e(D_i) = \frac{\sum_k R_k(x_k) | \, x_k \in D_i}{\sum_i R_e(D_i)} \quad , i = 1..n \tag{5.1}$$

B. Based on PDR

Packet delivery ratio (PDR) measured at each node determines the ability of forwarding packets to the next node in the network, which also forms a crucial factor while selecting the forwarding node. The node x_k in dominating set, with highest PDR is selected as the forwarding node. The PDR is continuously averaged across $\forall x_k$ such that $x_k \in D_i$.

$$\forall x_k \; x_k \in D_i, \mathrm{PDR}(x_k(t)) \leftarrow \alpha \, \mathrm{PDR}\big(x_k(t)\big) + (1-\alpha)\mathrm{PDR}\,(x_k(t-1)) \tag{5.2}$$

where $\alpha = .01$ and t accounts for temporal update.

Reliable PDR (R_{PDR}(Di)) of DS = {D1, D2 …Dn} is computed as the product of individual PDRs

$$R_{PDR}(D_i) = \Pi_k \text{ PDR } (x_k (t)|x_k \in D_i , i = 1..n \qquad (5.3)$$

Any node x_k which has a low PDR disqualifies the corresponding DS for routing.

From (5.1) and (5.3), decision for selecting the reliable Dominating set (RDi) follows the combination of Re and R_{PDR} for each Di∈ DS

$$RD_i = \frac{W1 * R_{PDR}(D_i) + W2 * R_e(D_i)}{W1+W2}, i = 1..n \qquad (5.4)$$

where W1 and W2 are selected appropriately such that W1+W2=1.

The dominating set with largest RDi will be chosen as the rDS qualified for routing.

5.4.2 Simulation Results

The proposed approach RBDR is implemented in NS2 for networks with varying number of nodes and different mobility and the performance in terms of overall PDR, packet drop and overhead is compared with AODV and DSR. The simulation parameters chosen are described in Table 5.1. It is observed that RDBR outperforms the existing protocols AODV and DSR in terms of the above metrics.

The PDR shown in Fig. 5.12 is calculated as the mean value of 1000 independent runs of the simulation corresponding to number of nodes chosen for each episode for each of the 4 different methods viz. AODV, DSR and DBR, RDBR (both proposed in the present chapter). The high value of the PDR, averaged out of the results of 1000 run along with the low variance highlights the credibility of DBR and RDBR.

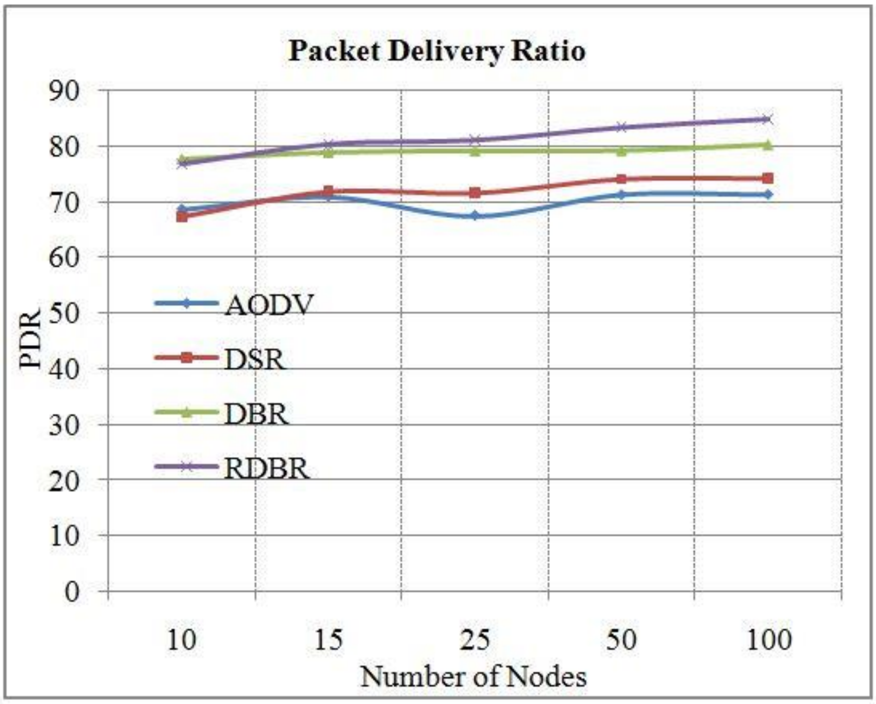


Fig. 5.12: Packet Delivery Ratio v/s Number of Nodes.

It is interesting to note that both DBR and RDBR perform almost similarly for smaller number of nodes. However, the RDBR shows pronounced improvement in performance with the increase in number of nodes, presumably due to the resilience of RDBR in withstanding the failure of relatively larger number of nodes in the network.

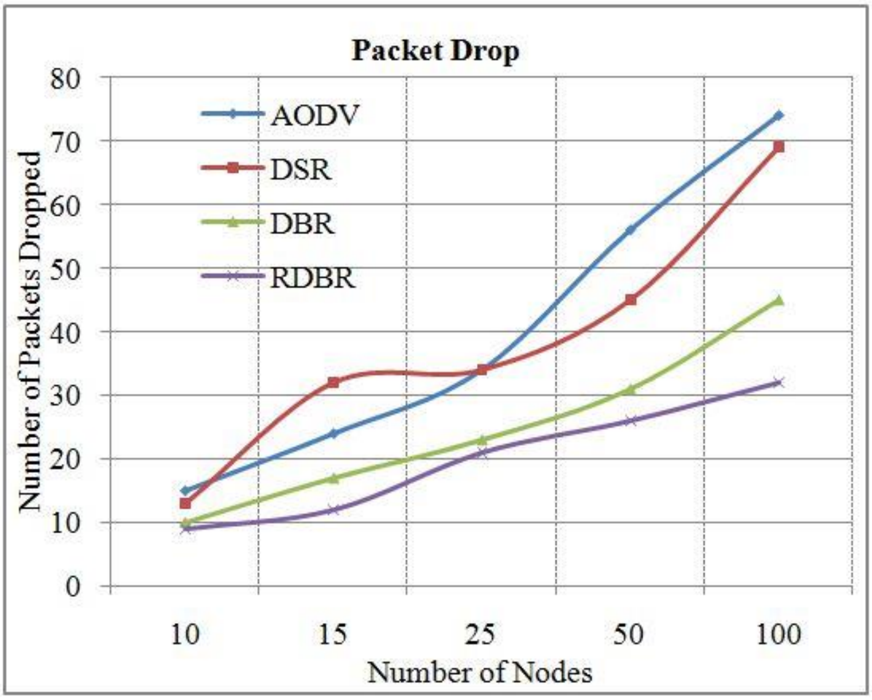


Fig. 5.13: Number of Packets Dropped during Transmission v/s Number of Nodes. The packet drop in RDBR is very less compared to the other two after a run of 500 seconds.

Since the re-route establishment is handled by the node in the reliable Dominating set rDS, consistent routes are ensured with minimum delay, thereby reducing the packet drop significantly, as is evident in the Fig. 5.13. This also explains the nearly linear nature of the increase in PDR as against the nonlinear increase in AODV and DSR. Also while maintaining the linearity, RDBR performs better than the DBR in respect of packet drop and routing overhead (Fig. 5.14), thanks to the judicious choice of the domination node based on PDR and residual energy.

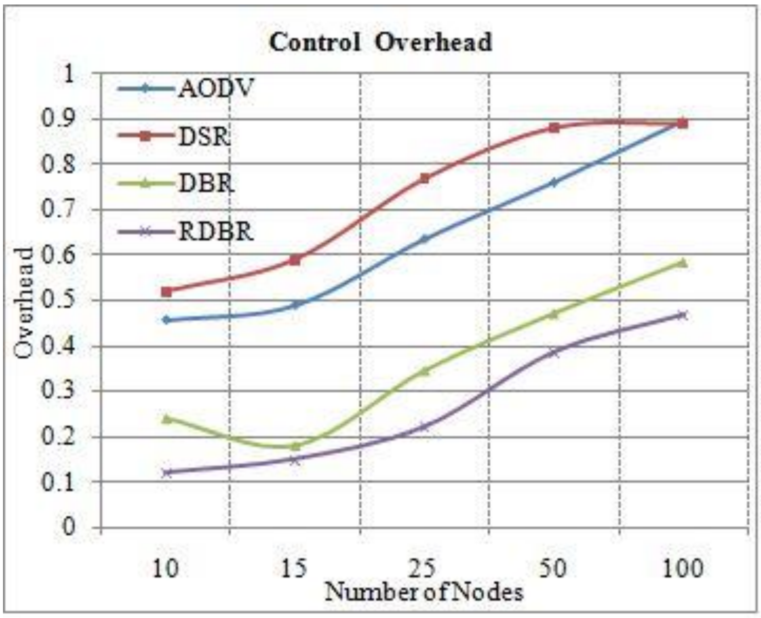


Fig. 5.14: Routing Overhead v/s Number of Nodes.

Table 5.2 and 5.3 summarizes the results of 1000 independent Monte Carlo runs corresponding to varying size of the network measured in terms of number of nodes (spanning over the same area). The PDR shown in Table 5.3 is seen to be better for DBR and RDBR than the same for AODV and DSR. The lower value of the variance emphasizes the credence of the proposed algorithms. Similar conclusion can be inferred from Table 5.4 which shows relatively lower values of overhead, punctuated by low variance.

Protocol	**PDR**	**Number of Nodes**				
		10	**15**	**25**	**50**	**100**
AODV	Mean	68.53	70.754	67.393	71.134	71.54
	Variance	8.389	8.324	8.0523	8.429	9.24
DSR	Mean	67.07	71.583	71.344	73.864	74.009
	Variance	7.926	11.414	11.192	11.209	11.212
DBR	**Mean**	**77.68**	**78.88**	**79.167**	**79.208**	**80.23**
	Variance	**7.823**	**7.203**	**6.158**	**6.453**	**7.319**
RDBR	**Mean**	**76.54**	**80.134**	**80.864**	**83.167**	**84.688**
	Variance	**7.32**	**3.281**	**5.324**	**6.34**	**7.073**

Table 5.2: Mean and Variance of PDR out of 1000 Independent Runs, corresponding to Different Number of Nodes.

Protocol	Overhead	Number of Nodes				
		10	**15**	**25**	**50**	**100**
AODV	Mean	0.457	0.49	0.635	0.780	0.844
	Variance	0.14	0.127	0.148	0.19	0.15
DSR	Mean	0.52	0.59	0.768	0.88	0.89
	Variance	0.08	0.104	0.122	0.199	0.188
DBR	**Mean**	**0.24**	**0.180**	**0.345**	**0.471**	**0.584**
	Variance	**0.069**	**0.085**	**0.102**	**0.15**	**0.108**
RDBR	**Mean**	**0.12**	**0.151**	**0.221**	**0.385**	**0.467**
	Variance	**0.05**	**0.07**	**0.091**	**0.14**	**0.102**

Table 5.3: Mean and Variance of Overhead out of 1000 Independent Runs, corresponding to Different Number of Nodes.

5.5 Conclusion

The efficacy of using the dominating set to establish the routes has been proposed and demonstrated in the present chapter. While the routing based on dominating set, DBR holds promises for tangible improvement in performance of MANET, the present chapter also demonstrates convincingly a method, RDBR to identify reliable routes considering the residual energy and the node PDR. While metrics like PDR, packet drop and control overhead are used for comparing the performance of both DBR and RDBR vis-à-vis AODV and DSR, the performance is also emphasized using large number of independent Monte Carlo runs. It is encouraging to note that the performance of the algorithms DBR and RDBR are mostly linear with respect to the number of nodes, which favours the adaptation of the algorithm for larger networks as well.

It has been observed that some of the nodes could be malicious to the extent of not forwarding the packets, even if it has got the sufficient energy. In RDBR, such nodes are likely to get consideration during the early stages of network operation. But gradually the low PDR accumulated in the malicious node could lead to the node to get disqualified automatically, though they may be energy rich. In general it can be seen that the routing techniques discussed in this chapter predominantly utilizes the richness of the existing connections. In a dynamic system like MANET the routing could also be influenced by the routes that are likely to be formed as the time elapses. The identification of nodes based on the possible topology in the course of time, is discussed in the chapter to follow.

Chapter 6

ENHANCING THE PERFORMANCE OF ROUTING PROTOCOL BY PREDICTING THE LINK AVAILABILITY THROUGH BELIEF PROPAGATION

In this chapter, an attempt is made to predict the longevity of the links by utilizing fuzzy decision process and belief propagation. Initially the link is selected based on the signal strength while the final choice accommodates the node energy also. Two methods are introduced (i) Link Prediction Routing (LPR) and (ii) Reliable Link Prediction Routing (RLPR) to discover most reliable link in the context of arbitrary node and link failure. The predicted value is propagated and can be used to select the neighbouring nodes, as data forwarding nodes.

6.1 Introduction

The dynamic nature of MANET results in a topology that evolves in time. Accordingly the nodes in the network and the links connecting them could change randomly, thereby making the route establishment process based on static connection not effective always. On the other hand, the routes can be decided by propagating the belief based on link and node availability from source node to the destination node. While at each node the decision to propagate the belief is based on well-known theory of Markov process [102,103], the present chapter also portrays a modification on the decision making process as a fuzzy function, computed on the signal strength and node energy.

6.1.1 Significance of Link and Node Life Time in Routing Decision

Link and node failures account for major routing problems in MANET. The definition of life time refers to the availability of link/node during the message transmission. Even with a well acclaimed superior performance of on demand routing algorithms, the stability of the established route is at the mercy of the node and link failures. Even if the routing algorithm finds the route with respect to the shortest path, there is a chance of node failure due to the battery drain and link failure on account of node movement. Obviously high node mobility could also imply higher route failure.

In case of route failure, in the normal course, the route is re-established by initiating the procedure from the beginning, which may lead to an enormous time delay and control overhead. All these may lead to objectionably large amount of packet drops. If one can predict the node movement with a reasonable amount of accuracy, then route can be established between source and destination, with better stability.

6.1.2 Belief Propagation (BP)

Belief propagation is the best message passing method and it is the way of organizing the global computation of marginal belief in terms of local computations [104]. It is used in computing in a distributed manner, where each node computes its belief based on the message received from its neighbours. Referring to Fig. 6.1, messages are associated with the edges of the graph and are recursively updated through local computations at the vertices of the graph. Message from node i to node j is designated as M_{ij}.

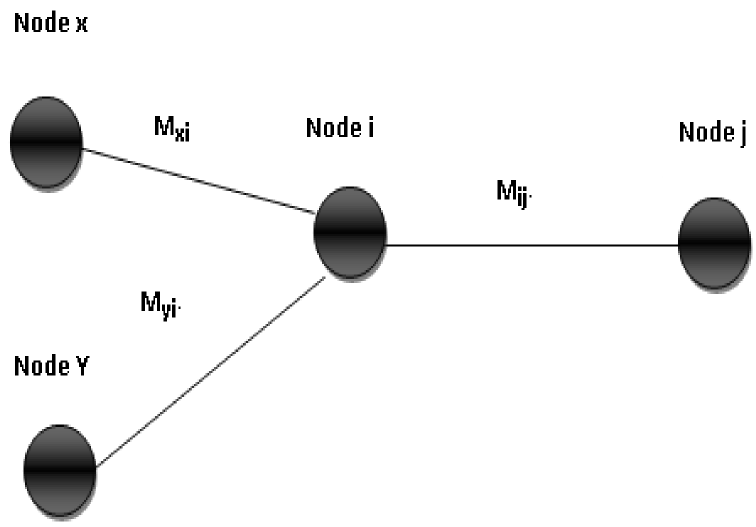


Fig. 6.1: Belief Propagation- A Typical Example.

After a number of iterations, a series of conversations is likely to converge to consensus that determines the marginal probabilities. Marginal probability at a node is the product of all incoming messages at that node [105]. Estimated marginal probabilities are called beliefs. Equation 6.1 represents the marginal probability at node i in the Fig. 6.1.

$$M_i = \prod_{x=1}^{n} M_{xi}\,, where\ n\ is\ the\ no.\ of\ incidences\ on\ node\ i \qquad (6.1)$$

6.1.3 Markov Process (MP)

Markov process is a stochastic process that satisfies the Markov property [106], that if one predict the future of the process based solely on its present state, without depending on the complete past history. The changes of state of the system are called transitions and the probabilities associated with various state changes are called transition probabilities. Transition matrix is used to describe the probabilities of particular transitions. Thus Markov chain is a discrete time stochastic process defined over a set of states 'S' in terms of matrix P: <p_{ij}> of transition probabilities.

Consider the state S denoted by a set of nodes {S_1, S_2,...,S_k}. The process starts from S_1 and further moves from S_i to S_j. Move or step is decided by a probability function denoted by p_{ij} given by,

$$\forall\ i, j \epsilon S,\ 0 \leq p_{ij} \leq 1,\ \ \sum_j p_{ij} = 1 \tag{6.2}$$

A node S_i with incident probability M_i propagates the message M_{ij} to the node S_j given by

$$M_{ij} = p_{ij} * M_i \tag{6.3}$$

The message M_{ij} propagates through the network following a random walk [107]. A typical message transmission is illustrated in Fig. 6.2.

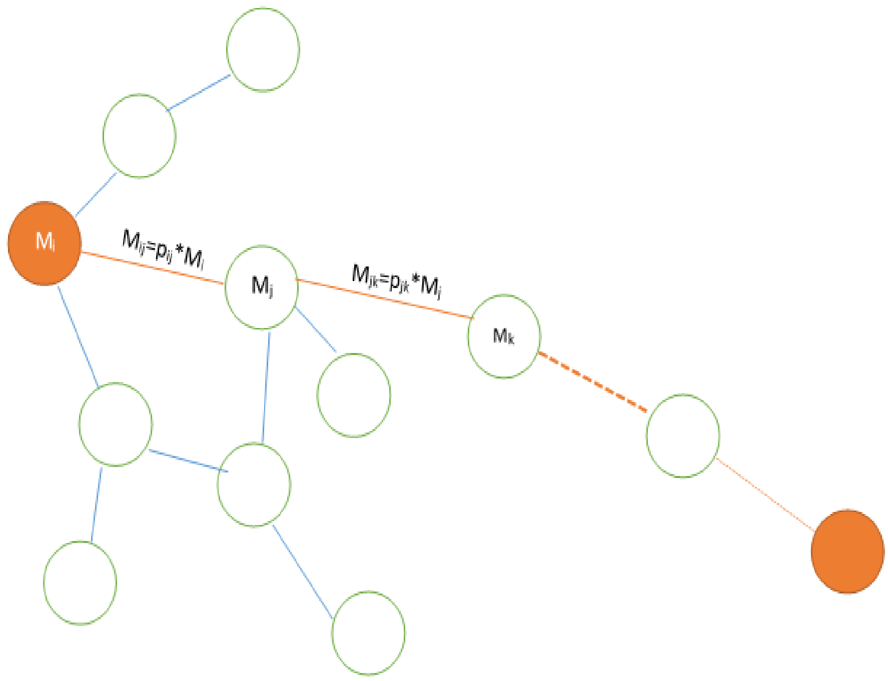


Fig. 6.2: Illustration of Message Transmission M_{ij}.

6.2 Related Research

A survey of the published literature available brings out that many methods have been formulated for predicting the neighbours of a given node for data forwarding. In [108] a Gauss-Markov random process is used to estimate the mobility of the node based on the speed and direction. However the method considers only the link life time in choosing a branch from a node. On the other hand, authors in [109] predict the position of neighbours, based on the past location history. But maintenance of the past location history could be cumbersome in large networks.

In [110] the authors tried to address the problems in heterogeneous networks and proposed a method using belief propagation to minimize the transmission overhead and complexity in message passing, where no attempt has been made to improve the PDR but only concentrates the load balancing among users. A belief propagation distribution algorithm has also been proposed in [111] for cell association and subcarrier allocation of highly dense networks; however does not address the availability of nodes and links in future. Gaussian sum cubature belief propagation (GSCBP), proposed in [112] uses the Gaussian sum to represent the messages propagated through neighbouring vehicles, which provides accuracy in communication. This method tries to increase the communication accuracy but no attempt is made to predict the life of the link. Paper [113] utilizes the information kept in the cache of each Base Station (BS) which transmits the cached information to neighbouring BS. The routes are established by the BS combining the cached information through collaborative action. As claimed by authors, the collaborative collection can lead to the reduction of the average delay and network overhead in route establishment. However, the restrictions on the memory to cache large amount of data from neighbouring BS often reduces the effectiveness of the approach.

The sections to follow reports the improvement in route identification using belief propagation considering link availability and the residual node power, different from the work surveyed above, thereby making the routes consistent in performance.

6.3 Link Prediction using Belief Propagation

The Link life time Prediction Routing (LPR) using belief propagation, presented below, propounds the idea of assessing the behaviour of the node with respect to the signal strength, before a prediction is made for future existence of the links. Following the idea presented in [107] a random walk from source to destination is created based on the degree of connectivity in the network. For each node, branching out of a given node a score for each pair of node is generated according to the schemes given in Section 6.1, and propagated further into the network. By retracing the route corresponding to the maximum score at the terminating end, the route is established. The chance of route break during transmission cannot be fully avoided, but the resultant route failure can be reduced. When a route break occurs after establishing the route, the intermediate node is responsible for finding the route for the rest of the path, until the destination is reached.

Referring to Fig. 6.3, the network is represented as a graph G = (V, E). For each pair of nodes, set signal strength as a score

(However some links from a given node are pruned based on the value of signal strength). For a given node i, if S_{ij} is the strength of the link from node i to node j, the node i computes a transition probability to node j given by

$$p_{ij} = \frac{S_{ij}}{\sum_{i=1}^{n} S_{ij}}, where\ n\ is\ the\ degree\ of\ the\ node\ i. \qquad (6.4)$$

Each node i propagates the belief B_i to every neighbouring nodes, by multiplying the incoming belief with p_{ij}. Node j in turn multiplies the incoming belief with the transition probability generated at node j for further propagation down the network. For the source node, incoming belief is assumed to be 1. Resulting spanning tree is constructed from the source to destination, as illustrated in Fig. 6.3.

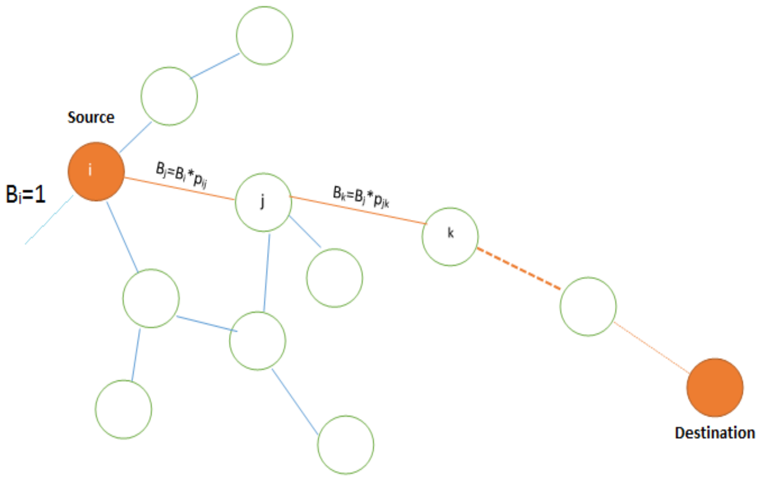


Fig. 6.3: Illustration of LPR Algorithm.

The destination node, having the maximum accumulated belief is considered as the winner, is retraced to the source, there by establishing the route.

6.3.1 Simulation Results

The LPR algorithm described above is implemented in NS2 with varying simulation time. The performance of the algorithm is evaluated in terms of Packet Delivery Ratio (PDR), Packet Drop and Control Overhead against AODV and DSR. The simulation parameters are described in Table 6.1.

Parameters	**Options/Values chosen**
Mac Protocols	IEEE 802.15.4
Number of nodes	50
Simulation area	500X500
Packet size	512 bytes
Simulation time	100,200,300.400 Seconds

Table 6.1: Simulation Parameters.

For the LPR algorithm, the mean value of the PDR shows a pronounced improvement over the other two algorithms as shown in Fig.6.4. The noticeable impact of signal strength in deciding the transition probability is brought out in the increasing nature of the PDR with time, which may be contrasted with the nearly steady nature of the PDR for AODV and DSR. Fig. 6.5 illustrates the nature of packet drop, which is significantly reduced in LPR, as a natural justification of the improved PDR. Finally the efficiency is evaluated in terms of control overhead. The overhead is also noticeably low in the case of LPR, as against the other two algorithms, clearly bringing out the consistency of the routes established, thereby confirming the credence of the proposed LPR (Fig. 6.6).

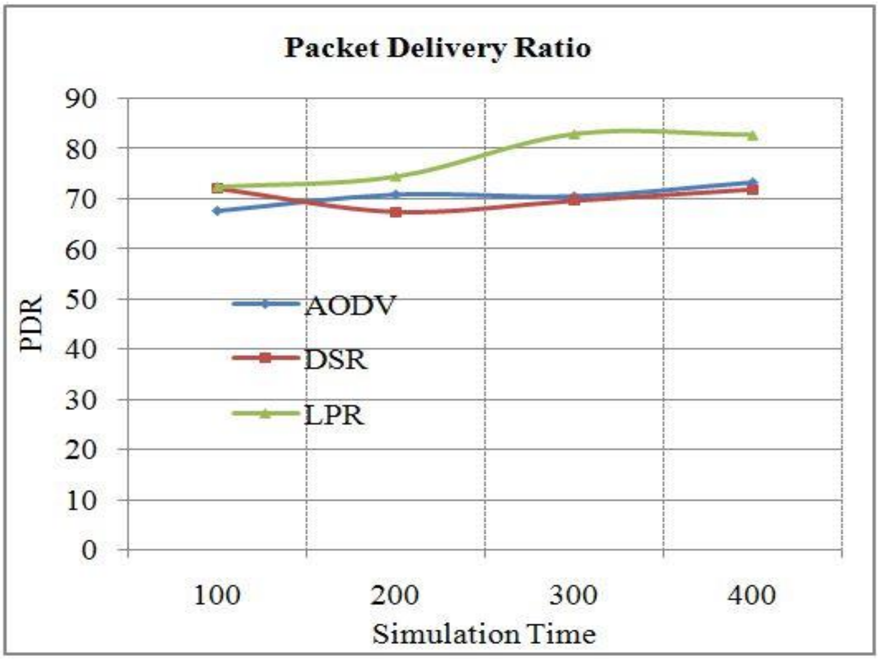


Fig. 6.4: Comparison of LPR with AODV and DSR in terms of PDR.

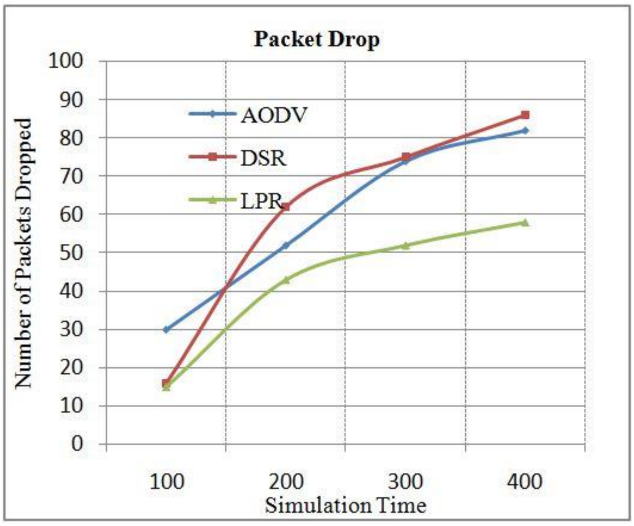


Fig. 6.5: Comparison of LPR with AODV and DSR in terms of Packet Drop.

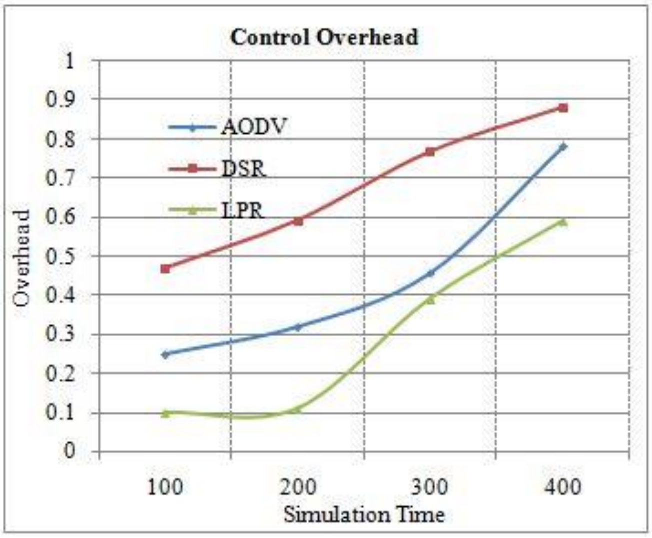


Fig. 6.6: Comparison of LPR with AODV and DSR in terms of Control Overhead.

Corresponding to each epoch in a progressive span of 100 seconds, the simulation is executed 1000 times and the mean PDR from 1000 independent runs and the corresponding variance is given in Table 6.2 for each of the algorithms viz. AODV, DSR and LPR. The improved performance of LPR in producing large PDR is obvious from the relatively better values of mean value in Table 6.2. The low value of the variance in the 1000 simulations further underscores the remarkable confidence in the PDR achieved in the case of LPR. The mean and variance of 1000 independent execution corresponding to overhead is also listed in Table 6.3, for each of the algorithms. Here again the relatively lower values of mean and variance ascertains the acceptance of the LPR algorithm.

Protocol	**PDR**	**Simulation Time in (s)**			
		100	200	300	400
AODV	Mean	67.540	70.758	70.393	73.134
	Variance	8.329	6.610	7.472	6.47
DSR	Mean	72.072	67.344	69.583	71.864
	Variance	7.513	7.456	8.23	8.029
LPR	**Mean**	**72.23**	**74.16**	**82.76**	**82.88**
	Variance	**7.319**	**6.441**	**5.954**	**5.992**

Table 6.2: Mean and Variance of 1000 Independent Runs for PDR.

Protocol	Overhead	Simulation Time in (s)			
		100	200	300	400
AODV	Mean	0.250	0.320	0.457	0.780
	Variance	0.080	0.080	0.122	0.998
DSR	Mean	0.470	0.592	0.767	0.880
	Variance	0.080	0.104	0.122	0.99
LPR	**Mean**	**0.099**	**0.109**	**0.390**	**0.590**
	Variance	**0.069**	**0.07**	**0.085**	**0.73**

Table 6.3: Mean and Variance of 1000 Independent Runs for Control Overhead.

6.4 Link Prediction using Belief Propagation based on a Fuzzy Decision to Compute Transition Probability

The idea of LPR is extended to Reliable Link Prediction Routing (RLPR), when the signal strength and residual energy of the nodes decide the generation of the transition probability. Selection of the route is carried out in the same way in both LPR and RLPR. Inclusion of the node life time (in terms of residual energy) along with the link life time (in terms of signal strength) in the prediction of the route, is shown to enhance the robustness of the route selection process below.

In RLPR proposed here, the node and link life time with respect to the node energy (X1) and signal strength (X2) are both considered. A fuzzy function on the node energy and signal strength, which are treated as fuzzy linguistic variables, is computed to establish the node transition probability. The signal strength and node energy are fuzzyfied using the fuzzy membership function $\mu(x) = e^{-(x- c_i)^2/2}$ (as mentioned in Equation 4.3), for the ith fuzzy set and x could represent either node energy or signal strength.

The support for the fuzzy sets is defined as {0..1} and i= 1 to 5 defines the five fuzzy sets on the variable x as shown below.

Very Low	Low	Medium	High	Very High

Following the approach in sec. 4.4, $c_i \in \{ .05, .25, .5, .75, 1\}$.

For a given node i, the transition probability p_{ij} is computed using a fuzzy function evaluated on the basis of the rule base already given in Table 4.3 (repeated below in Table 6.4 for clarity).

X2 / X1	Very Low	Low	Medium	High	Very High
Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
Low	Very Low	Low	Low	Low	Low
Medium	Very Low	Low	Medium	Medium	High
High	Very Low	Low	Medium	High	Very High
Very High	Very Low	Low	High	Very High	Very High

Table 6.4: Rule base.

To decide on the transition from node i to node j, the consequent from the rule base table is accumulated to compute the fuzzy decision.

$$q_{ij} = \frac{\sum_{l=1}^{5}\sum_{m=1}^{5}\mu_l(x1)\mu_m(x2)c_{lm}}{\sum_{l=1}^{5}\sum_{m=1}^{5}\mu_l(x1)\mu_m(x2)} \qquad (6.5)$$

Thereafter the transition probability p_{ij} is given by

$$p_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}} \text{, where } n \text{ is the degree of the } i^{th} \text{ node} \qquad (6.6)$$

The nodes propagates the belief as in the case of LPR using the p_{ij} given in Equation 6.6. Destination node selects the route with the highest value of belief in the same way as discussed in the case of LPR.

6.4.1 Simulation Results

RLPR is implemented in NS2 simulator with varying simulation time. As in the case of LPR, the performance of the proposed work is evaluated based on the parameters PDR, Control Overhead, and Packet Drop. Simulation scenario described is the same as the one given in Table 6.1.The simulation of the network scenario is executed for the durations viz. 100 s, 200 s, 300 s, 400 s.

The improved performance of RLPR over LPR and other two existing algorithms viz. AODV and DSR is illustrated in Fig. 6.7 to 6.10. Fig. 6.7 shows the marginal, but steady, improvement in PDR for the RLPR algorithm over LPR. Similarly packet drop and control overhead are also seen to be significantly lower in RLPR as against the other three methods, which are evident from Fig. 6.8 and Fig. 6.9. The marginal improvement in the case of RLPR may be attributed to the presence of only reliable nodes in the route as an improvement over the LPR. Fig. 6.10 portrays the comparison of LPR, RLPR, AODV and DSR based on end to end delay, from which it is observed that both the LPR and RLPR have less delay than AODV and DSR. But the delay in RLPR is slightly more than the LPR. In the pursuit of including reliable nodes in the route selection, the path established by RLPR may not be the shortest, and hence could face increased delay, though RLPR achieves improved robustness in terms of consistently high values of PDR and lesser number of packet drops.

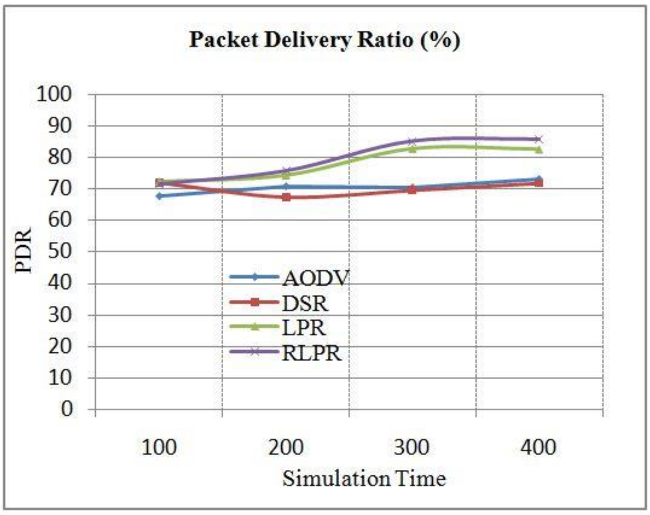


Fig. 6.7: Comparison of AODV, DSR with LPR and RLPR in terms of PDR.

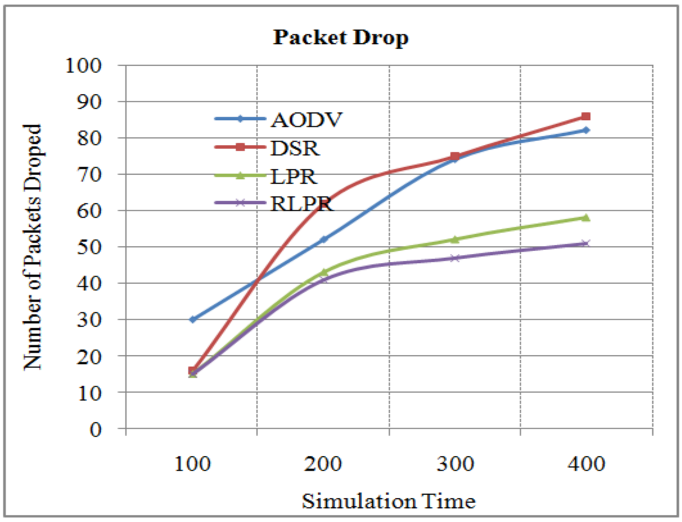


Fig. 6.8: Comparison of AODV, DSR with LPR and RLPR in terms of Packet Drop.

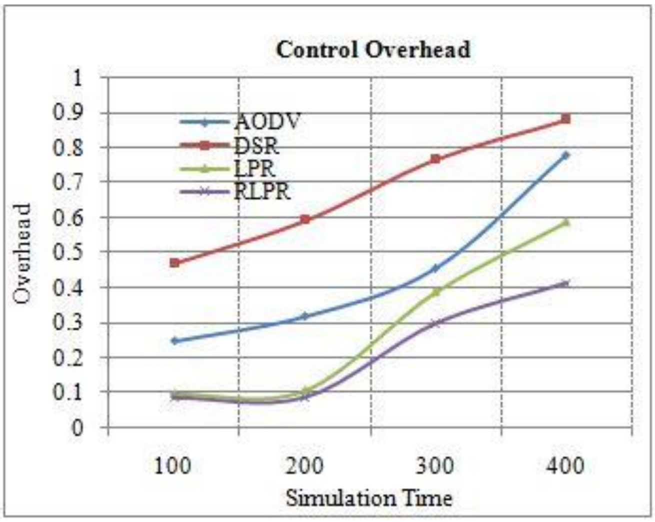


Fig. 6.9: Comparison of AODV, DSR with LPR and RLPR in terms of Control Overhead.

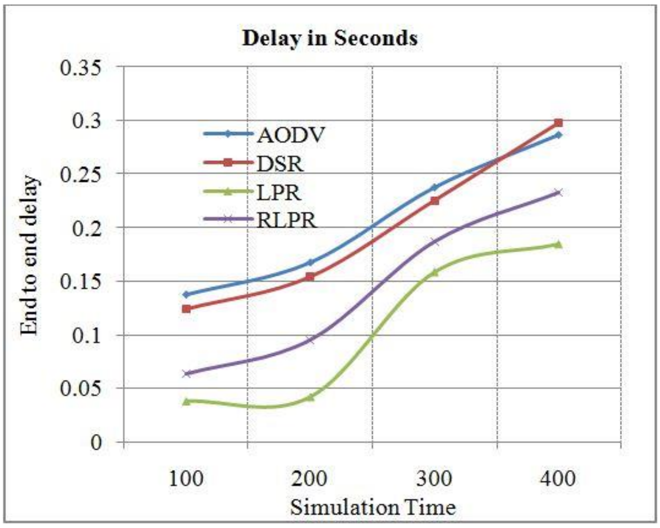


Fig. 6.10: Comparison of AODV, DSR with LPR and RLPR

in terms of End to End Delay.

For evaluating the PDR, 1000 independent runs were carried out for each duration and the average of PDR is calculated, along with its variance for all the four methods. Results are listed in Table 6.5, which clearly shows that the mean value of the PDR of both LPR and RLPR is better than AODV and DSR. In general the larger value of the mean value of PDR along with the lower value of the variance also highlights the assurance of the proposed algorithms in respect of PDR. However it is interesting to note that for duration of 100 Seconds of elapsed time the RLPR performs less than the LPR, presumably due to the less number of failures of the node in the initial stages, when both LPR and RLPR follow the same strategy for route establishment. Table 6.6 summarises the comparison of overhead, which brings out the superior performance of RLPR over the other methods. Table 6.7 reconfirms the observation made above regarding the marginal increase in delay of RLPR over LPR.

Protocol	**PDR**	**Simulation Time in (s)**			
		100	200	300	400
AODV	Mean	67.540	70.758	70.393	73.134
	Variance	8.329	6.610	7.472	6.47
DSR	Mean	72.072	67.344	69.583	71.864
	Variance	7.513	7.456	8.23	8.029
LPR	**Mean**	**72.23**	**74.16**	**82.76**	**82.88**
	Variance	**7.319**	**6.441**	**5.954**	**5.992**
RLPR	**Mean**	**71.69**	**75.846**	**85.149**	**85.759**
	Variance	**6.583**	**5.669**	**4.137**	**4.17**

Table 6.5: Mean and Variance of 1000 Independent Runs for PDR. The relatively high value of PDR shows the improvement in performance of LPR and RLPR, while the low value of variance indicates the trustworthiness.

Protocol	**Overhead**	**Simulation Time in (s)**			
		100	200	300	400
AODV	Mean	0.250	0.320	0.457	0.780
	Variance	0.080	0.080	0.122	0.998
DSR	Mean	0.470	0.592	0.767	0.880
	Variance	0.080	0.104	0.122	0.99
LPR	**Mean**	**0.099**	**0.109**	**0.390**	**0.590**
	Variance	**0.069**	**0.07**	**0.085**	**0.73**
RLPR	**Mean**	**0.089**	**0.09**	**0.299**	**0.413**
	Variance	**0.068**	**0.0695**	**0.069**	**0.68**

Table 6.6: Mean and Variance of 1000 Independent Runs for Overhead.

Protocol	**End to End Delay**	**Simulation Time in (s)**			
		100	200	300	400
AODV	Mean	0.137	0.167	0.237	0.286
	Variance	0.039	0.060	0.061	0.061
DSR	Mean	0.124	0.154	0.225	0.297
	Variance	0.038	0.0682	0.068	0.058
LPR	**Mean**	**0.038**	**0.042**	**0.158**	**0.184**
	Variance	**0.035**	**0.035**	**0.055**	**0.042**
RLPR	**Mean**	**0.063**	**0.095**	**0.187**	**0.233**
	Variance	**0.034**	**0.035**	**0.053**	**0.041**

Table 6.7: Mean and Variance of 1000 Independent Runs for End to End Delay.

6.5 Conclusion

The present chapter has established the improved performance of finding the routes using belief propagation. Two algorithms have been presented and the performance demonstrated viz. LPR and RLPR, to select the route that could be stable from source to destination. Both the methods establishing the route by propagating the belief from the source to the destination nodes. The first method LPR is formulated based on the signal strength only to calculate the transition probability of a given node. The best path is selected based on the belief accumulated at the destination node. The second method RLPR further strengthens the path identification by including the node energy, in addition to signal strength. The transition probability is calculated on the basis of a fuzzy decision function, extracted from a rule base with signal strength and residual energy as antecedence. Simulation studies carried out on 1000 independent runs for different durations from 100 to 400 seconds, reveal that the LPR and RLPR perform much better than AODV and DSR. The delay is observed to be little higher for the RLPR in comparison with LPR possibly because of landing in a longer path in the pursuit to achieve a higher robustness, manifest in terms of large PDR. The choice between LPR and RLPR is decided by the application which weighs fast delivery against robustness.

Chapter 7

CONSOLIDATION OF ROUTING ALGORITHMS PROPOSED AND DEVELOPED

Thesis has concentrated on the development of algorithms for improving the routing performance in MNAET. Various aspects like reduction of overhead due to packet flooding, identification of routes based on dominating sets with improved performance in respect of packet delivery and overhead, establishment of sustainable routes by predicting the availability of routes, have been discussed at length and demonstrated through elaborated simulation. A consolidation of different algorithms proposed in the thesis would be in order to assess the relative merits and applicability.

7.1 Introduction

On the basis of an extensive evaluation of common routing algorithms viz. DSDV, AODV and DSR for MANET through simulation on NS2 over a variety of complex wireless network models and configurations with a view to derive new directions, further improvements have been taken up in the on demand algorithms in the present thesis. Three major aspects have been addressed as part of the dissertation.

(i) Reduction of flooding overhead in route establishment.

(ii) Reduction of route re- establishment delay by choosing the route through dominating set.

(iii) Establishment of reliable route, based on the prediction of node and link availability, through belief propagation.

An overall assessment of the techniques developed in the present dissertation is summarized in sections to follow.

7.2 Assessment of the Algorithms Developed

One of the well-established method in route establishment in MANET is through flooding of control packets. In order to alleviate the problems of excessive control overhead due to over flooding, the chapter 4 introduced and demonstrated the establishment of route discovery process, using restricted flooding. Here the route request packet (RREQ) received at a node is forwarded to the most prominent node based on the success of the previous attempt and remaining energy available in the node. Table 7.1 summarises the comparison of the demonstrated method against the AODV and DSR algorithms.

Method	Routing Strategy	Salient Features/ Outcome
Reduction of Control over head in on demand algorithms- Method 1	Routing strategy based on the possibility of connection to the destination. Routing based on the expected value of the success rate in establishing a route through a node.	Nearly 10 % improvement in the Control over head vis-à-vis AODV Nearly 20% improvement in the Control over head vis-à-vis DSR.
Reduction of Control over head in on demand algorithms- Method 2	Routing based on the (i) The success rate through a node and (ii) residual energy available in a node Decision to forward the RREQ from a node is based on a fuzzy function computed on success rate and residual energy.	Improvement of the tune of 40 to 45 % in control over head in comparison with AODV and DSR. Inclusion of residual energy enhance the robustness of the proposed algorithm. Influence of the threshold on performance has been studied.

Table.7.1: Summary of Reduction of Control Overhead based on Restricted Flooding.

It was quite encouraging to note that the method described above resulted in a definite improvement in the control overhead, demonstrated through a number of simulations of varying simulation time on a large network. The independent Monte Carlo run also underscored the success of the methods as evinced by low variance in control overhead.

Appreciating the fact that the routes established through largely connected nodes achieve route re-establishment quickly, the dominating set based routing established in Chapter 5, concentrates on developing routes from source to destination. The suggested method DBR identifies the domination nodes based on connectivity and establishes the routes through the domination nodes. Noting that the choice of dominating set is random from among the available sets, the concept of DBR is extended to RDBR in order to select the most appropriate dominating set, thereby making the route reliable. The best dominating set is selected based on the connectivity, residual energy and packet delivery ratio. It is interesting to note that the PDR is improved, while reducing the packet drop and control overhead. Table 7.2 recapitulates the features of proposed algorithms.

Method	Routing Strategy	Salient Features/ Outcome
Improving the routing performance using Dominating set-DBR.	Algorithm for determining the dominating set based on maximum connectivity.	~10% improvement in PDR and ~20% improvement in overhead.
Enhancing the routing performance using efficient Dominating set-RDBR.	Formation of dominating set based on (i) residual energy of the nodes (ii) PDR of the previous trials of each node Routing through Dominating set.	The inclusion of residual energy in the decision process helps to enhance the robustness of the route. ~30% improvements in PDR and ~40% in overhead.

Table 7.2: Assessment of DBR and RDBR Algorithms.

The low value of variance of the PDR and control overhead demonstrated through independent Monte Carlo runs also have confirmed that the proposed algorithms performs better than the other existing algorithms like AODV and DSR.

The frequent breakage of links in MANET necessitates regular re-establishment of routes. Link break occurs because of the node failure and link failure, due to random node movement. The basic idea to overcome this problem is to build the long lived route. The stable routes are identified by predicting the availability of the node and link, using belief propagation in the proposed methods LPR and RLPR. The belief content received at the destination leads to the selection of reliable route. Starting from the source node the belief is propagated through all possible connections. Table 7.3 summarises the main findings of the proposed methods.

It is well acknowledged that the nodes in the MANET can move randomly. The initial assignment of random velocities meant to simulate the movement in different directions. However the changes in the velocity subsequently, as part of the traffic can live to changes in the signal strength. In all the simulations carried out in the thesis, signal strength is taken as a major parameter, thereby ensuring that the variations in traffic do not hamper the quality of observations.

Method	Routing Strategy	Salient Features/ Outcome
Route establishment predicting the link availability through belief propagation-LPR	Predict the link life time with respect to the signal strength. Predicted value propagated using belief propagation. The path with the highest accumulated belief is selected as the route.	~10% improvements in PDR and ~40% in control overhead than AODV and DSR. Belief propagation supports the re - establishment of route from the failure point.
Route establishment predicting the link and node availability through belief propagation – RLPR	Predicting the link and node life time based on a fuzzy function computed on signal strength and node energy. The path with the highest accumulated belief is selected as the route.	15% more PDR in RLPR and 50% reduction in control overhead. The delay in RLPR is slightly more than LPR.

Table 7.3: Assessment of LPR and RLPR Algorithms.

The LPR and RLPR algorithms have resulted in very high values of PDR and low values of control overhead. The independent Monte Carlo runs confirms this fact from the low variances of the metrics.

A complete overview of the performance of the different techniques developed in the thesis is pictured in Fig. 7.1 and 7.2. It can be seen that the RLPR scores best among all in respect of PDR because of routing through reliable nodes. However, the relatively high routing delay in RLPR, possibly due to the conservative nature of the algorithm reveals the fact that the RLPR can be used in those cases where slight delay in packet delivery can be tolerated. The control overhead is minimum for RDBR due to the improvement in route re-establishment through dominating set. The extra effort required to compute the dominating set, though occasionally required, would necessitates the nodes to spend more energy.

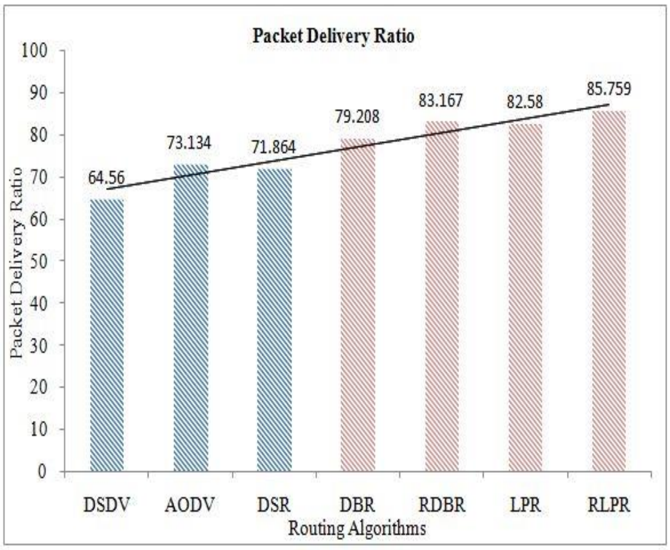


Fig. 7.1: Comparison of Different Algorithms Developed based on PDR.

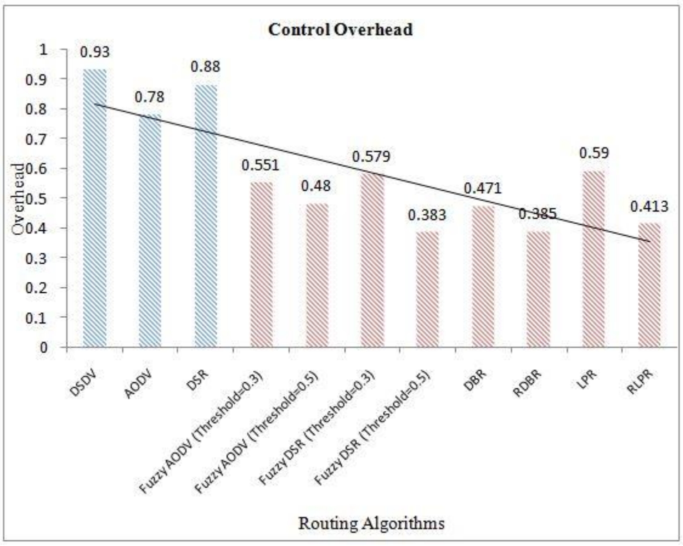


Fig. 7.2: Comparison of Different Algorithms Developed based on Control Overhead.

It is encouraging to note that the performance of the algorithms are mostly linear with respect to the number of nodes, which favours the adaptation of the algorithm for larger networks as well.

7.3 Conclusion

A comprehensive study of existing routing algorithms reveals that, further improvement is required in On-demand routing algorithms for MANET. Route request flooding is a major concern in route request phase in all on demand algorithms. A modification in the flooding procedure is applied to the AODV and DSR algorithms for reducing the RREQ and control overhead. The property of dominating sets are extensively used for further improvement in the routing algorithms. In DBR and RDBR, proposed in the thesis, the destination is reached through the dominating sets and the best dominating set from among the available set was selected based on the connectivity and remaining energy of the node. Routing strategies incorporating residual energy could make the algorithm robust. The sustainability of the route is improved in LPR and RLPR by using belief propagation. LPR used the signal strength as the measure to compute the belief and RLPR incorporated the residual energy of the node also. It was observed that the route chosen in LPR and RLPR may not always lead to the shortest path, though at the same time the route selected is robust.

The incorporation of soft computing techniques in decision making process of the algorithms proposed in the thesis has shown commendable promise in the improvement of attractive traits like packet delivery ratio and control overhead. The consolidation of the work has brought out the relative performance of all the techniques proposed. The simulation results reported in the thesis also hold out the scalability of the proposed algorithms for networks of larger sizes, running for longer duration.

Chapter 8

CONCLUSION AND FUTURE DIRECTIONS

The thesis, spanning over seven chapters, has brought some organised attempts towards the development of improved on demand routing algorithms in MANET. The new approaches proposed are demonstrated to be performing better than the existing routing algorithms. Setting out with an extensive study on the existing on demand routing algorithms for MANET, to bring out the issues relating to performance against standard metrics, the thesis has concentrated on improvements in the routing strategy to alleviate the issues that have precipitated during the extensive review.

It is well known that packet flooding through transmission of RREQ is a well-accepted technique in on demand algorithms, whenever there is a requirement to establish a route. One of the obvious draw back of the packet flooding is the excessive amount of control packets, leading to increase in control overhead required to establish the routes. The thesis has proposed and demonstrated new algorithms to bring down the overhead due to packet flooding. The algorithms effectively makes use of the expected value of the packets transmitted in selecting the node to be included in the routes. The resulting choice obtained after comparing the expected value with a threshold, in effect reduced the nodes selected to be included in the RREQ flooding. The simulation of the algorithm on networks of size for different durations of time spanning over 100 to 400 s demonstrated nearly 10 % improvement in the control over head over AODV and nearly 20% over DSR. Extending the choice also to include the residual energy of the node, a modification based on fuzzy set theory in the above algorithm has shown impressive reduction in control overhead, in comparison with the AODV and DSR algorithms. Improvement of the tune of 40 to 45 % in control over head was noted in comparison with AODV and DSR, in the simulations studies carried out on networks of similar complexity. The selection of threshold value indicated above is significant in the control overhead reduction, to the extent that relatively larger value of threshold limits the choice of nodes to be included in RREQ flooding. Independent Monte Carlo runs with varying threshold have highlighted the improvement in control overhead, underscored by low variance.

On account of the frequent movement of the nodes the topology is unpredictable, thereby disturbing the stable routing in

MANET. One of the preferred approaches would be to route the data through nodes which have maximum connection. Utilizing this principle, the thesis proposed and demonstrated an algorithm DBR, which discovers the domination nodes from the connectivity matrix and establishes the routes through one of the dominating sets. Testing the algorithms on network with number of nodes varying from 10 to 100, brought out that the performance metrics like PDR and control overhead improved to 10% and 20% respectively. The improvement can be attributed to the reduction in the re-route establishment process. The method was further augmented (RDBR) to include the selection of the most acceptable dominating set based on the residual energy of the node and the accumulated PDR of each node in given dominating set. The simulation on networks of varying size as above revealed further improvements to 30% in PDR and 40% in control overhead. Here again the improvement in the performance has been confirmed through independent Monte Carlo runs.

Continuing further on the efforts to increase the stability of the routes established, the thesis has proposed and validated the route formation through belief propagation. Incorporating the influence of link availability, the LPR algorithm proposed in the thesis compute the belief on each node based on signal strength and propagates the belief on all possible routes. Destination node decides the route depending up on the accumulated belief. The resulting route establishment holds potential in reliable operation of the network, with reduced efforts in route re-establishment also. The LPR has performed to achieve 10% improvements in PDR and 40% in control overhead than AODV and DSR, verified through simulations on network of size varying from 10 to 100 nodes. Extending the concept further, the RLPR algorithm reported in the thesis utilizes the residual energy in addition to link availability to compute the belief through a fuzzy function. Simulations on network of complexity similar to what was used for testing LPR, the RLPR showed an improvement of 15% in PDR and 50% reduction in control overhead. It is interesting to observe that, the routing strategies incorporating residual energy could make the algorithm robust, at the same time making it more conservative also, since the route chosen may not always lead to the shortest path. The choice between LPR and RLPR is decided by the application which weighs fast delivery against robustness. In this case also the Monte Carlo runs have emphasised credibility of the performance metrics demonstrated.

On the whole, the thesis has made a systematic effort in using soft computing techniques in evaluating the decision functions required for reducing the packet flooding and selecting the dependable routes. All the proposed techniques have demonstrated commendable performance, through elaborate simulation in NS2 running on High Performance facility with 6.1

TFLOPS computing speed enabled with sNow software suite. The simulation results of the new algorithms show promise in the enhancement of the improvement of packet delivery ratio and control overhead. The consistent performance of algorithms for networks of varying sizes, operating for longer duration, confirms the scalability of the routing algorithms for networks of larger sizes. The verification of the relative performance of the algorithms through independent Monte Carlo runs has helped in adding credence to the proposed algorithms.

As one tries to derive the further directions of future research form the results summarised in the present thesis, it turns out that the routing in Ad hoc networks is a live problem on account of the diverse requirements of deploying such networks. In situation where the infrastructure is not available, not trusted and does not offer enough time and resources for setting up the network (due to emergency or high expenditure), the Ad hoc networks are the only solution. It is an accepted fact that the present day technology facilitates the ready and tremendous availability of IOT devices [114], which solves most of the problems of connectivity, to aid data streaming. Still some situations like the forestry, rare animal tracking, space exploration, undersea operations, and setting up temporary offices such as campaign headquarters as part of disaster management, may not come under the reach of the ready connectivity through internet. The algorithms developed in thesis thus become handy in the above situations for disseminating data through the reliable and shortest path wherever possible.

The thesis has addressed the problem of link prediction using belief propagation. Looking from a different stand point, the work could be extended to utilize techniques like classical optimisation or evolutionary approaches like genetic algorithms, and particle swam optimisation, in order to incorporate optimal strategies in evolving the dependable routes. Dynamic models can be built based on a set of measurable parameters like connectivity and utilising the possible facility to monitor such parameters, the parameters can be estimated online to make the prediction better. In the recent years there has been lot of interest in the energy conservation in MANET. One of the proposed approaches to handle the situation recommend sensors for monitoring power levels within a restricted group of nodes in MANET. These monitoring nodes then operate as a localized sensor network, augmenting the instantaneous monitoring of the power level. The routing algorithms proposed in the thesis can be extended to perform better with the online assessment of the power position in the network.

Over the recent years there has been an increased interest in undersea exploration for a variety of purposes like mining and establishment of habitats, all requiring robust undersea communication among static and moving entities. The underwater sensor networks (UWSN) [115,116] are being laid out for harvesting the undersea resources. The absence of an establish facility like under the sea suggests itself the deployment of MANET with dependable route establishment. Signal monitoring techniques to assess the range based on robust undersea propagation models can go a long way in strengthening routing algorithms proposed in the thesis. The fact that the power is a premium for undersea operation adds credence to the algorithms developed in the thesis, which incorporates node power as a major factor in route establishment. The same framework can be effectively extended to underground network (UGSN) [117,118], which have tremendous applications in mining, disaster management and laying of underground pipelines.

As the world moves forward to reach out to the “unfathomed caves of ocean” and grace the flower “born to blush unseen”, the MANET will be a technology to reckon, to lay and operate a robust communication network for assured performance.

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1) Preetha K G, A Unnikrishnan, K Paulose Jacob, “Probabilistic Approach to Reduce the Route Establishment Overhead in AODV Algorithm for MANET”, International Journal of **Distributed and Parallel Systems (IJDPS)** Volume 3, Number 2, March 2012.

2) Preetha K G, A Unnikrishnan, “Enhanced Domination Set Based Routing in Mobile Ad hoc Networks with Reliable Nodes”, Journal of Computers and Electrical Engineering, **Elsevier**, **SCIE**.

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4) Preetha K G, A Unnikrishnan, “Improving the Routing Performance of Mobile Ad hoc Networks Using Domination Set”, International Conference on Information and Communication Technologies, **Elsevier**, *Procedia Computer Science 46 (2015) 1209 – 1215,* **Scopus.**
5) Preetha K G, A Unnikrishnan, “Enhancing the Performance of Routing Protocol in MANET by Predicting the Link Availability Through Belief Propagation”, Accepted in **IEEE TENSYMP 2017.**

6) Preetha K G, A Unnikrishnan, “Fuzzy Decision Based Reliable Link Prediction Routing in MANET Using Belief Propagation”, Accepted in ICCII 2017, **Springer, Scopus**.

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