A
Ph.D Thesis

on

QoS–aware Multicast Routing Protocols in MANETs

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Declaration

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Abstract

Multicast routing protocol in MANETs is an emerging area that effectively improves the performance while lowering the energy consumption and bandwidth usage. The existing routing protocols focus on hop-count metrics and are not adaptable to densely distributed and highly mobile networks. Therefore, multicast communications with Quality of Service (QoS) metrics in highly dynamic networks poses interesting research challenges.

Multimedia applications such as the onboard data received by UAVs and transmitted to ground station need to support multiple QoS metrics such as throughput, energy, and jitter with limited bandwidth, energy constraints, dynamic topology, transmission errors and fluctuating link stability. The links between adjacent nodes are often not reliable and may break due to node mobility. Link breakage initiates the process of re-routing at the sender node (source node) i.e., the node at which the link breaks, leading to packet loss, delivery delays and control overheads. Hence to overcome link breakage, stability in the links is required for the duration of route refresh interval. Link stability metrics are used to improve network performance in terms of end-to-end delay, packet delivery ratio and available route time-span.

In this thesis, a novel approach for node mobility prediction is proposed. A node mobility model that considers stable link for route construction is used as the basis to predict the future positions of the nodes in the network. Hence, the links with long active duration time are identified, and the variation in signal strength parameter is used to identify whether the direction of the node is towards or away from the estimating node. Signal strength is considered as a QoS metric to calculate link stability for route construction. We also predict the movement time of nodes that define the route to the destinations.

Link and route stability are considered as the basis for reliable network communication, one protocol for link stability and one for route stability has been proposed in this work. These protocols identify and remove the weakest link in a stable route that causes during our previous work. The probability of successful transmission of periodic packets is used as a link stability metric which helps in the estimation of a stable path. Increased probability of successful transmission implies that the selected link will sustain for the longer duration (stable link) and it can deliver packets with improving reliability.

A multi-constrained QoS aware routing metric that determines a reliable forwarding node based on Link Stability cost Function (LSF) is proposed. The primary theme of underlying protocol is to find average contention count link, that is estimated with the help of received signal strength. LSF is based on contention count, hop count and the received signal strength at a node. A mobile network is created in which no node remains isolated, as well as nodes face lesser contention. Extensive simulations are carried out using Exata/Cyber simulator, and obtained results are compared with existing multicast routing protocols. A comparative analysis of the proposed protocols that consider multiple QoS metrics was also made with the existing Hop count based protocols. The results reveal that considering multiple metrics to represent the QoS reflects real world networks scenario such as the transmission of multimedia data across UAV networks realistically. Performance parameters considered for the study are Packet Delivery Ratio (PDR), Average End-to-End Latency, Average Route Lifetime, control & memory overhead.

The thesis concludes with the application of all the proposed protocols to the UAV communication scenario with multimedia data being captured in real time by onboard sensors in UAVs and transmitted over an adhoc UAV networks to the ground stations to form a common operational picture. The results were validated using simulations techniques and form an important study and software testbed for the unmanned aerial communication systems analysis.

Dedications

This thesis is dedicated to my parents

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This doctoral thesis would have been impossible without the support, reviews and constructive criticisms of many persons. It is a pleasure to thank all of them here.

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I feel delighted to thank my parents Mr. Shyam Sundar Singal and Mrs. Anita Singal. I feel helpless in defining your support in words. Appreciation, compassion, warmth, communication and financial support are just few of them which you provide me.

During the course of my Ph.D work I have been blessed with a jovial group of fellow scholars and some long lasting friendships. Dr. P Vinod, Dr. Chhagan lal, Dr. Rimpy Bishnoi, Dr. Anil Saini, Manoj Bohra, Dr. Smita Naval, Lokesh Sharma, Ashish Sharma, Sonal Yadav, Namit Bhati and Dr. Gaurav Mangal are few of them. They provided a ray of sunlight during days when end of the tunnel was nowhere in sight.

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Signed: ______________________________

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Chapter 1

Introduction

Mobile ad hoc networks (MANETs) are infrastructure-less wireless networks that consist of a set of mobile nodes communicating with each other directly or indirectly. In MANETs, a node can act as a host as well as a router. When a node is a source or destination of a data session, it acts as a host and it acts as a router when it is an intermediate node of an active route. Due to lack of centralized administrator (system), a node in a MANET can join or leave the network at any time during the communication process. MANET is an easily deployable, self-configurable, fault resilient, mobile and flexible network that finds applications in infrastructure-less environments such as the military battlefield, emergency services like road/rail accidents, search and rescue operations, disaster recovery operations, location aware systems, vehicular networks, multi-player games and teleconferencing (audio/video), etc [1].

Routing in MANETs requires intermediate nodes if the sender and the receiver are not in each others' communication range. The multi-hop relaying method is a key concept for MANETs [1]. Multi-hop relay techniques are used to relay the data packets between any pair of source and destination nodes through intermediate nodes. Selection of intermediate nodes determines the route from sender to receiver node(s). So, there should be an effective routing protocol that can discover, sustain and reconfigure route(s) in a network whose topology changes dynamically due to the mobility of nodes [2].

Once a route is defined, it may not be expected that this connection is sustained for longer durations as nodes are moving. As a result, MANET routing protocols refresh the routes periodically at intervals called 'route refresh time'. Even then, routes may break as any link may fail because of moving nodes. This may result in loss of data and increase delay because of retransmission time. Each route disconnection before refresh time adversely affects the performance of MANET. Selection of intermediate nodes in a routing protocol assumes significance especially for services that require a minimum QoS.

Quality of Service or QoS in a network depends on the data loss, delay and jitter. For high QoS, it is imperative that there should be only negligible data loss (such as multimedia data, videos). Delay is defined as the time interval between transmission of a packet and its reception at the destination. A higher delay cannot be indicative of good QoS. Another important metric is jitter. If all packets of a message suffer equal delay then at receiver inter-packet delay is not observable. However, if packets suffer non-uniform delay because of MANET routes being changed over time, there is inter-packet delay which is termed as jitter. In QoS, jitter is considered more significant measure than delay because it tells about the variations in the delays for video streaming. Any QoS-aware routing algorithm should not incur end-to-end delay as well as jitter more than predefined respective thresholds.

For a broadcast or multicast communication from single source to many receivers, unicast routing shall incur more cost in terms of power, delay and bandwidth requirement because of multiple uses of common links. Multicast routing can overcome these limitations as instead of establishing one-to-one route from source to destination, one destination at a time, multicast routing shall discover links that can connect all destinations to source. This reduces number of links involved in communication, number of data transmissions at intermediate node and route discovery and establishment overheadMANET performance can be improved by adopting multicast routing.

Research efforts in MANETs are broadly divided into (1) general purpose or application-specific routing methods, (2) applicability of such networks to different

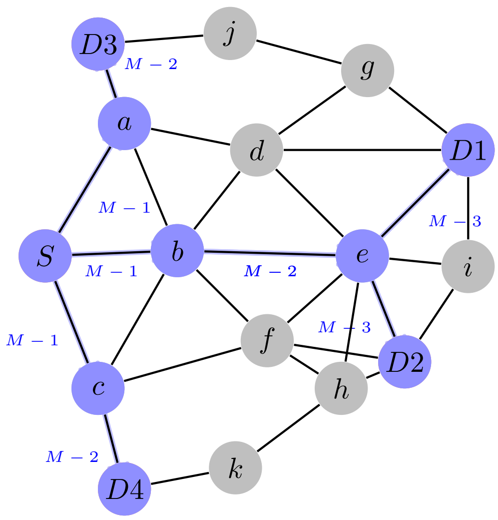

FIGURE 1.1: Multicast Communication

domains, (3) incorporating QoS into MANETs and (4) lightweight/cryptographic solutions for security in MANETs.

1.1 Research Challenges in MANETs

The use of MANETs in various real world applications is still limited. Major challenges to MANETs are embedding QoS (Quality of Services), detection and prevention of attacks, reduction in energy consumption [3, 4], incorporating fault-tolerance and reducing delay of nodes [5]. This is due to following characteristics of MANETs:

- Bandwidth Utilization: The scarcity of bandwidth in wireless channel causes packet drop. Improve the bandwidth utilization at each node.
- Connectivity Maintenance: Dynamic and unpredictable topology due to node mobility are the reasons for route failures. Existing routing protocols deal with the situation by periodic refresh or refresh on demand.
- Energy Efficient: The short lifetime of MANET devices.
- Link characteristics: Node mobility and high bit error rate of radio links leads to fluctuating link quality which includes metrics such as bandwidth and delay.

1.2 Quality of Service in MANETs

An adequate quality of the connection is desirable in all MANET applications i.e. connection should not have low bit-error rate and should not fail while transmission is ongoing. In addition, data should not suffer inordinately high delays during transmission. Research community has invested efforts in improving QoS in data transmission through MANET [6–8]. Majors to QoS provisioning in MANETs are highly dynamic network topology requiring periodic route refreshing, multi-hop routing wherein a route may fail if any link gets disconnected, energy and bandwidth constraints that may affect the number of hops and data transfer rate, transmission errors, latency, security, etc. To achieve QoS in bandwidth constrained medium, it is imperative that routing solution should reduce the overhead of route establishment, select a route that can be sustained for longer durations and minimize exchange of control messages.

QoS is a measurement of guarantees for uninterrupted transmission of multimedia data while maintaining certain quality parameters such as Packet Delivery Ratio, End-to-End delay, Average Route Lifetime, etc. required by applications. The idea of providing QoS in MANETs is not to void overhead but to keep it as low as possible. In MANETs, maintaining QoS (without resource reservations) for data communication requires:

- Route should remain available till the desirable duration.
- Control and memory overhead should be lower.
- Higher bandwidth and lower error rate.

A use-case scenario of an ad-hoc network with flying nodes is described such as UAVs (Unmanned Aerial Vehicles), UAS and drones [9] as shown in Figure 1.2. UAVs are capable of creating an ad-hoc network for communication with considerable altitudes and thus, provides advantages over ground-based ad-hoc networks [10]. A network at an altitude level is usually complex compared to other ground-based wireless networks because flying nodes have different configuration parameters in terms of higher node mobility and higher transmission ranges [11], but to extend the coverage of communication networks that can perform with multi-role capabilities UAVs, can employed [12]. This scenario develops a network that assists in border surveillance and monitoring. Approach assumes three headquarters A, B and C that are supposed to monitor the border and coastal areas for detection of any abnormal intrusion of the air space. They deploy some highly movable devices on ground to construct an ad hoc network and communicate data from flying node to end server nodes. In some areas, where they cannot execute MANET or grounded-based devices, they have to use some flying devices to monitor the coastal regions. Therefore, an adhoc network between UAS (Unmanned Aerial Systems, i.e., a network of two or more UAVs) and MANET devices has been established for reliable communication.

FIGURE 1.2: Use Case Scenario (Case Study)

1.3 Motivation

Most of the proposed routing protocols [13–15] for route selection are dependent on minimum hop-count and optimize the path length but ignore the issues related to stability or persistence of the link. Consequently, the selected path may not necessarily be the desirable one. Link stability is the ability of link between adjacent nodes to remain established for a definite duration. It fluctuates due to the mobility of nodes, congestion in the network, exhaustion of resources like bandwidth in the network, energy of nodes, etc. These factors may lead to link disconnects and route reconfiguration. The reconfiguration overhead increase latency and adversary affects QoS Therefore, a more stable path should be preferred to the shortest path. The path selected using traditional routing protocols is mostly the shortest path [16, 17]. To minimize hop-count, longer hops are usually selected without considering the quality of link in terms of data transmission errors. Following are the motivations for the work on QoS-aware routing solutions presented in the thesis:

- Growing popularity of multimedia services a need to support the Quality of Service (QoS) metrics.
- Available QoS–aware multicast routing protocols are partially equipped to solve the problems that are provoke by link and route failures.
- The existing literature, which targets the QoS provisioning for multicast routing protocols in MANETs, partially considers the other challenges such as node mobility and radio link characteristics that leads to the selection of low lifetime routes.

To overcome the above challenges, there is a need of devising a reliable QoS–aware MRP (Multicast routing protocol) that is simple, scalable, robust and energy efficient. Nowadays, Unmanned Aerial Vehicles (UAV) are using adhoc network routing protocol for communicating streaming data called Flying adhoc networks (FANETs) i.e. also a part of the motivation for the work.

1.4 Objectives

Our objective in this thesis is to introduce a set of QoS-aware metrics that would be useful in selecting a stable link and route among all available options. The use of these QoS-aware metrics during the route discovery process will lead towards the discovery of routes exhibiting longer stability and consequently longer persistence. The proposed routing techniques should adapt to densely as well as sparsely distributed networks and assure an economic use of bandwidth.

To address the limitations of existing multicast routing protocols, our objective is to devise QoS–aware Multicast Routing Protocols for various MANET applications. Proposed MRPs should exhibits the following properties in order to ensure the adequate level of QoS to the applications during their data communication process.

- Stabilize (longer time) route by maximizing the multicast active route time (i.e. route remains connected). So as to reduce the number of costly reconfigurations due to link failures.
- To incorporate QoS constraints in ODMRP (On-Demand Multicast Routing Protocol) to escalate their performance in terms of throughput, Delay and overhead.
- To improve performance metric (Available Route Lifetime) in MRP by resolving the issues of node mobility and link failure.

1.5 Contributions

Multimedia streaming services need to support certain QoS parameters. QoS is difficult to ascertain because of continuously varying links availability due to dynamic topology, limited availability of resources like energy and bandwidth. In this thesis, the multicast routing protocols have been proposed that identify a reliable route by including QoS metrics such as link quality, nodes mobility prediction, and congestion at the node. Major contributions of this thesis are as follows:

1. **Mobility Prediction and Link stability in Multicast Routing**[J-1] A MRP has been proposed by applying SINR as a QoS-metric for identifying a reliable route in multimedia communication in MANETs. A mathematical model has been created for estimation of temporal stability of a link in node's communication range. Node mobility prediction helps to identify a node which can sustain communication link till 'Route Refresh Interval' [17]. Detail approach is presented in Chapter 3.

2. **Multicast Routing: Link and Route Stability**[J-2] Two techniques have been proposed for establishing a reliable route on the basis of performance of a node in respect of packet delivery. The stable link is found on the basis of the probability of successful transmissions of periodic packets. A link with higher probability is selected as a stable link. The stability of a route is determined by minimum of stability of constituent links. Presence of stable links may not ensure end-to-end stability. In the second method, the main objective was route establishment with better end-to-end route stability. The detail approach is presented in Chapter 4.

3. **Multicast Routing: Multi-objective base Function**[J-3] A link stability factor (LSF) is proposed and consisting multiple QoS metrics to estimate the stability of a link. LSF is calculated based on contention count, hop count and received signal strength. Formation of a mobile network in which no node remains isolated, as well as nodes face lesser contention. Chapter 5 presents the detail approach.

4. The application scenarios of UAV networks has been considered to evaluate the performance of our proposed work in Chapter 6. The results are discussed with multiple inputs and multiple outputs system. In the case study UAV, Unmanned ground vehicles (UGV) and Unmanned surface vehicles (USV) are used to transmit the captured data from one end to another end.

To prove the novelty of proposed work, each contributions have been evaluated with the help of performance metrics such as packet delivery ration, average end-to-end delay and average route lifetime, etc.

1.6 Thesis Structure

This thesis is organized as follows. In Chapter 2, we have provided a small overview of MANETs and routing techniques, have been discussed. A complete literature survey of MANETs multicast routing protocols is also included. Chapter 3 we discuss our first multicast routing protocol for applying link stability and mobility prediction in adhoc networks. By applying probability estimation approach, Chapter 4 we present how to incorporate link and route stability in a multicast routing protocol. Multicast routing protocol on the basis of multi-objective base function has been discussed in Chapter 5. A UAV network based test case is presented in Chapter 6. Conclusions of the thesis are discussed in Chapter 7 that also provides the directions for future work.

Chapter 2

Background & Overview

Multicast communication plays a crucial role in Mobile Adhoc Networks (MANETs). MANETs provide low cost, self configuring devices for multimedia data communication in military battlefield scenarios, disaster and public safety networks (PSN). Multicast communication improves the network performance in terms of bandwidth consumption, battery power and routing overhead as compared to unicast for same volume of data communication. In recent past, a number of multicast routing protocols (MRPs) have been proposed [5, 18, 19]. Multicast based group communication demands dynamic construction of efficient and reliable route for multimedia data communication during high node mobility, contention, routing and channel overhead.

This chapter gives an insight into the merits and demerits of the currently known research techniques and provides a better environment to make reliable MRP. It presents a ample study of various Quality of Service (QoS) techniques and existing enhancement in mesh based MRPs. Mesh topology based MRPs are classified according to their enhancement in routing mechanism and QoS modification on On-Demand Multicast Routing Protocol (ODMRP) protocol to improve performance metrics. This chapter covers the most recent, robust and reliable QoS and Mesh based MRPs, classified based on their operational features, with their advantages and limitations, and provides comparison of their performance parameters.

2.1 Introduction to MANETs

Mobile Ad hoc Networks (MANETs) came into existence with an aim to handle the undesirable disruptions in communications that may occur due to disasters such as earthquakes, floods and fires or due to human activities like terrorist attacks, military operations and so on. MANET is a type of wireless communication network which does not have any infrastructure and central administrative control. In past few years, MANETs have been deployed for diverse application such as audio/video conferencing, emergency rescue operations, traffic control and online lectures, etc.

These networks possess some excellent features such as fast deployment, flexibility, robustness, mobility support and highly dynamic network topology (fading, shadowing, network partition) [20]. In MANET, node can communicate with relay (intermediate) nodes if communicating host nodes are not in its range (multi-hop routing).

MANET is a group of wireless mobile nodes that may act as host as well as router. MANET is a self-organized network that can be deployed anywhere, at any time to support particular conditions. In contrast to MANETs, infrastructure-dependent wireless networks are more reliable and provide Quality of Services (QoS) assurance. The unreliability in MANETs occur due to limited battery power, limited bandwidth (channel capacity), heterogeneity, high routing overhead and unpredictable node mobility. Bandwidth, delay, signal strength and other metrics are used for QoS assurance in multicast group communication for both data and real-time traffic.

In recent years, multicasting has been greatly appreciated in any type of group communication like audio/video conferencing, video lectures. Multicast Routing Protocol (MRP) communicates datagram to a group of destinations recognized by single multicast address at single transmission time [18, 21]. Multicast transmission helps to improve node energy, congestion on channel capacity, time and resource utilization as compared to Unicast Routing Protocol (URP), in case of transmission of datagram to a group of destinations. Multicasting in MANETs is more complex than wired networks, in terms of node energy and bandwidth. High mobility, low channel capacity and battery issues attracted attention of many researchers towards multicast routing protocols to build robust, reliable and scalable networks.

Multicast routing protocols have been improved by the researchers consistently on the basis of various evaluation metrics like quick route recovery, reliability, improved QoS (less energy consumption, reduce channel capacity utilization), less congestion(interference), improved Packet Delivery Ratio (PDR) and end-to-end delay, network life time and last but not the least, security. Group communication faces many challenges and issues such as resource management, synchronization, power management and routing management [18]. Real time applications require reliable and stable communication among multicast group members.

In this chapter, mesh based MRPs have been explored and classified on the basis of modifications in routing mechanism and QoS metrics adaptation. In this chapter, we shall discuss issues and challenges such as energy efficiency, reliability, security and QoS aware multicasting. At last, a taxonomy of proposed mesh based MRPs is presented on the basis of their techniques, features, modification components and improvement parameters.

Rest of the chapter is organized as follows: Current state of multicast routing protocols has been described in Section 2.4. The proposed modifications in mesh based protocol are further discussed in Section 2.5. Section 2.6 elaborates the multiple mechanisms and requirement of estimating link stability. Section 2.7 discusses the design issues and challenges in multicast routing protocol. Finally, the summary is given in the Section 2.8.

2.2 Routing in MANETs

Routing protocols are formulated with an ultimate goal of discovering a reliable path to transmit the data packet successfully to its final destination. However, methods of route discovery and techniques to cope with route failure are different. Routing protocols are categorized as unicast and multicast. These protocols can be sub-divided further as Proactive, Reactive, and Hybrid [22] shown in Figure 2.3. Proactive routing is a table-driven approach in which each node maintains a routing table that contains routing information, at all times, to reach another node in the network. Whereas reactive routing is an on-demand protocol, in which route discovery process occurs only when a node intends to send packets [23]. The hybrid method combines the features of both proactive and reactive routing approaches. This protocol reduces control overhead caused by proactive technique and reduces the latency caused by reactive technique. Topology-based multicast routing protocols (MRP) [24] are Tree-based, Mesh-based, and Hybrid. In Mesh-based MRP, packets are broadcast along the mesh network. Mesh-based MRP are more robust than Tree-based MRP as they provide redundant paths between a source-destination pair, and exhibit better performance in the event of link failures.

Many reactive Mesh-based MRP such as On-Demand Multicast Routing protocol (ODMRP) [16], [13], [25], E-ODMRP [17], BODS [26], CQMP [27] have been proposed for MANETs. Each categories of routing protocol has its advantages and disadvantages. In the proposed approaches, mesh-based reactive routing protocols (such as ODMRP) are used in place of tree topology protocols (such as MAODV [28]). This choice of using mesh topology is made because it provides reliable data communication which happens by path redundancy and leads to a reduction in route reconfiguration.

2.3 Unicast v/s Multicast

Unicast and multicast are two types of communication mechanisms supported by MANETs. Multicast communications offers several benefits such as reduced transmission time, economic bandwidth consumption and proper utilization of power resources over multiple receivers by n (receivers) times as compared to unicast communications. Multicast routing is used for transmitting video data in group-oriented video streaming data transmission [29]. There should be an effective routing protocol that can discover, sustain and reconfigure links in a network whose topology changes dynamically due to the mobility of nodes [2].

In Unicast, one source and one destination and Multi-casting is the transmission of packets to a group of hosts. Advantages of multicast over multiple unicast transmission:

- Reduced Bandwidth consumption.
- Improved transmission efficiency.
- Reduced Energy consumption.
- Decreases the cost such as delay and control overhead.

For common links in data communication between source to destinations, the network resources such as bandwidth, energy, delay and control overhead will used single time. It leads to the given advantages and also can be understood with the help of the example given below:

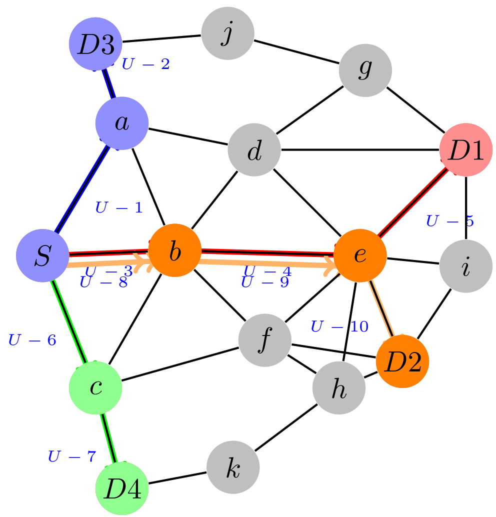

Figure 2.1: Unicast Process

In Figure 2.1, a network scenario is shown of one source and four destinations. In unicast process, packets have to be sent separately to a each destination one-by-one sequentially. In reference to Figure 2.1, source S transmits to D_1. Once this transmission is completed, then only packets destined for D_2 are sent after establishing a suitable route (red in this case). Then, orange path is established for communication to D_3. Finally, source communicates with D_4. This requires setting up of four paths and using these for packet transmission. Whereas in multicast, paths to all destinations are discovered in only one route set-up phase, also shared links ($S \rightarrow b \rightarrow e$) are used once and not multiple times as was the case with unicast. For four destinations their is individual path, and common paths are using the resources twice. In Figure 2.2, the multicast process is shown for the same scenario. Here, a single broadcast packet has to be sent for all the destinations. So it helps improving latency and reducing the energy consumption and network resources.

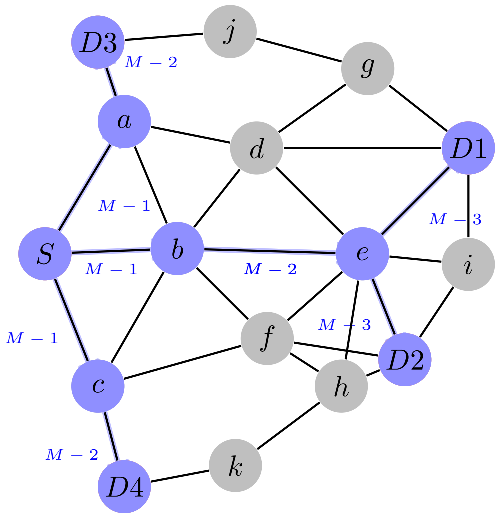

FIGURE 2.2: Multicast Process

Unicast network, total number of links (L_U) are:

$$L_U = \sum_{i=1}^{k} (K_i)$$

Multicast network, total number of links (L_M) are:

$$L_M = \bigcup_{i=1}^{k} (K_i)$$

If each link requires same energy E_ℓ per bit of transmission, energy saving shall be $L_F \times E_\ell$ where $L_F = L_U - L_M$

Over past few years, many unicast and multicast routing protocols have been proposed for MANETs with an aim to reduce transmission overhead and optimize resources consumption. In the field of networking, multicast communication has become the most researched area because of the rising popularity of group communication applications such as teleconferencing, multi-player games, etc. Multicast routing protocols have been designed specifically for group-oriented communication, i.e., the multicast source sends copies of a message to multicast receivers through broadcasting. Multicasting can improve the efficiency of wireless communications as it reduces energy and bandwidth consumption, latency, transmission overhead, etc. Hence, to support group communication with better QoS, multicast routing is preferred. Among multicast routing protocols, reactive protocols are more appropriate as they create a route on demand and require less power consumption and control overhead in the network. Therefore, there is a need to formulate a reliable multicast routing protocol for MANET that ensures better performance regarding higher throughput, minor latency, and reduced transmission overhead.

2.4 Taxonomy of Multicast Routing Protocol

Wireless networks are categorized as infrastructure and infrastructure less networks. Cellular network is an example of infrastructure network, with high set-up cost and time. Adhoc network is an example of infrastructure less network with cost-effectiveness and less set-up time.

Adhoc means "for the purpose", self-organizing network architecture. There is no requirement of base station. Adhoc networks are further classified as Mobile Adhoc Networks (MANETs), Vehicular Adhoc Networks (VANETs), Wireless Sensor Network (WSN), Wireless Mesh Network (WMN).

Routing protocols for MANETs can be categorized on the basis of mechanism as reactive (routes are created on demand), proactive (pre-determined routes are stored in routing tables and are periodically updated) and hybrid (some nodes have predefined and some have on-demand). Alternately, in terms of number of destinations, that a protocol can transmit data in parallel to a given source, routing can be Unicast (only one destination supported) or Multicast (for group

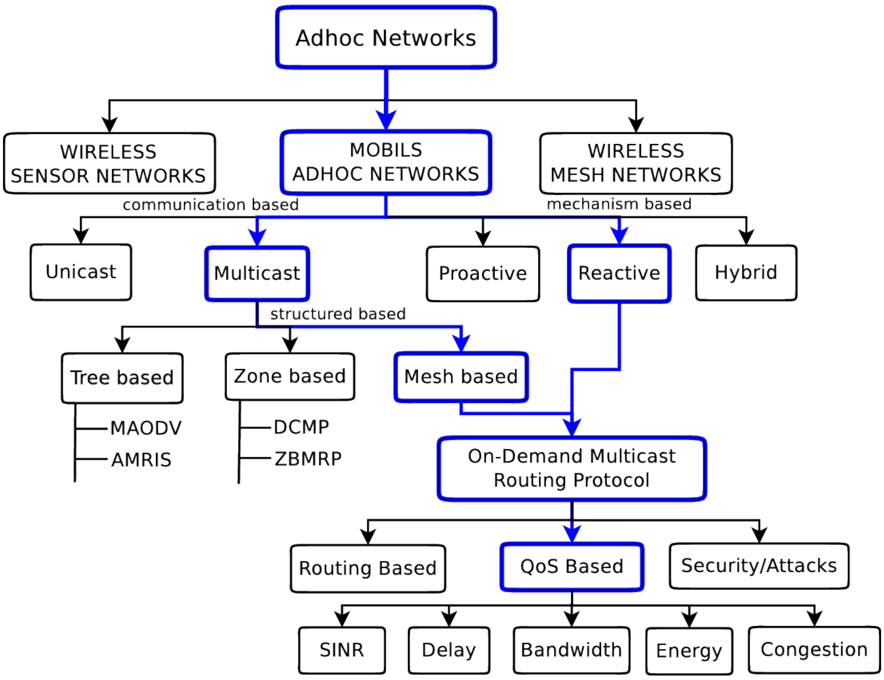

FIGURE 2.3: Taxonomy of Routing Mechanism in MANETs

of destinations). Figure 2.3 presents an overall picture of routing mechanisms in MANETs.

Numerous unicast routing protocols [30] supporting Quality of Service (QoS) have been explored. These protocols provide a stable path from a source to single destination. Multicast Routing Protocols (MRP) [18, 24] is needed to be explored to address the limitations of unicast routing protocols. MRPs can be classified on the basis of their routing structure as (1) tree-based, (2) zone-based, (3) mesh-based, (4) hybrid. Tree based MRP is very efficient in routing in network and provides better packet delivery ratio as compared to other protocols, but there is excessive reconfiguration overhead in case of re-routing. In tree based MRP, there are many protocols such as Multicast Ad-hoc On demand Distance Vector routing (MAODV) [31], Ad-hoc Multicast Routing protocol utilizing increasing Id numberS (AMRIS) [32], Ad-hoc Multicast Routing protocol (AMRoute) [33], etc.

For limited reconfiguration and rebuilding caused by redundancy of packets, mesh based MRP is better than others [18]. In mesh based MRP, more than one path exists between pair of source and destinations. There are many protocols such as On-Demand Multicast Routing Protocol (ODMRP) [34], Enhanced On-Demand

Multicast Routing Protocol (EODMRP) [14], Forwarding Group Multicast Protocol (FGMP) [35] and Team Oriented Multicast (TOM) Protocol [36] that create mesh structure after route construction.

Zone based MRP forms a cluster of source, receiver and intermediate nodes in routes. Selection of zone leaders on the basis of first announcement for better and robust decisions. There are many protocols that provide zone based structure for transmission such as Dynamic Core based Multicast routing Protocol (DCMP) [37], Cluster Based Stable multicast Routing Protocol (CBSRP) [38].

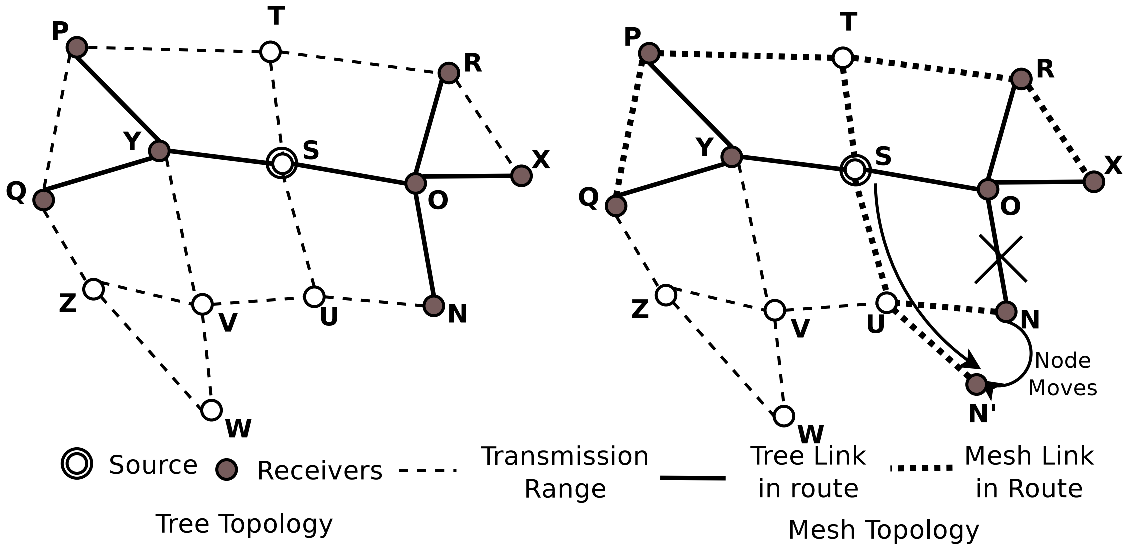

Figure 2.4: Difference between Tree and Mesh Topology

To better understand the topological difference between tree and mesh topologies, a scenario has been considered in which one sender and five receivers are present as shown in Figure 2.4. The major difference in between tree and mesh topologies is the number of alternative paths provided between two nodes. The former provides only one path while the latter provides multiple paths for single destination. Due to single path option, tree topologies are not suitable for applications in which link failures may occur due to node movement.

For example, source S is transmitting data to multiple receivers. If link between O and N fails or node N moves to N', then tree topology cannot continue transmission. The mesh topology provides another route to transmit the data due to multiple or alternate paths available between source and destinations.

In this chapter, the focus is on mesh based multicast routing protocols and explaining multiple enhancements in ODMRP protocol on the basis of QoS and Routing Modification.

2.5 Mesh based Multicast Routing Protocol

Mesh topology is robust and reliable for communicating data to the destination in case of node mobility or link failure. It doesn't require reconfiguration of network because there already exist redundant (multiple) paths for every destination.
All forwarding group members, multicast group members and links between them form a mesh. The characteristic feature of mesh is that the node doesn't care about upstream node, from which the packet has arrived, and it rebroadcasts non-duplicate packet. If one node lies in the transmission range of other node, then both nodes share a mesh link. So, the mesh structure has more connected links than tree and increases the robustness of multicast group, which is convenient in generous and frequent link breaks for ad-hoc networks [39].
Robustness of ODMRP protocol depends upon number of senders and mobility speed. At low mobility and large number of senders, ODMRP creates redundant routes, some of which may be useless while at high mobility and less number of senders, it offers less redundant routes [40].

1. Forwarding Group Multicast Protocol(FGMP) for multi-hop, Mobile Wireless Networks FGMP [35] provides reliability by transmitting data via Forwarding Group and maintains a multicast mesh. In this protocol, both the source and receivers advertise their existence through respective broadcasting packets known as Source Join broadcast (FGMP-SA) Approach and Receiver Join broadcast (FGMP-RA) Approach. When a destination node receives a join request from other node, it updates its own Join table and broadcasts it to other members of group to update their respective table. FGMP reduces overall overhead by limiting flooding within Forwarding Group. FGMP-SA

provides better throughput as compared to FGMP-RA in case of less number of senders than receivers in a network. FGMP protocol is not scalable and it does not support high mobility because it gives better results in small network.

2. Core-Assisted Mesh Protocol(CAMP): CAMP [41] has been designed to support multicast routing protocol in mobile adhoc network using a shared mesh structure. In order to limit the control traffic, CAMP uses core node for creating a mesh. To prevent packet replication or looping in the mesh, each node maintains a cache to keep track of recently forwarded packets. The algorithm ensures that all the nodes from reverse shortest path are included in the mesh. Like other core based protocols, it doesn't require whole traffic flow from core nodes. CAMP is based on salient assumption about route information available (proactive) and existence of beacon protocol. So it has got high routing overhead because of proactive protocol [27].

2.5.1 On Demand Multicast Routing Protocol

Sung *et al* [34] have proposed ODMRP (On-Demand Multicast Routing Protocol), a reactive mesh based adhoc multicast routing protocol that gives reliable routes. This protocol consists of following steps:

1. Source sends request of 'Join Query' and waits for 'Join Reply' from receiver(s). These query packets are sent periodically to whole network.
2. On receiving 'Join Query' packet, intermediate node rebroadcasts it and sets previous hop address only if received packet has not been seen earlier and discards duplicate packets.
3. Multicast receiver receives 'Join Query' packet from intermediate node(s) and sends 'Join Reply' to respective previous hop address.
4. On inspecting 'Join Reply' packet, an intermediate node checks if the address field matches with its own address. If yes, it creates join table, labels itself as member of forwarding group and forwards the packet to previous hop address.

5. At last, source receives the join table from intermediate node and selects minimum hop route to forward the data packet. Source also sends acknowledgement to multicast receiver and builds a mesh structure for available route to different destinations.

6. The periodic transmission is used to refresh the routes and all member tables.

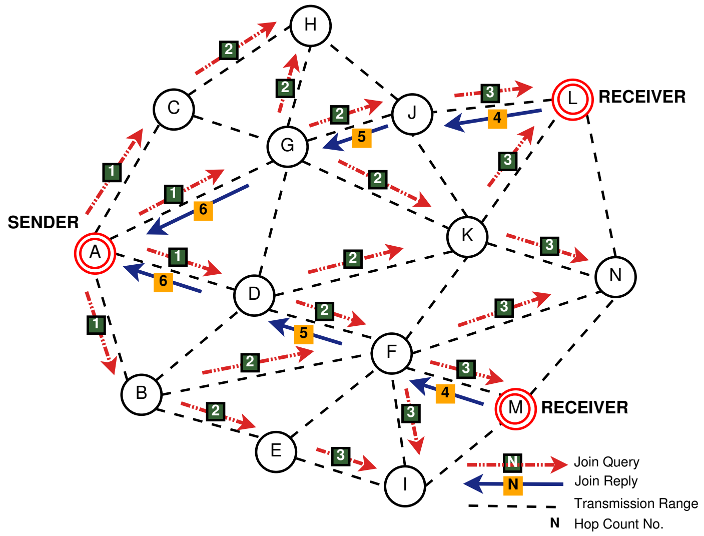

FIGURE 2.5: ODMRP Work Flow

Work flow of ODMRP protocol is illustrated in Figure 3.1. In topology presented here, there is one sender, two receivers (shown inside double ring). In ODMRP, forwarding nodes use the shortest path between multicast group members. Red arrow indicates 'JOIN Query' and blue arrow indicates 'JOIN Reply'. Weight on an arrow indicates hop count value for respective link. A link marked with both red and blue arrow is part of the path which extends back to source. Information about other possible paths is not discarded and would be used to establish links in case of disconnections induced by mobility. For example, in Figure 3.1, route $A \rightarrow G \rightarrow K \rightarrow L$ is established as soon as $A \rightarrow G \rightarrow J \rightarrow L$ is disrupted because of movement of J. As a result, this mesh structure is more resilient over tree-like topology as there is no requirement to reconfigure the entire route, if node's position changes.

ODMRP is widely used protocol for group communication in multicast routing protocol due to major advantages of high packet delivery ratio with some limitations like higher control overhead and redundancy of packet. So, scalability issues occur in ODMRP. Many modification techniques have been applied on ODMRP [34] to improve the routing overhead. Mesh based multicast routing protocol can classify based on (1) modified routing mechanism and (2) on adding QoS parameter, for improvement in ODMRP protocol.

2.5.1.1 Routing Based Protocols

Routing mechanism in MRP is modified to make it more reliable and robust in terms of packet delivery ratio, end-to-end delay, control overhead and traffic load. Enhancements in the base ODMRP protocol are based on following routing modification approach:

1. Local Route Repair: This mechanism is used in order to avoid global broadcast of messages in case of route or link failure. Only broken link can demand for route and repair it by local recovery mechanism.

2. Receiver Joining: In this mechanism, if any new incoming destination wants to join current route, it can request for a route from nearby forwarding node, multicast group or source by broadcasting request packet.

3. Dynamic Timer Adaption: Motion adaptive refresh interval is utilizing link breakage report to source by receiver. Receiver can make adaptive interval according to their average link lifetime in route to make reliability.

4. Periodic Hello: Periodic Hello packet is broadcast between nodes to extract neighbors' information or link quality.

5. Route Discovery Suppression: It is used for limiting the number of simultaneous route discoveries as another discovery in process. Route Discovery Suppression (RDS) helps us to reduce load on network.

6. Conserving FG joining: In this mechanism, omit the joining of excessive number of Forwarding Group nodes in route to reduce overhead.

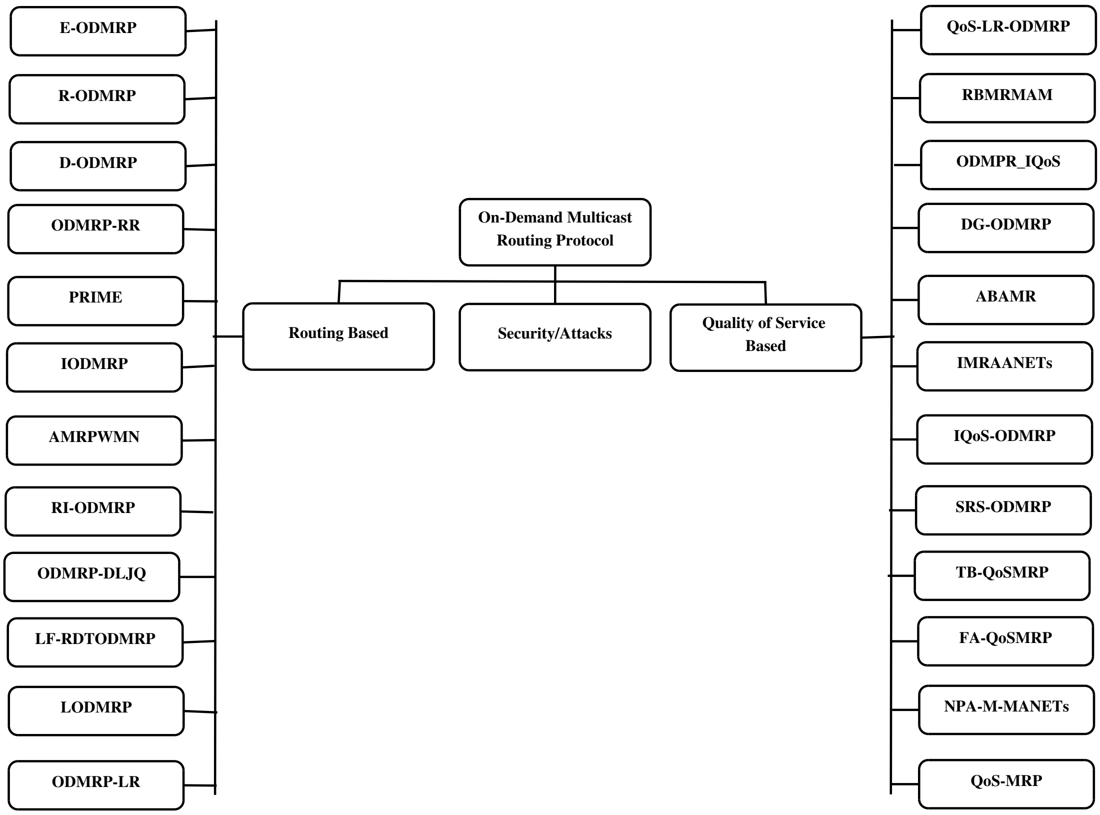

Figure 2.6: Enhancement in ODMRP on Routing and QoS

These multiple mechanisms have been used to improve mesh based ODMRP protocol. In Figure 2.6, routing modification protocols over ODMRP protocol have listed.

1. ODMRP-MPR: On-Demand Multicast Routing Protocol with MultiPoint Relay in MANETs ODMRP-MPR [39] inducts multipoint relay techniques to reduce the control overhead, obtain high stability and effectively solve the unidirectional link problem of wireless communication. In network, each node N selects some neighbors on the basis of their distance from N and decides 2 hops as its multipoint relay (MPR), only those neighbors will retransmit the flooding packet broadcast by N.
   ODMRP-MPR reduces flooding overhead generated by Join Query, retransmission of Join Reply, and avoids uni-directional link in forwarding path. It increases additional overhead by sending periodic Hello messages. NS2 simulator [42] has been used for simulation and comparing the control

overhead and PDR with varying number of senders and multicast group size with ODMRP protocol.

2. RODMRP (Resilient On Demand Multicast Routing Protocol): The authors have offered more reliable forwarding path in case of node or route failure in mobility [43]. The redundant packet forwarding improves PDR, while eliminating the possibility of flooding in networks. They create Non-Forwarding node (NFG), that is not a member of Forwarding Group. It is further characterized into active non-forwarding node and passive non-forwarding node. Active non-forwarding nodes forward the data packet in network to improve the degradation in performance caused by node failure. It finds improvement in packet delivery ratio as compared with ODMRP on NS2 simulator.

3. EODMRP (Enhanced ODMRP with Motion Adaptive refresh): Enhancement in ODMRP with refresh rate dynamically adapt to the environment and receiver joining. Receiver initiates join query (Receiver Join Query) in network to join a multicast group [14]. If there exist a route to Multicast Receiver or Forwarding Group member, they should reply with Receiver Join Reply. Receiver increases TTL value and repeats process until the upper limit of TTL reaches. In worst case scenario, if no route is found, the receiver floods a refresh request packet.
   Compares the variation in PDR and control overhead with increment in number of receivers with Qualnet simulator. Simulations show that E-ODMRP achieves higher PDR. Protocol has some limitations because it uses dummy packets and transmits to a sub-tree to prevent recovery explosion, which may result in extra overhead. It increases routing overhead by sending Receiver Join Query (RJQ) packet by receiver node to join current route and needed additional processing power. Attacker can also waste their resources by sending numerous RJQ request.

4. AMRPWMN (Adaptive Multicast Routing Protocol for Wireless Mobile Adhoc Networks): Improves control packet overhead by broadcasting Join-Query packets according to the current Packet Delivery Ratio. Due to excessive network overhead and collision, the protocol uses PDR to evaluate Join Query transmission [44]. Sender in the network broadcasts join query packet

according to probability variable, which is calculated by PDR. If PDR is high, AMRPWMN can transmit more Join Query, else there would be much collision in network. Simulation has been carried out on Glomosim 2.03 simulator [45] and effect of variation of number of senders on different packet delivery ratio has been analysed.

5. LF-RDTODMRP (A Robust and Efficient On-demand Multicast Routing Protocol for Adhoc Network): This protocol cuts down the unnecessary redundant routes and their data transmission. They limit some nodes to flood Join-Request packets and forbid it to be a forwarding node [40]. It adds a data structure (RDT table) for each forwarding node to make entry of multicast group, source address and time of entry. RDT table is used for reducing data transmission by using older route. This protocol limits the flood requests of JQ packet. It adds a Load_Table for storing number of times FG_Flag has been set by multicast group. The protocol sets a threshold value for FG_Flag. If the sum is greater than threshold, it drops the JQ packets. It sets the threshold value adaptive to the network for better output. This protocol has limitation of Hard to Selection of threshold for number of times FG_Flag has been set. Simulations has been carried out on Glomosim Simulator and obtained results of RDTODMRP, LF-RDTODMRP and ODMRP are compared based on PDR, Delay and Overhead with varying traffic load and number of senders.

6. ODMRP-LR (ODMRP with Link Failure Detection and Local Recovery mechanism): Addresses the problem of detecting link breakages and local recovery procedure in ODMRP. Tries to improve the disadvantage of E-ODMRP by reducing routing overhead [46]. Two methods have been used for detecting link failure: first, by utilizing the knowledge of time intervals between data packets that are to be received. Second, by using hello packets or data packets in predefined interval. In Glomosim simulator, results have been analysed for PDR and control overhead on varying TTL value with mobility or non-mobility.

7. RBMRMAM (Relay-Based Multicast Routing in Multirate-aware MANETs): Minimizes the total transmission time by extracting higher transmission rate

of relay node. Proposes Heuristic Relay Node Selection Algorithm (HRNSA) for choosing neighbor node that can use higher rate to cover more number of downstream node [47]. It includes three modules: Information collection algorithm, Relay node selection algorithm and Relay notice algorithm. Throughput and delay are estimated with increasing number of nodes and speed of nodes and compared with that of ODMRP protocol on NS2 Simulator.

8. ODMRP-RR (Multicast Routing Protocol for Reduction of Relay node in MANET): Reduces network overload by reducing number of relay nodes to enhance the performance of ODMRP. It tries to reduce the number of relay nodes that are used for constructing the route. It uses Round Robin scheduling for route construction for many sources [48]. All the sources do not send join query packets simultaneously. It uses round robin mechanism to differentiate between different sources and allots them distinct time slots. Computes average number of FG nodes for different number of source nodes on NS2 Simulator and Physical testbed.

9. ODMRP-DLJQ (Improving Performance of On-Demand Multicast Routing by Deleting Lost Join Query Packet): Improves the performance by restricting the domain of Join Query packet, which has been lost. It is achieved by augmenting (increasing) the join query packet with minimum extra information which denotes the number of visited nodes from previous forwarding group nodes [49]. If the current JQ visited many nodes and doesn't get any previous FG node, then discard it. It reduces overall overhead with increasing number of forwarding group and hop count over Glomosim Simulator.

10. PRIME (Interest-Driven Approach to integrated Uni-Multicast Routing): PRIME [50] establishes meshes that are activated and deactivated by the presence or absence of interest in destinations and groups. PRIME establishes enclaves for flows of interest on-demand, and send proactively signals to update routing information within enclaves. Region of network with interest in the destination of flows receives timely updates as compared to other networks.

Meshes are activated using Mesh-activation Request (MR), which make receiver change their state from inactive to active state. The destination must start advertising its presence periodically using Mesh Announcements (MA). An enclave of multicast flow is a connected components that contains those node dissemination of information for flow. Analyzes group delivery ratio and delay with increasing number of group in Multicast and Unicast traffic for AODV, ODMRP and PUMA on Qualnet 3.9 Simulator.

11. RI-ODMRP (Receiver Initiated Mesh Based Multicasting for MANET using ACO): RI-ODMRP [51] approach has been designed to find optimum paths between two communicating nodes. It initializes request by the node that wants to join the multicast group. An Ant Colony based mechanism is used for multicast routing protocol. Initialize/requesting node is named as core. It defines role of the node by binary number 11, 01, 10, 00, where first byte is for forwarding group node and second one is for multicast group node. The process of route set up is performed in three steps: (1) Multicast Group Announcement, (2) Multicast Group Joining and (3) Join Reply. It evaluates average robustness and packet delivery ratio with mobility speed and compared with ODMRP on NS2 Simulator.

12. D-ODMRP (A Destination-driven ODMRP for MANETs): To improve the multicast forwarding efficiency in MANETs, D-ODMRP [52] uses existing multicast destination node as forwarding node. In this protocol, the path from multicast source to multicast destination tends to use those paths passing through another multicast destination. In Figure 2.7, an example has represented for one source and two receivers. In ODMRP protocol, paths P1 and P2 are selected, by default, for receivers R1 and R2 respectively. In D-ODMRP, R2 is nearer to R1 as compared to other receiver, so R2 can pick a route P2' via R1 as intermediate node and doesn't require any separate route.

    If such multiple paths are available, the one leading to the least extra cost is preferred. It also takes deferring time to calculate delay for reaching packet to the destination. Simulated D-ODMRP for packet delivery ratio and control

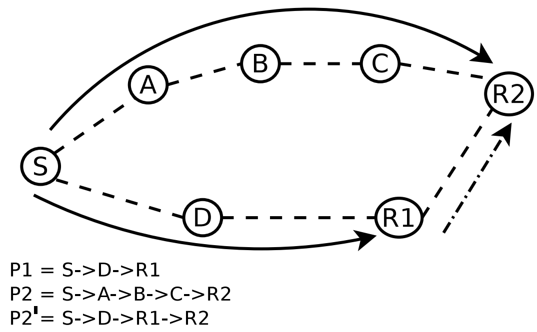

FIGURE 2.7: D-ODMRP Protocol

overhead and compared the results with that of ODMRP protocol over NS2 Simulator.

13. LODMRP (Level Based On-Demand Multicasting Routing Protocol for MANETs): Protocol tries to confine flooding of control packets within network by broadcasting only a part of these packet based on level-based approach [53]. Each node decides to broadcast a Join Query packet based on its distance from the sender. The threshold for discarding join query is number of hops. Level represents the number of hops from sender to the node. Neighbor nodes transmit more packets as compared to far away nodes. Control overhead, efficiency and delay are analyzed with increasing number of sender and traffic load and compared results with ODMRP protocol over Glomosim Simulator.

2.5.1.2 QoS Based Protocol

Quality of Service parameters are not used to discover path from source to destination, but to gratify the QoS requirements often given in terms of delay, congestion, bandwidth and power. In this section, the improvements have discussed briefly that have been made in ODMRP protocol proposed by different authors to ensure QoS support and reliable in case of route or link breakage. In Figure 2.6, QoS based modification protocols on ODMRP have listed.

Figure 2.8 represents QoS metrics that have been used by researchers for enhancement in ODMRP protocol, to make it more robust, reliable and reduce control overhead. These metrics have been used to render a route efficient and less prone to link failure due to high stability links. Researchers always try to refine QoS metrics to improve delivery ratio without degrading network throughput.

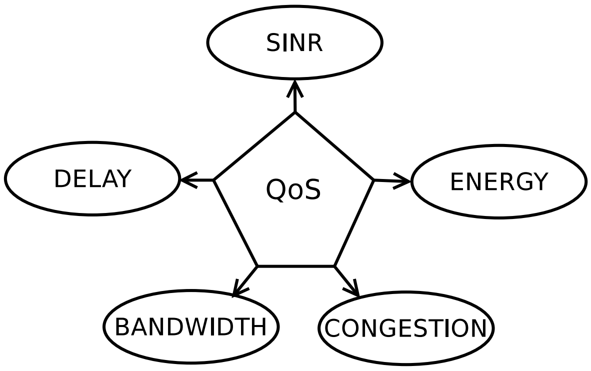

FIGURE 2.8: QoS Metrics

1. QoS-LR-ODMRP (Quality of Service and Local Recovery for ODMRP Multicast routing in Adhoc Networks): It proposes a new technique for supporting QoS routing in ODMRP by making acceptable estimation of available and required bandwidth with local route discovery [54]. Protocol ensures that every node in the route set up phase based on bandwidth calculations for available bandwidth. Consumed bandwidth of node channel is given by reserved bandwidth for flow on upstream and downstream neighbor of node. The protocol sets up route on the basis of available bandwidth of forwarding node. Protocol also proposes local route discovery on link breakage due to node mobility. It evaluates PDR and traffic admission ratio with increasing speed of node over Glomosim Simulator.

2. A cooperative framework for reliable multicast forwarding in MANETs [55]: It offers higher reliability and connectivity among multicast members in comparison to other existing reactive protocols. Innovative framework is based on the cooperation between MAC and routing protocol. It also adds some new features to ODMRP and IEEE 802.11 MAC layer for reliable forwarding. Added ODMRP with D3MP (Dynamic Mesh Based Multicast MAC Protocol) and RRAR (Round Robin Acknowledge and Re-transmit). Evaluates Signaling Overhead, PDR and Delay with variation in Multicast Group size on NS2 Simulator.

3. AAM-QoS (Agent Based Adaptive Multicast Routing with QoS guarantee in MANETs [56]): This protocol guarantees QoS in terms of bandwidth, delay, jitter and packet loss with agent based adaptive algorithm. Set of static and mobile agent moves around the network and collects the routing information. It is clustering of nodes and then selection of QoS aware cluster head. The algorithm identifies intermediate node and discovers multiple paths to satisfy multiple constraints and sets up a QoS aware path for the required multicast route. It evaluates packet delivery ratio and latency with mobility and group size on NS2 simulator.

4. IMRAANETs (An Improved Multicast Routing Algorithm in Adhoc Network [57]): Analyzes the power variation of nodes to predict the topology change and link state. Calculates transmission power and rate of change of received power for any two intermediate nodes. Calculates the response time to inform source about unreliable link/node to prevent route failure. It reduces the route failure numbers and delivery delay without increasing extra overhead. It compares response time with failure time to trigger the routing warning function. Simulations have been carried out for both ODMRP and Extended protocol to evaluate PDR with varying mobility speed.

5. TB-QoSODMRP (A Tree based QoS Multicast Routing Protocol for MANETs [58]): It proposes a model that searches for QoS guaranteed path for a single source to set of destinations. Physical area is partitioned into equal sized hexagonal cells as shown in Figure 2.9 and a leader and backup leader are elected to maintain updated information about the topology. Position based QoS Multicast Routing Protocol was proposed with GPS enabled on each node (device). The leaders are in the range of each node in the hexagonal cell. They find route on the basis of available bandwidth and delay to reach other intermediate nodes or destination. It is a type of group or cluster of nodes to transmit data effectively to each node by leader. Evaluates TBQMRP for CTRL packets transferred and packet loss ratio with mobility speed on Glomosim Simulator. There is a drawback because of leader and backup leader. As all communications, go through the leader node, it has higher bandwidth and energy.

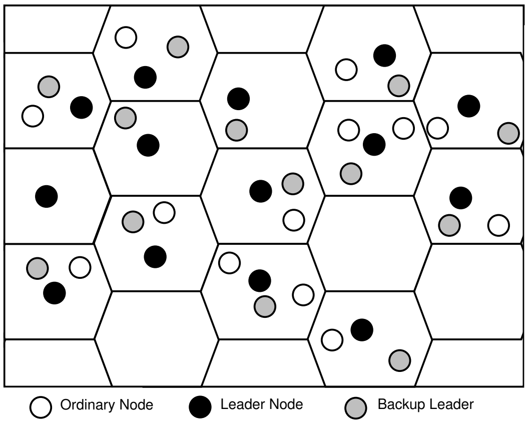

FIGURE 2.9: Hexagonal cells in a Scenario

6. ODMRP-IQoS (Providing Interference-aware Quality of Service Support for ODMRP [59]): Interference-aware QoS-ODMRP investigates bandwidth consumption under 2-hop interference model. Evaluates available bandwidth by employing a bit vector, named as Time Tag, to trace the transmission status within 2-hop neighbors. Finds clique [1] in network to avoid transmission interference. TTag is used for recording transmission status in most recent time from one hop neighbors. Nodes exchange TTAG with neighbors periodically for estimating bandwidth requirement. It analyzes delivery ratio and delay with increasing payload and shows improvement mainly with payload increment over Glomosim Simulator. Periodic transmission of TTag among neighbors is major con for the protocol performance. Clique identification can consume time and resources.

7. IODMRP (Improvement of wireless multicast routing with Energy-efficiency based on ODMRP [60]): It takes partial nodes in forwarding group that relay packets and its choice is based on forwarder density and power state. Lesser the number of neighbor forwarding nodes, higher is the PDR. A subset of forwarding group forwards the packet and this subset is determined on the basis of probability, p($0 \leq p \leq 1$). Calculates power state (PS) of node by dividing current received power by initial power. Analyzes end-to-end delay and PDR of IODMRP over different number of receivers and maximum mobility speed over NS2 simulator.

[1] two or more nodes are in same transmission range

8. DG-ODMRP (Delay-Guaranteed Multicast Routing in Multi-rate MANETs): It estimates one hop delay and end-to-end delay based on varied transmission rates by monitoring the sensed busy to idle ratio of shared channel [61]. Calculating both delays using IEEE 802.11 MAC is still challenging, because the radio channel is shared among neighbors. One hop delay is sum of deferring and transmission time. Protocol senses busy to idle ratio of shared channel for one hop delay. The end-to-end delay can be determined by summing up all one hop delays in route. This approach also considers link with maximum signal rate. Compares one hop and end-to-end delay with DGMR and AQOR in single and multi-rate environment on NS2 simulator.

9. LSMRM (Link stability multicast routing protocol in MANETs): Authors select stable forwarding node that is based on link connectivity with high stability in mesh based multicast routing protocol [5]. Stable route is selected by determining stable nodes which have high link quality in terms of estimated received power, bit error rate per packet and distance between communicating nodes. They have maintained link stability database at every node. The drawback is that they have not given any mathematical and analytical model to prove or validate their implementations and results. They have improved PDR, delay and routing overhead over changing multicast group size and transmission range and compared the obtained experimental results with ODMRP and EODMRP.

10. SRS-ODMRP (Stable Route Selection in ODMRP with Energy Based Strategy): Stable Route Selection forwards data on the basis of node energy. To select stable route, route expiration time and residual energy have been considered [62]. Stable Weight Based method is used for ODMRP protocol to improve reliability. Calculates Residue Energy (RES) and Route Expiration Time (RET), combines them to calculate shortest route. It appends position, direction, speed and mobility. It analyzes end-to-end delay and control overhead with variation in mobility speed and multicast group size on OPNET simulator.

11. IQoS-ODMRP (A novel routing protocol considering QoS Parameter in MANETs): Extends the ODMRP protocol to make it more suitable in disaster area network with group communication [63]. Adds QoS parameters like bandwidth and delay in ODMRP. Takes consideration of mobility and analyses the effect of time interval of sending packet with change in mobility. Improves PDR and delay and compares the result with QoS-ODMRP on GlomoSim Simulator.

12. LLMR (A link stability-based multicast routing protocol for Wireless mobile adhoc network): This protocol finds the longer route (stable multicast route) in high mobility scenario [64]. Authors have used weighted multicast routing algorithm to generate stochastic Steiner tree within expected duration time EDT. Then they applied learning automata-based approach to solve the problem. They have done extensive simulation on NS2 and compared the result with LSMRM and EODMRP protocol to validate the results. They have calculated route life time and PDR with changing host speed and multicast group size. Improves PDR and delay. Compares the result with QoS-ODMRP over Glomosim Simulator.

13. FA-QoSMRP (Fuzzy Agent Based QoS Multicast Routing in MANETs): It provides the desired Quality of Service for user in group communication [65]. A set of agents are used to operate in the following sequence. Creation of QoS Multicast mesh networks by using fuzzy inference system. A path to transmit the packet to receiver is selected from QoS Mesh. Mobile agents are employed to maintain QoS path. Analyzes PDR and control overhead and results reveal that FA-QoSMRP operates better than ODMRP on NS2 simulator.

14. MMRNS (Neighbor Support reliable multipath multicast routing in MANETs): Authors have proposed a scheme for multipath multicast routing in MANETs using reliable neighbor selection [19]. In this, a mesh is created from source to multicast destinations using maximum reliable pair factor of neighbors. In this algorithm, the reliable pair factor depends upon energy and signal strength of node. Neighbor nodes are pruned by minimum threshold value and maintain route against node/link failure. Authors

have analyzed their results with ODMRP and EODMRP protocol in terms of PDR and control/computation overhead in respect of number of nodes and groups with mobility considerations. Figure 2.10 shows random network

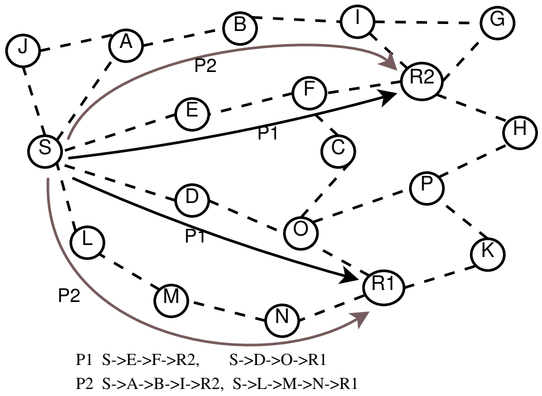

Figure 2.10: Multiple Multicast using Reliable Network Selection

topology consisting of one source(S) and two destinations(R1 and R2). In this Figure, MMRNS picks up two reliable paths for each destination at any time t. Firstly, the source transmits data through higher priority level path P1 to destinations R1 and R2. In multicasting, load of the transmission has been increased on single node/link due to multiple transmissions. So, using different priority paths, load can be reduced by transmitting data through multiple paths like P2.

15. On-Demand multicast routing protocol with efficient route discovery: Limited flooding in ODMRP reduces the packet overhead drastically, by sending JQ messages from only delay satisfaction nodes [66]. Calculates one-hop delay for every node by summing up transmission delay, contention delay and queuing delay. Node selects minimum hop delay node to transmit the data and only floods Join Query messages. Analyzes delay, overhead and PDR with increasing number of multicast receivers over NS2 simulator and compares results with ODMRP and EODMRP protocol.

16. QoS-MRPM (QoS Based Multicast Routing Protocol in MANETs): QoS based MRP provides stable multicast paths with enough bandwidth [67]. Entropy is treated as an important parameter to find stable path. Protocol uses bandwidth reservation mechanism to achieve QoS. It can be used to

select stable path with longer lifetime. Compares the results of Average Delay and PDR with varying Velocity of Sending Packet for ODMRP over NS2 simulator.

17. Extending ODMRP for On-Site Deployments in Disaster Area Scenarios: It extended the ODMRP protocol for making it more suitable in disaster area network with group communication [68]. It is link quality based routing protocol that requires Hello packet transmissions. Firstly, they prioritize control messages and used Overhead Reduction Mechanism to provide better throughput in disaster areas. Evaluates packet loss ratio for GPS packet per node over NS2 simulator and tested it on Physical testbed.

18. NPA-MAM (New Power-aware multicast algorithm for mobile adhoc networks): Power aware multicast routing algorithm uses the residual battery life for multicasting from source to a group of destinations [69]. Proposed protocol considers residual energy as a QoS metric while forwarding the data packets. The proposed model chooses a node with maximum remaining power among all the nodes. It extends the network lifetimes of the node and the network without degrading the network throughput. Compares the results with network life time, control bytes per data and PDR with varying group size on NS2 simulator.

19. NPA-MAM (New Power-aware multicast algorithm for mobile adhoc networks): Power aware multicast routing algorithm uses the residual battery life for multicasting from source to a group of destinations [69]. Proposed protocol considers residual energy as a QoS metric while forwarding the data packets. The proposed model chooses a node with maximum remaining power among all the nodes. It extends the network lifetimes of the node and the network without degrading the network throughput. Compares the results with network life time, control bytes per data and PDR with varying group size on NS2 simulator.

Protocol Name	ODMRPMPR	R-ODMRP	EODMRP	AMRPWMN	LF-RDTODMRP	ODMRP-LR	RB-MRMAM	ODMRP-RR	ODMRP-DLJQ	PRIME	RI-ODMRP	DODMRP	LODMRP	QoS-LR-ODMRP	ODMRP-IQoS	DG-ODMRP	AAM-QoS	IMRAANETs	IQoS-ODMRP	SRS-ODMRP	TB-QoSMRP	MMRNS	FA-QoSMRP	NPA-MAM	QoS-MRPM
Year of Publication	2003	07	08	09	09	09	09	10	10	12	11	12	13	08	09	09	10	10	10	10	11	12	12	13	s12
Modification Components:																									
Forwarding Group	✓	✓	✓	–	–	–	✓	✓	✓	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	✓
Routing Selection	✓			✓	–	–	–	–	✓		✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Features:																									
Local Route Repair	–	–	✓	–	–	✓	–	–	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–
Receiver Joining	–	–	✓	–	–	✓	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dynamic Timer Adaption	–	–	✓	–	–	–	–	–	–	–	–	–	✓	–	–	–	–	–	✓	–	–	–	–	–	–
Mobility Handling	–	–	–	–	✓	–	–	–	–	✓	–	–	–	–	–	–	–	–	✓	✓	–	✓	–	–	–
Link Asymmetry	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Energy	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	✓		✓	✓	✓	✓	✓	–
Delay	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	✓		✓	✓	–	–	✓	–	–
Signal Strength	–	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	✓	–	–	–	–	–	✓	–	–	–
Bandwidth Reservation	–	–	–	–	–	–	✓	–	–	–	–	–	–	✓	✓	–	✓	–	✓	–	–	–	–	–	–
Congestion/Interference	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	✓	–	–	–	–	–	–	–	–	–	–
Application feedback	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–	–	–	–
Techniques:																									
Periodic Hello	✓	–	–	✓	–	✓	–	–	–	–	–	–	–	✓	✓	–	–	–	✓	–	–	–	–	–	–
Link Quality	–	–	✓	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–
Passive Ack	✓	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Join Query Delaying	–	–	–	✓	–	–	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	✓
Route Discovery Suppression	–	–	–	✓	✓	–	–	–	✓	–	–	–	✓	–	–	–	–		–	–	–	–	–	–	✓
Conserving FG Joining	–	–	–	–	✓	–	–	✓	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–
Improvement Parameter:																									
PDR	✓	✓	✓	✓	✓	–	✓	✓	–	✓	✓	–	✓	✓	✓	–	✓	✓	✓	–	–	✓	✓	–	✓
Delay	–	–	–	–	✓	–	✓	–	✓	✓	–	–	✓	–	✓	✓	✓	–	✓	✓	–	–	–	✓	✓
Overhead	–	–	–	–	✓	✓	–	–	✓	–	–	✓	✓	–	–	–	–	–	–	✓	✓	✓	–	–	–
Category	A	A	A/B	A/B	A/B	B	C	A	B	A	A	B	B	A/C	C	C	C	C	C	C	C	C	C	C	C
Simulator	1	1	3	2	2	2	1	1	2	3	1	1	2	2	2	1	1	1	2	4	2	1	1	1	1

TABLE 2.1: Summary of Mesh Based Multicast Routing Protocols ('✓' Supported and '–' Not_Supported)

The table 2.1 represents the summary of mesh based multicast routing protocols. In the table, protocols are classified in the given components such as modification components, features, techniques and improvement parameters.

2.6 Link Stability

Quality of Service is calculated on the basis of link stability. Fluctuating link stability in wireless networks has a fundamental impact on network performance. Researchers try to make efficient routing protocols that are able to deal with link unreliability. Route persists for longer duration because stable links are selected as the route constituents. As a result, reduced computations due to less re-routings lead to reduced overhead. Here, a brief overview has presented of link stability requirements and its metrics.

2.6.1 Requirements of Link Stability

In this section, the requirement and benefits of incorporating the concept of link stability have been discussed in the route discovery process. Few of them have listed below:

- Energy Efficient

  Energy can be conserved by reducing number of reformations, i.e. selecting a stable route. Node energy is wasted due to broadcast of request and reply packets for repeated demand of route, in case of multiple links failure.

- Accuracy

  It is essential to estimate a longer/stable path from single discovery in order to ensure that link would not break for any reason.

- Reactivity

  Due to high mobility in the network, our protocol should be well adaptive to every small change in the network.

- Stability

  Stable route in terms of prolonged persistence should be selected. Nodes at minimum distance and with maximum residual power are regarded as more stable than others.

There is a flaw between stability and reactivity that they can't be performed together because both are opposite to each other. So, need to make reactive protocols that satisfy both conditions; stabilization and reactivity.

2.6.2 Link Stability Metrics

Link stability metrics help us to find QoS aware links. Following metrics are listed that affect the link stability:

- Signal Strength or SINR or BER
- Transmission Delay or ETX
- Residual Energy or Power
- Bandwidth Reservation
- Congestion or Interference

1. **Signal Strength/SINR/BER:** SINR is the power of certain signal of interest divided by sum of interference power from other signal and background noise. SINR is estimated from signal strengths between nodes for transmitting data.

   $$\text{SINR} = \frac{Rec\_signal\_Power}{other\_Interference + background\_noise} \tag{2.1}$$

   Bit Error Rate (BER) can be decided from number of bits dropped out of total number of bits sent to the destination node. SINR is used to find stable link that has more lifetime than other nodes. Continuous SINR values could be taken to predict the direction or mobility of node.

2. **Delay/ETX:** Total Delay can be calculated by summing up the Transmission delay (packet transfer time between nodes), Queuing delay (packet has to wait in queue for getting sequenced) and Processing delay (after queuing time for transferring the packet or wait for channel).

$$Delay = TD + QD + CD \tag{2.2}$$

   where, TD is Transmission_Delay, QD is Queuing_Delay and CD is Contention_Delay. Transmission delay is the time taken to transmit a packet from one hop to next hop. In QoS metric, link with lower transmission delay will be included in the route for establishing the stable path. Queuing delay and processing delay are approximately equal to all node or otherwise it depends upon the type of application being executed.

3. **Residual Energy/Power:** Energy has always been a major concern in MANETs. Node residual energy and energy consumption are calculated for n transmissions. Most of the times, assumption is been made that all nodes have same transmission power. Node which has more residual energy and less power consumption in data transmission is selected as intermediate node for transmission on route.

$$\text{Power Ratio} = \frac{RemainingPower}{TotalCapacity} \tag{2.3}$$

   Power ratio tells us about node's remaining power. Power ratio can be calculated by dividing remaining power by total capacity and conclude that it lies between two ranges; Low range and High range. Values above threshold comes in High power range.

4. **Bandwidth reservation:** Network bandwidth reservation is used to identify the capacity of participating node and the corresponding link. A minimum bandwidth is required to communicate data for QoS aware routing protocols. Available bandwidth of a node can be estimated through the idle time of channel and transmission range. Idle time of channel can be calculated by monitoring the node, whether it is busy or not in receiving or sending any packet. Bandwidth reservation is compulsory in multimedia applications

for improving delay and jitter in data streaming. For better analysis, estimation of precise network bandwidth and total bandwidth consumption is required in transmission from requesting applications.

5. **Congestion:** Congestion can be estimated in terms of interference and load on a node. Path encounter could be calculated for every node to estimate congestion on a link or a node. Path encounter can be detected when a node comes in the transmission range of participating node. Path encounter value is the number of nodes in the transmission range [70] or number of nodes that are affecting (consuming) network bandwidth of participating node. A node with minimum path encounter value should be selected for route selection. Occurrence of congestion depends on various parameters. It can be related to bandwidth consumption and conflict due to simultaneous transmissions.

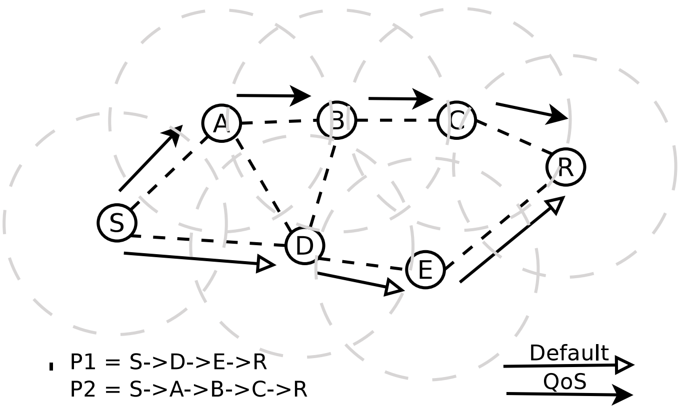

FIGURE 2.11: QoS_Route Construction

'

Figure 2.11 depicts a QoS aware route and a default route construction. Two routes $P1$ and $P2$ are shown. $P1$ is default route and $P2$ is QoS aware route. QoS metrics are used to calculate stable link for transmitting data. In basic ODMRP protocol, receiver R can be reached via nodes D and E as forwarding group member, due to smaller hop count and faster response from P1 route. It can not be ascertained if it is a stable route or not. QoS metric could be used to calculate link availability time for finding stable and robust link for route construction as shown in P2. Although, route P2 has increased number of hops, yet entire route would remain stable till route expiration time.

2.7 Multicast: Issues and Challenges

Although researchers have designed numerous multicast routing protocols and techniques, yet there remains a number of open issues and challenges. All available protocols provide mechanism to improve the performance of ODMRP protocol. However, each of these approaches suffer from certain issues [71] are listed as follows:

(i) ***Energy Efficiency:*** Mobile nodes typically run on limited energy resources, so it is required to design energy preserving protocols for group communication. Low throughput and high interferences over wireless channels is due to high energy consumption in MANETs.

Energy consumption can be reduced by decreasing number of nodes that are included in forwarding group and selecting the nodes that have highest energy to transmit the datagram, to make equal consumption by every node. Broadcast communication can also preserve energy.

Many protocols have been proposed for energy conservation [60]. If a high-energy link as compared to other nodes is selected in advance, then energy would not be consumed due to retransmission of packet at MAC layer. Energy issues increase with high mobility and high contention because of using shared channel based MAC protocol.

(ii) ***Robust and Reliable Multicasting:*** Due to arbitrary movement of mobile nodes, link failures are usual in MANETs. MRP should be resistive to mobility and exhibits high PDR. Reliable multicasting ensures that data from source node should reach every destination with ditto set of messages.

In MANETs, the reliability of multicast frames cannot be guaranteed because it depends upon mobility, multicast group size and traffic load. In multicast routing protocols, there are no RTS/CTS control frames to enquire about the availability of channel. Moreover, there is no provision of acknowledgement to achieve reliable communication. Unreliability in the network increases due to transmission of real time multimedia traffic. A node is unstable or unreliable due to its high and unpredictable mobility.

(iii) ***Efficiency and Control Overhead*** Efficiency can be defined as ratio of total number of packets received to total number of packets transmitted at receiver. Total number of control packets transmitted in the entire network to maintain routes to multicast group signify control overhead. Bandwidth consumption at a node is higher due to control packets like transmission of hello packets, route request packets etc.

(iv) ***QoS Aware Multicasting:*** QoS is achieved by set of service parameters during data streaming over multicast group from a source. QoS attributes like delay, bandwidth, probability of packet loss, signal strength, etc., are vital in order to get enhanced performance in terms of PDR and end-to-end delay. It facilitates reduced number of route reconfigurations in the network in case of link or route failure.

Large number of approaches with QoS support have been published for mesh-based protocol. Due to highly dynamic topology of network, providing QoS support is very difficult. A QoS modification can be executed at different layers according to the application requirements. At MAC layer, delay and packet loss ratio can be determined. Similarly, received signal strength, bit error rate and transmission quality can be obtained at physical layer.

Real-time video streaming requires a minimum bandwidth to communicate, so the QoS parameter can enhance transmission quality and bandwidth assurance.

(v) ***Secure Multicasting:*** In MANETs, secure networking has become a subject of great concern to researchers because wireless networks are more prone to passive and active attacks. In multicast scenario, security is more sophisticated due to number of receivers attached to the network. A single attacker node can degrade the performance of entire network.

The multicast routing protocol should be efficient to provide protection from denial of service attacks, misbehaving nodes, unauthorized access to data, etc. To make MANETs secure from unauthorized access of data, by applying encryption mechanisms with group key management. Although, there is a need to mitigate excessive overhead that would be generated due to cryptography techniques. In addition, mobile nodes run on limited energy resources and have low computing power thus, applying such complex techniques would drain off available resources.

In MANETs, security is receiving additional attention due to infrastructure less network, no central administration, dynamic topology, etc. Several solutions have been proposed for security in MANETs, but not much light-weighted mechanisms. Mainly, approaches are based on delay calculation, behavior analysis, trust and geo-casting. Geo-casting is used for calculating node position in battlefield to check authenticity of node because single node can be caught and made malicious. Thus, a flexible and high security mechanism is required that can adapt to all conditions discussed above. All these conditions are difficult to implement in order to secure multicast routing protocol for multicast communication.

2.8 Summary

This chapter discusses the state of the art research in mesh based multicast routing protocols in MANETs. From discussions as presented earlier, it can be inferred that selecting QoS metric for the specific problem domain is significant especially in MRP. A suitable QoS metric is useful in assessing "goodness" of a routing solution as per requisite performance. Various enhancements in ODMRP have been discussed on the basis of routing modifications and Quality of Services parameters. Protocols have been categorized on the basis of type of modifications to achieve better throughput in terms of packet delivery ratio, end-to-end delay, control overhead and packet loss ratio. A critical review of existing multicast routing protocols have been presented; and each protocol is discussed with its advantages and limitations. Issues regarding multicast routing protocols in MANETs are discussed in this chapter. In the next chapter, we are presenting our proposal on link stable multicast route protocol. The proposed solution selects a reliable route for multicast communication in MANETs. Subsequently, a novel mobility prediction method is applied on a mobile node to predict the node movement for uninterrupted transmission.

Chapter 3

Mobility Prediction Model and Link Stability based Multicast Routing Protocol

In recent years, link stability is receiving attention in MANETs. A link is said to be stable if it maintains connectivity for a duration longer than the refresh time of routing protocol. Selection of a stable link ensures that overhead of re-routing is reduced, the probability of data loss is lowered and this improves reliability of communication. Temporal stability (is used synonymously with stability) of a link is likely to improve network performance in terms of end-to-end delay, DSDR (Data Success Delivery Ratio) and ART (Available Route Time). Energy consumption, bandwidth and communication delay during routing are major concerns in ad-hoc networks.

As signal strength is inversely proportion to the square of the distance, connectivity is adversely affected as nodes move away from each other. Larger the distance between two nodes, higher is the probability of non-existence of a communication link. In MANETs, a link is stable if the respective nodes are either stationery or moving slowly. Increase in mobility of nodes is likely to result in link failures. A robust routing algorithm should be able to predict how stable is the link between two moving nodes. Earlier approaches [5, 72] have employed received signal strength, SINR for estimating link stability. The objective of our proposed routing technique is to estimate and select a stable link from a set of requesting nodes between the current pair of nodes for route discovery process. In this way, the frequent changes in MANETs can be dealt with topology while maintaining end-to-end delay, control overhead and quality of received data within limits. In this work, mesh-based reactive routing protocol is proposed. This choice has been made since mesh-based routing protocol provides reliable data communication in MANETs due to path redundancy, leading to a reduction in route reconfiguration.

In this chapter, we present a mathematical model for estimating/predicting stability of a link between two mobile nodes in a MANET and use this to identify a stable link in 'route selection' phase of our approach to multicast routing. Our enhanced protocol is compared to the ODMRP, which is reliable multicast reactive routing protocol presented in the subsection (2.5.1). During simulation process, we have used long duration simulation to analyze the consequences originated by the unpredictable characteristics of wireless ad-hoc networks. Our proposed protocol supply some acuity on the questions and their feasible answers for multimedia communication in multicast mobile ad-hoc networks.

Our proposed routing prediction framework may be useful in video monitoring and surveillance. It could be used in disaster recovery where surveillance is used. It helps the people who are in trouble, using an ad-hoc network of mobile devices such as Unmanned aerial vehicles (UAVs) [9], underwater and grounded vehicles(UGV) [73], etc. UAVs devices need to be equipped with minimal hardware and a camera to communicate the streaming data to base station at the ground. Besides the extensive simulation using multicast constant bit rate virtual data generator, the contributions presented in this chapter are listed below.

1. A novel node mobility prediction method is proposed to protect the network from link and route failures. Proposed QoS-aware routing protocol uses this prediction to select the most stable link at each intermediate node.

2. LSMRP method has taken for estimating reliable links for communicating streaming data before route establishment.

3. An accurate estimation of total active time of response node in the communication range of requesting node with low overhead to ensure reliable transmission and increase network throughput till the route refresh interval.

4. Incorporation of signal strength during route discovery phase to establish a more resilient network.

The rest of the chapter is organized as follows. Section 3.1 presents the overview of previous work on the multicast routing protocol. Section 3.2, introduces the mobility prediction with its benefits and issues. The proposed algorithm and mathematical model is discussed in Section 3.3. Experimental setup and result analysis are presented in Section 3.4 followed by concluding remarks of the chapter in Section 3.5.

3.1 Related Work

This section describes basic MRP [14, 34] and its enhancement based on link stability, route stability [74] and mobility prediction [75]. The differences in various topology selections for achieving better network throughput has been discussed. Issues in the existing MRP and signal strength estimation method is also discussed.

Sung *et al.* [34] have proposed ODMRP (On-Demand Multicast Routing Protocol), an on-demand mesh based ad-hoc multicast routing protocol. It gives reliable routing mechanism for multicast receiver. It is source initiated Multicast Routing Protocol. The algorithm identifies and uses a forwarding group (FG) (a subset of intermediate nodes to forward the packets). When source node wants to transmit the data to multicast group receiver, it broadcasts Join Query (JQ) packets. An intermediate node receives non-duplicate JQ packet, buffer the receiving end information and retransmit for further routing. Finally, Multicast receivers receive the JQ packet, check group membership whether it is in the list of receivers. After making an entry in the route table, the multicast receiver sends Join Reply (JR) packets to their respective previous node (hop) addresses. When an intermediate node receives JR packets, it check the entry of previous hop address in JR packets whether it matches with its ID or not. If it is a true intermediate node, then forwards the packet to their corresponding previous hop node and set the FG flag to true, because it is on the path in-between source and destinations. Further JR would be received by a source node, coming through a set of forwarding group nodes. At last, the source sends acknowledgment packet to receiver group for confirmation of route. At this time, the source starts transmitting data to multicast group receivers. The route construction process is pictorially depicted in Figure 3.1, which as follows:

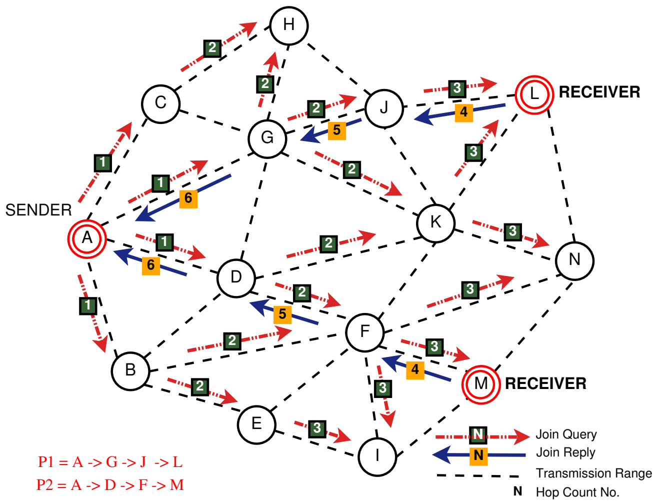

FIGURE 3.1: ODMRP Work Flow

The process constructs the path from source to destination nodes and builds a mesh structure topology of active nodes. There is a new idea of a soft state that any node can leave the network without transmitting any control message. In ODMRP, routes are periodically refreshed to maintain changes in membership information. In [28], shows that mesh based MRP outperforms tree based MRP.

In Figure 3.1, there is one sender, two receivers (shown inside double ring). Weight on an arrow indicates hop count value for the respective link. Information about other possible paths is not discarded and is used to establish links in the event of connection failure caused due to node mobility. For example, a route $A \to G \to K \to L$ is established as soon as $A \to G \to J \to L$ is disrupted because of movement of J. As result shows, this mesh structure is more resilient than tree-like topology, as there is no requirement to reconfigure the entire route during the change of node position.

Issues in ODMRP: To decide periodic refresh interval is a critical problem for improving throughput in terms of packet delivery ratio. In ODMRP, link selection is performed on the basis of minimum hop count and delay. Highly mobile networks link failure is more often due to node mobility. Due to fixed route refresh interval (RRI) time packets continue to drop till next route request initiates.

EODMRP is an enhancement in ODMRP, is achieved by making dynamically adapting their refreshing rate and receiver joining to the environment [14]. The receiver has to initiate join query (Receiver Join Query) in the network to join a multicast group in-between transmission. If a route exists, multicast receiver or forwarding group member should reply with Receiver Join Reply. If one hop neighbors does not have any route to the respective source node, receiver increases TTL value and repeats this process until the upper limit of TTL is reached. In worst case scenario, if no route is found, the receiver floods the network with refresh request packets.

The protocol has its limitations due to the use of dummy packets and their transmission to a sub-tree to prevent recovery explosion, which results in extra overhead. The performance is also impinged by increases routing overhead caused by Receiver Join Request (RJR) packets, sent by the receiver node to join current route thereby resulting in additional processing power. Attackers can also force new nodes to waste their resources by transmitting numerous RJR request.

In [75], Lee *et al.* have proposed a technique to select a stable route while avoiding rerouting that arises due to node movement. They have tried to predict the node's movement and in advance reconstruct paths in case there is topology difference. Two methods for mobility prediction are proposed first make use of GPS-equipped devices to calculate exact positions of corresponding nodes to select a stable route. Alternatively, they have used Link expiration time (LET) to calculate node movement using variation in transmission power. Authors have transmitted periodic hello packets to the entire network for measuring transmission power of a node. Due to extra control overhead and high-cost GPS device, this protocol is not suitable for reliable mobility prediction.

In [76], Dario *et al.* have proposed a probabilistic predictive multicast algorithm (PPMA). PPMA tried to improve the disadvantages in terms of scarcity of reliability and multicast tree suspension due to link failure when node movement away from transmission range. Authors improved the construction process of the multicast tree by selecting higher residual energy node for data transmission to achieve maximum multicast tree active time. In this way, they can reduce the number of costly reconfiguration of trees. Authors have also calculated relative node movement to predict their future positions to calculate stable multicast tree. They have used node residual energy for predicting the maximum stable link for the multicast tree, but the node with maximum energy may be possibly prone to link failure due to node movement. So authors have to predict the active time of multicast tree on the basis of node positions. It is hard to predict their tree active time using node energy consumption.

In [15], Xia *et al.* have shown mobility prediction model for multicast networks. The author has also used received signal strength indicator to predict the node movements. The author has integrated the proposed model with MAODV protocol. SMR protocol searches for the additional available link and adapts according to their modification in network routing. They have used free space, two ray ground and shadowing propagation model to simulate MANETs. They have estimated local and relative stability metric to synthesis link stability. Continuous examination of node position is analyzed by the periodic packet to predict the exact node position. The author has simulated their proposed work with low mobility scenario and varying network size, source, multicast group receivers. In this paper, they have enhanced the work on tree based MAODV protocol and compared the result in terms of network route lifetime, network throughput, and average end-to-end latency. To maintain the multicast tree, hard in the ad-hoc network because in tree topology if a single link got out of coverage area, it leads to an unreliable route, and relative estimation model is not satisfied in all network conditions as compare to other existing models.

1. **Distance Estimation through Received Signal Strength:** Received Signal Strength Indicator (RSSI) calculates the signal strength of incoming node in the communication range of estimating node [77, 78]. Variation in

signal strength can be used to calculate the node distance and direction with respect to the estimating node.

$$RSS = P_t - P_L(d_0) - 10\alpha log_{10}(\frac{d}{d_0}) + X_{\sigma_{RSS}} \quad (3.1)$$

Equation 3.1 represents the RSS estimation at any point d according to the physical layer model and transmission range of a node, where P_t is transmitted power, α is path loss exponent, X_σ is zero-mean Gaussian random variable and P_L is path loss.

The Figure 3.2 depicts values of SINR and BER (Bit Error Rate), as the distance between two nodes vary in a XXX communication channel implemented in Exata simulator. It shows the variation about increment and decrement in distance between pairs of adjacent nodes. At the point of the maximum distance (i.e. nodes got disconnected) between nodes, BER reaches its maximum error value 1 and SINR to the lowest level. At this maximum distance, a node can sense other nodes, it is not able to make a successful transmission. If BER is negligibly small (approaching zero), the node can

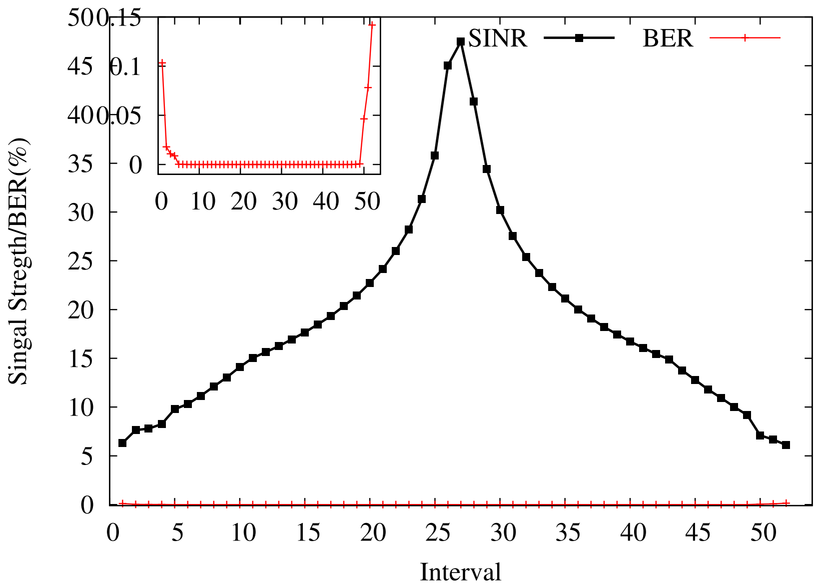

FIGURE 3.2: SINR and BER on distance variation

transfer their data successfully to receiving end. Variation in signal strength increases at nearest points as compared to distant points. These changes of signal strength may be used to predict future node position (if node is coming closer or going away) to rescue link from failures in highly mobile scenarios.

In Figure 3.3 illustrated that why selection of an intermediate node is based on it's and neighbors mobility is significant. To explain the requirement of mobility prediction in LSMRP due to link failure in high mobility scenario, we consider a simple example. Source 'S' wants to transmit data to receiver 'D'. Possible paths are (1) $S \rightarrow A \rightarrow E \rightarrow D$, (2) $S \rightarrow C \rightarrow E \rightarrow D$ and (3) $S \rightarrow B \rightarrow E \rightarrow D$. Due to mobility of nodes, A and B move to A' and B'. In new positions, A is not in range of E and route 1 is broken. Similarly, B in its new position is not in range of S and route 3 is no longer available. So stable route is route 3 via C. ' node 'C' can make a stable route between nodes 'S' and 'E' till route expiration time. Using mobility to predict future position of a node and its impact on the route in future can be used for selecting stable route nodes.

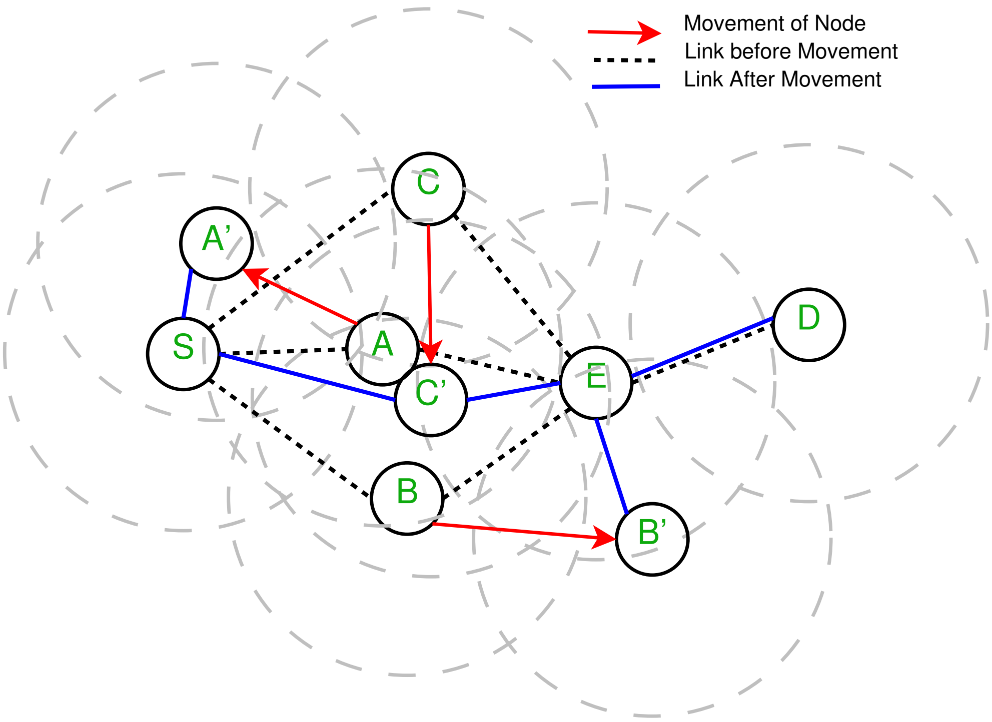

FIGURE 3.3: Requirement of Mobility Prediction

3.2 Mobility Prediction & Overview

Determination of future topology of a network helps QoS-aware routing to select a reliable link for transmitting data from one end to other. Predicting the network topology in advance, makes it easier to communicate with other devices while lowering bandwidth consumption, transmission delay, and power consumption. This can also save the number of reconfigurations due to route failure without generating extra control overhead. Different mobility prediction algorithms have been applied to the routing algorithm to improve the data communication [75]. Most of the papers used Global Positioning System (GPS) to predict the network topology [79]. GPS can estimate the exact coordinates of the devices. There are many other prediction methods available [80], some of which are listed below. Mobility prediction methods are classified into three categories:

1. Movement history based prediction: In this method, user predicts the network's future topology on the basis of previous movement patterns. It gives us correct results if predicting inconsistent network topology. In a highly mobile network model, this history-based prediction might fail to give appropriate results.

2. Physical Topology based prediction: In topology-based methods, prediction depends on the physical characteristics of the mobile nodes. GPS-enabled devices can use to estimate the future location of the mobile node [75]. GPS is not suitable for every scenario.

3. Logical Topology based prediction: In this approach, the process does not depend on any of the physical characteristics or previous history. It simply depends on the logical topology of the network to correctly classify the node movement. It is based on various parameters like neighbor's movement, cluster position(distance from cluster head). Moreover, it can calculate the variations in distance according to time, using signal strength.

3.2.1 Is Global Positioning System (GPS) does Limitations?

GPS may not be able to work efficiently for certain scenarios (indoor, fading). In case of GPS, coordinates of nodes are updates only when there is some major displacement in the nodes position. Meanwhile, during this displacement, the route might break, or node might cease to exist in communication range. GPS devices are still expensive in terms of money, energy(batteries drain off quickly). Devices equipped with GPS are rare. GPS does not work properly at indoors or at altitude. Moreover, its sparse coverage results in the poor reception and sometimes, lags in up-to-date maps status.

3.2.2 Mobility Model

The mobility model is used to define the technique of mobile node movement in the network. In the model, the maximum and minimum speed, pause time, direction, location, pattern of mobile node movement is specified. Various mobility models [81] that support wireless ad-hoc networks. This work has focused on Random Waypoint Mobility Model.

Random WayPoint (RWP): Random WayPoint [82] mobility model was first proposed by Johnson and Maltz. In this model, the mobile node can move at any random place. Node randomly selects a destination point and starts traveling towards the direction with random speed varying from minimum(0) to the maximum. It reaches the destination and then pauses for some time (seconds) to start again.

Effect of Node Speed: Mobile node's speed affects the performance of the network in terms of throughput. Mobility prediction of a node is not precise at high speeds. Therefore, it can not predict the node movement in high-speed networks.

Benefits of Prediction: Prediction of node movement or future topology helps us to stabilize the link for minimum route expiration time. So, this can improve the total success delivery ratio to a greater extent without increasing control overhead.

3.3 Mobility Prediction with Link Stability Based MRP

To test our hypothesis that selection of stable link improves performance of MANET routing protocol, we have implemented LSMRP (Link stable aware multicast routing protocol in MANETs) (Appendix A) in which SINR is used to assess the stability of a link. Higher the SINR value across a link, the more stable is presumed to be. The details of LSMRP are presented in Appendix A. Comparison with ODMRP indicates that LSMRP outperforms in terms of Packet Delivery ratio and Average End-to-End delay. As SINR has been used by other researchers also, we proposed a new routing method called “Moralism” based on inclusion of our novel mobility prediction model. Moralism is an extended version of LSMRP. In the previous protocol, signal strength was embedded as a QoS-metric to improve network performance. As analysis of simulation results for LSMRP shows that some links fail during route refresh interval because nodes move away from communication range of others. Therefore, prediction of node movement is required for estimate the stabilize link.

3.3.1 Introduction

Mobility prediction with Link Stability based Multicast protocol (Moralism) is the enhancement of LSMRP protocol to resolve the issues of link failures and displacement of a node outside the communication range. In mobility prediction, the node movement is predicted according to their last estimated positions. GPS attached devices has not used to get node’s exact coordinates for calculating the distance between corresponding nodes to the route [83]. Exact coordinates are not needed for mobility prediction as the only conern is computing a node’s maximum active time in another node’s transmission range. The devices have less mobility speed in ground level devices and Random Way Point (RWP) mobility model is assumed for node movement pattern in this approach.

In ODMRP, routes are reconstructed after every ‘route refresh interval (RRI)’ [14] to map the changes of network scenario. Route reconstruction does not depend on route failure; rather a route periodically reconfigures after a route refresh interval (RRI). RRI is predefined by the administrator of the network. Network performance varies according to its RRI. In [14], authors have tried to resolve it by assigning a dynamic value of RRI according to network scenario.

As stated earlier, a set of stable links helps in constructing a stable route. To identify a stable link, one needs to estimate the time a node is likely to sustain a link by remaining in vicinity of the preceding node. The active time need to be estimated for each of neighboring nodes residing in the node's communication range to find a reliable link. To this end, we need to calculate the distance traveled by the node after entering the transmission range of another node. Once this distance is travelled, the time can be easily estimated by dividing the distance by average node speed. In our model, we assume that the speed remains constant and, hence, average speed is nothing but speed at which a node enters the communication range of preceding node.

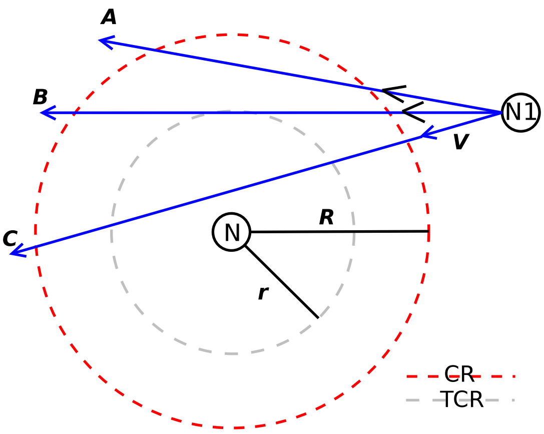

FIGURE 3.4: Possibilities of Node Movement

To determine the total distance traveled by a node, its position coordinates must be well known. For estimating traveled distance, we define two terms – (1) Communication Range (CR) and (2) Threshold Communication Range (TCR). The communication range can be defined as the maximum distance at which a node can sense or receive data packets from another node. Let us consider two nodes N and N_1. Node N has been selected as part of the route and link $N \rightarrow N_1$ is being evaluated for its stability. The outer circle, marked red, in Figure 3.4 shows the communication range of N and is denoted by R. Once N_1 enters this range, minimum time it should remain in this range is atleast RRI (Route Refresh Interval). Multiplying RRI with speed of node gives us the minimum distance that N_1 should spend in CR of N. This is represented by TCR (Threshold Communication Range) in our model. The TCR value is set as a product of RRI and node speed. In Figure 3.4, inner circle represents TCR. Here, r is the distance corresponding to 'RRI $\times$ v where v is average speed of the node within TCR.

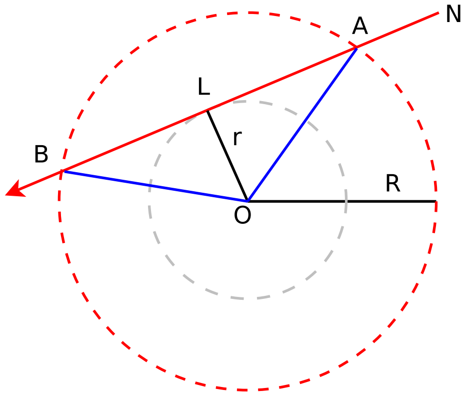

FIGURE 3.5: Possibilities of Node Movement

It may be mentioned that R depends on the transmission power and channel characteristics, but $'r'$ depends on the speed of the node N_1 relative to N. Higher the speed, larger is the value of r. To remain in communication range of N_1, node N should travel a distance of r in its communication range. Let r_{max} represents maximum value of r at the highest possible speed. For any node entering the inner circle or TCR, the link is assumed to be stable i.e. link remains active for RRI. This can happen only if any tangent to circle representing TCR has a length ateast equal to $2 * r_{max}$. So in Figure 3.5,

$$AB = 2 * r \text{ As } OA = OB = R$$

If L is midpoint of AB,

$$LA = LB = r_{max}$$

Applying Pythagoras theorem

$$(OA^2 = OL^2 + LA^2)$$

$$R^2 = r_{max}^2 + r_{max}^2$$

$$R^2 = 2r_{max}^2$$

To satisfy the assumption that any node travelling at constant speed and entering TCR shall maintain a stable link $R \geq 1.41 r_{max}$. In our simulation framework, this condition is satisfied as at maximum speed of $18m/s$, $r = 180m$ and $R = 500m$.

In Figure 3.4, is shown the possible movements of node N_1 in the communication range of node N, as depicted by paths A, B and C. Path A is discarded from our set of stable links due to its trajectory outside TCR. Node N_1 does not remain in the communication range of N for sufficient amount of time and this link may break much before RRI. Path B is tangential path and may just survive RRI. To improve reliability, we shall select path C as it shall have highest active time among all three paths.

In path C, Node N_1 is moving towards N node. To predict the total distance traveled by node N_1 in CR and TCR of node N, we are using Mathematical Model described in next section. Threshold traveling time (TTT) is estimated from CR to TCR by applying timer at entry and exit time. After estimating TTT, the total distance travelled in communication range of N is product of TTT and speed v. Similarly, the total time taken from TCR to CR is also equivalent to TTT. Now, the paramount problem is to calculate total travel time in TCR in order to achieve the maximum active time of a node. In Figure 3.10, the trajectory of the node N_1 is shown moving inside the TCR. In this case, this has to calculate $A'B'$ to calculate total distance AB. Already, calculated BB' and AA' that is equivalent to TTT. It can divide $A'B'$ into two equal parts viz. $A'L$ and $B'L$ by drawing perpendicular (L) on $A'B'$. It can easily calculate $A'L$ by Pythagoras theorem, if OL (distance of perpendicular) is known and r is known as a radius of TCR. OL is also perpendicular to AB and dividing it into two equal parts AL and BL. So OL of $\measuredangle AOL$ can put equal to OL of $\measuredangle A'OL$ that eventually helping in measuring the $A'L$ value.

After estimating active time of nodes that are demanding route for the multicast destination, select a node with maximum active time for reliable route till next reconfiguration of the route. A group of stable links makes a stable route. Each node selects maximum active time node as a forwarding node to contribute in the construction of the stable path. There may be some cases where a node suddenly changes the direction, it may cause link failure. In RWP mobility model, a node is moving in the same direction with constant speed to its destination point. So there would be less probability of link failure due to mobility. In the high mobility scenario, there would be an increase in packet drop in last time interval of route expire time as node would have escape away of a node from communication range. However, Moralism still gives the better result than old existing protocol due to selecting a reliable link from all others.

3.3.2 Route Discovery Process

In Algorithm 1, we represents the process of route construction for multicast destinations. Source (s) node wants to transmit data to a set of destinations called multicast group address (D). It starts discovery process for a stable route by sending Join Query (JQ) message to its one-hop neighbors. One hop neighbor nodes start forwarding packets to their corresponding neighbors. After receiving first JQ message, an intermediate node n stores the message and estimates the SINR value of the link with the previous hop node n_0 (from which JQ message was received) and initiates a timer for Expiry Time. Node n predicts an active time of requesting node n_0 in its CR and stores it along with the message. An expiry time is used to store all the requests coming from different neighbors that demand route with the same source and multicast group addresses. After the end of Expiry time, receiving node n discards the requesting packets and selects the node with maximum active time in its CR and sets it to its previous hop address. This process continues till all multicast destinations select their respective stable links for communicating data. Multicast destinations start sending Join reply (JR) to their previous hop address in response to JQ. After receiving JR, the source starts transmitting data for Multicast Group Address. In this protocol, the process of route construction of ODMRP is not altered but link stability is incorporated in selection of the route links. Therefore, the process of multicast route construction and maintenance is same as ODMRP protocol.

Algorithm 1 Algorithm for Predicting and Estimating Stabilize Link

Require: s {Source node}
$D = \{d_1, d_2, \cdots, d_k\}$ {set of k destinations}
$P_{s \rightsquigarrow D}$ {Stable Path from source to destinations}
ζ {SINR Value}
Ensure: : Stable paths from $s \rightsquigarrow D$

$P_{s \rightsquigarrow D} = \emptyset$
s broadcasts 'Join Query'
$u = s$
Repeat:
for $v \in$ neighbor(u) **do**
  $time_{max} = 0$
  if Received First Join Query Request from $n1$ **then**
    $t \leftarrow Cal\_Active\_Time(link, msg)$
    Store Msg, t, & SINR of $\ell_{v \to n1}$
    SetTimerTime ← Current_Time on v
  else
    Interval (i) = Current_Time − SetTimerTime
    if ($i \leq$ 'Expiry Time') and (! duplicate) **then**
      Receive packet from neighbor $n2$
      $t \leftarrow Cal\_Active\_Time(link, msg)$
      Store Msg, t, & SINR of $\ell_{v \to n2}$
    else if ($i \gneqq$ 'Expiry Time') or (Expire_Timer) **then**
      Discard the current Packet
      Select the node with 'Maximum Active Time'
      for $j \in$ store link for a node v **do**
        if $time_{max} < t_j$ **then**
          $time_{max} = t_j$
          $\ell^v_{stable} = \ell_{v \to j}$
        end if
      end for
    end if
  end if
  $P_{s \rightsquigarrow D} = P_{s \rightsquigarrow D} \quad \cup \quad \{\ell^v_{stable}\}$
end for
if $v \notin D$ **then**
  $u = v$
  Goto **Repeat**
end if

[1]

In Algorithm 2, we illustrates that how the Active time of a requesting node in the CR of receiving node is predicted/estimated. Requesting node broadcasts periodic messages which are used for estimating signal strength at neighboring nodes. Node 'n' receives messages and estimates SINR value through physical

Algorithm 2 Calculate 'Active Time'

Require: $n_1 \rightarrow n_2$ {Link}
msg {Message:set of Information}
T_D {Total Distance in Comm Range}
Ensure: : Active Time of a Node in Communication Range
Node Broadcasting Hello Packet to one hop neighbor
Node r receives first Hello packet from s
Estimate RSSI from s node
$Curr\_time \leftarrow Get\_time()$
for Continue receiving hello packets from s **do**
  if $Current\_RSSI_s \geq Threshold\_RSSI_r$ **then**
    $Analysis\_time \leftarrow Get\_time - Curr\_time$
    Goto **Label**
  else
    Discard the link
  end if
end for
Label:
$D = Analysis\_time * speed_s$
Predict Total Active time(T_T) using D
$T\_D = (R^2 - r^2 - D^2)/(2 * D)$
$T\_T = T\_D/speed_s$
Return T_T
[1]

layer information. The change in signal strength helps us to identify the direction of node movement. If the signal strength of a node is decreasing (increasing) continuously with successive transmissions, that means the node is moving away (coming closer). The signal strength is observed for the estimation of TCR to make sure that receiving node is active for a minimum required time in current route. Distance calculation D is done using analysis time(reaching node to TCR from CR) and corresponding speed. This distance is further used to predict a total active time of requesting node n_2 in CR of replying node n_1.

$$T_D = \frac{R^2 - r^2 - (D)^2}{2 * (D)} \tag{3.2}$$

Using Equation 3.2 (details are presented in next section), total distance traveled in transmitting range of node is computed. Here node n_1 has predefined R (distance of CR), r (distance of TCR) and D. So, the Total Travel Time (TTT) of node n_2 in the CR of node n_1 can be be obtained by dividing T_D by speed (v).

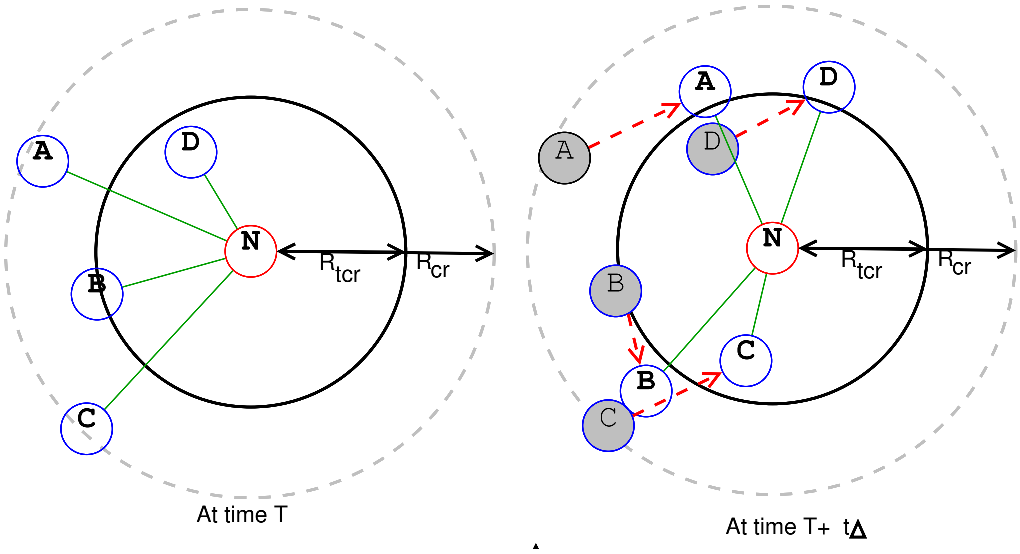

FIGURE 3.6: Moralism Example

Figure 3.6 depicts the steps involved in moralism algorithm. In this example, presenting the selection of a stable node from the set of the requesting node on the basis of maximum active time in node's communication range. In the first part at t time, node N request neighbors nodes (i.e. A, B, C, D) to discover next stable forwarding node for current route refresh interval. Node N calculating total travel time for each neighbor nodes in the communication range (R_{cr}) with the help of travelled distance from R_{cr} to R_{tcr}. At time t, neighbor nodes transmit periodic packets to N, which provides the information about their link quality. After δt time, neighbor nodes continuously informing their link quality and change their respective locations. Based on their previous values of link quality of neighbor nodes and total travelled time from R_{cr} to R_{tcr}.

Algorithm Correctness Proof: We can have the correctness proof of any algorithms with the help of different sets of inputs. If the algorithm works well for every case then we can say that our algorithm is correct. To prove the correctness for the proposed algorithms, we have taken a set of inputs. We have assume the communication range and threshold communication range to respectively 440 and 290 and Average speed of a mobile device is 6m/s. So the algorithm is working

SN	Source Node	Destination Node	Node Reciving	Node Transmitting	Expiry time	SINR	Analysis time	Total Distance	Time
1	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.9	0.0	12.23	31s	201m	33s
2	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.7	3.2	20.23	12s	733m	122s
3	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.6	4.3	38.32	21s	371m	61s
4	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.7	7.4	24.32	Discard (Duplicate Pkt)		
5	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.1	1.00	34.32	18s	450m	90s
6	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.6	10.23	15.34	Discard (High Expiry)		
7	192.0.0.3	192.0.0.5	192.0.0.2	192.0.0.8	1.23	4.34	Discard (less SINR)		

FIGURE 3.7: Input set for algorithms correctness proof

completely fine with the input sets. We have selected the highlighted node because it will stay for longer duration. If we are evaluation our algorithm in terms of Time complexity, it will take O(v^2), v is requesting nodes for estimating node.

3.3.3 Mathematical Model for Stability Prediction

In our model, the network has N number of mobile nodes, and M number of links among the nodes. A link between any two nodes exist only when these are in each others' communication range. With time, M may change. This can be represented by a graph $G(V, E)$ where $V = \{v_1, v_2, v_3, ..., v_n\}$ is the number of nodes and $E = \{e_1, e_2, e_3, ..., e_m\}$ is number of edges between vertices in the network. An edge or a link is present between two nodes if they lie in communication range of each other. In multicast MANETs, a route R_i spans j nodes ($j \leq n$) and k edges ($k \leq m$) for Source(S) and Multicast Group Destinations (MGD). Let's take an edge e_x as any intermediate link between source and destinations on a selected Route R_i. It may be possible that the link e_x in selected route R_i fails, due to the existence of mobility or unstable and unreliable link.

As stated earlier, stable links are estimated to lower the probability of link failures. Mobility prediction system tries to estimate stable links that sustain for the maximum time i.e. of all neighbors, the requesting node remains in communication range of computing node for the maximum duration.

Table 3.1: Symbols for Mathematical Formulation

Symbols	**Value**
V	Set of Mobile Nodes
E	Set of links
n	Number Nodes
m	Number of links
R_i	Route
CR	Communication Range
TCR	Threshold Communication Range
R	Radius of Communication Range
r	Radius of Threshold CR
U	Mobile Node Speed
t_e	Total_Elapsed_time
QoS	Quality of Services
MRP	Multicast Routing Protocol
LSMRP	Link Stability Based MRP
ODMRP	On-Demand MRP
E-ODMRP	Enhanced ODMRP
ART	Available Route Time
DSDR	Data Successful Delivery Ratio
TTT	Total Travel Time

3.3.3.1 Proof of Concept

Let's take a vertex v_a from set V to select its most reliable next hop node during route discovery for sending data packets to destination multicast group. The communication range of the node v_a is represented by v_a^{CR}. Let's take another node v_b that is moving with speed U into the communication range of the node v_a. Threshold Communication Range (TCR) (where $v_a^{TCR} \leq v_a^{CR}$) is also determined as per speed of v_b for predicting the stability of the link $v_a \rightarrow v_b$. To calculate total travel time, we need to calculate total distance(D) (chord AB) that node v_b traverses while remaining in the communication range of node v_a. Equation 3.3 is showing total travel time of the node v_b.

$$t^{TCR} \leftarrow Distance(D)/Speed(U) \tag{3.3}$$

In this network, three scenarios have been analyzed to compute the total travel time of node v_b, in communication range of the node v_a.

1. In the first case, node v_b enters the communication range of node v_a^{CR}, but may not travel minimum distance as mandated by threshold communication

range v_a^{TCR}, this case is shown in Figure 3.8. Such a node is not considered in our stable link prediction, because total time of link existence can not be estimated.

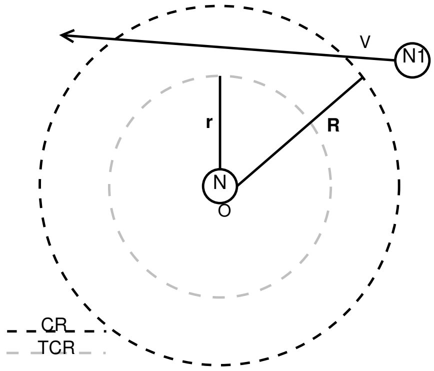

FIGURE 3.8: Mobility Prediction Model outside from TCR

2. In the second case, Node v_b enters inside the communication range of node v_a^{CR} and just touches the boundary of threshold communication range v_a^{TCR}, as shown in Figure 3.9. This link could be accepted only when no other link is available. Equation 3.4 shows the total distance. To calculate the total distance a perpendicular(L) on chord AB is drawn, which is generated by the ongoing node v_b. According to a mathematical theorems, perpendicular on the chord from center of the circle divides the chord into two equal parts. So, total distance AB is the sum of AL and BL or 2*AL.

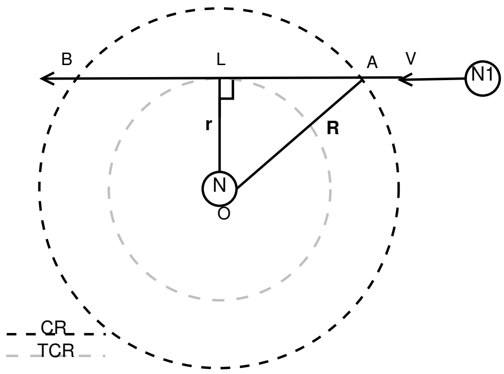

FIGURE 3.9: Node just coming inside and touch TCR boundary

$$D = AB \leftarrow AL + BL \tag{3.4}$$

$$D = 2 * AL \quad \because AL = BL \tag{3.5}$$

AL computed, which is the base of the right angled triangle. Value of AL is computed as follows using Pythagoras theorem.

$$(AL)^2 \leftarrow (AO)^2 - (OL)^2 \tag{3.6}$$

Other edges of the triangle are the radius R and r of circles representing CR (communication range) and TCR (threshold communication range). Perpendicular(OL) in the triangle is the radius of TCR, and the hypotenuse(AO) is the radius of the CR.

$$(AL)^2 = R^2 - r^2 \tag{3.7}$$

$$D^2 = 4(R^2 - r^2)$$
$$t = D/U = 2\sqrt{(}R^2 - r^2)/U$$

This time is the minimum that a node needs to spend in the communication range so as to ensure no link failure before RRI. This link is avoided unless there is no other possibility of link as the margin of error is too small and even a small variation can lead to link and subsequent route failure.

3. In the third case, the Node v_b enters in the communication range of node v_a^{CR} and also enters the threshold communication range v_a^{TCR}, as shown in Figure 3.10.

   Total distance travelled by the node v_b in the communication range of node v_a is AB.

$$AB = AA' + A'L + LB' + B'B \tag{3.8}$$

Total distance AB is divided into line segments: $AA', A'L, LB', B'B$. Perpendicular bisector L is projected on the chord AB to create right angled triangles for their use in calculating distances.
Since OL is perpendicular to $A'B'$ and perpendicular to a chord from the centre of a circle always divides the chord into two equal half, $A'L$ and LB'

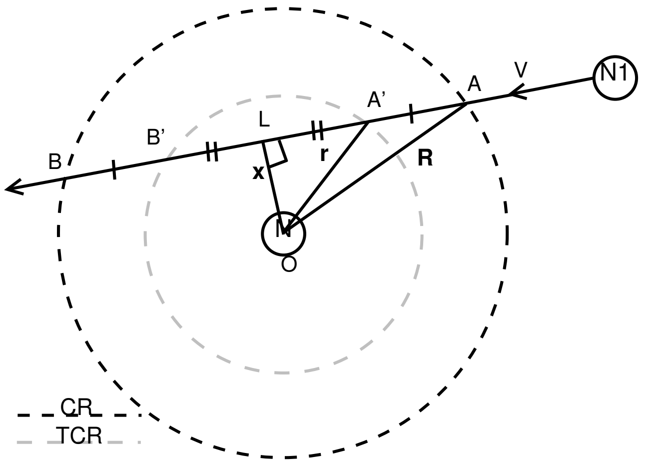

FIGURE 3.10: Node coming inside TCR

are equal.

$$\therefore A'L = LB'$$

Since OL is also perpendicular to outer circle chord AB, it also bisects. The Equation 3 shows that length of two small line segment AA' and BB' on a common chord on concentric circles are equal.

$$\therefore AA' = BB'$$

These two statements help us to reduce the Equation 3.8 as follows

$$\therefore AB = 2(AA' + A'L) \tag{3.9}$$

After projecting perpendicular, two right-angled triangles $A'LO$ and ALO have generated. Applying Pythagoras theorem on the first triangle

$$(A'L)^2 = (OA')^2 - (OL)^2 \tag{3.10}$$

Threshold communication range of node v_a, assumed as 'r' to a specific point, that is the minimum time required for transmitting reliable data between source and destinations. A temporary parameter $x = OL$ is considered.

$$(A'L)^2 = r^2 - x^2 \tag{3.11}$$

Applying Pythagoras theorem on triangle $\measuredangle ALO$ gives equation 3.12:

$$(AL)^2 = (OA)^2 - (OL)^2 \tag{3.12}$$

$$(AL)^2 = R^2 - x^2 \tag{3.13}$$

It is known that AL is sum of AA' and $A'L$ as shown in Figure. So, Equation 3.14 can use to break the equation 3.13 as

$$\because (AL) = AA' + A'L \tag{3.14}$$

$$\therefore (AA' + A'L)^2 = R^2 - x^2 \tag{3.15}$$

Using Equation 3.11 & Equation 3.15, helps to estimate $A'L$:

$$A'L = \frac{R^2 - r^2 - (AA')^2}{2 * (AA')} \tag{3.16}$$

R^2 and r^2, respective maximum and threshold communication range are already known. The length AA', however, needs to be computed. At the time of entry into, the communication range of the node v_a, the node v_b initiates a timer to calculate the total elapsed time(t_e) that it takes to the reach threshold communication range.

$$AA' = t_e * v \tag{3.17}$$

Once AA' is known, $A'L$ and, therefore, the total distance travelled is known.

3.4 Results: Performance Evaluation

Different simulations were performed to validate the performance of our proposal. It is assumed that all mobile devices are identical in respect of the configuration for the entire simulation. Nodes are provisioned with IEEE 802.11a/g networking interface card (NIC) with 24Mbps data rate. In this section, we have compared our proposed protocol with other multicast routing protocols. Our proposed protocol is evaluated on different performance metrics such as Successful delivery ratio, Available Route Time (ART), control overhead and link latency. Following paragraphs shows, how our proposed model outperforms other MRPs.

3.4.1 Experimental Setup and Simulation Parameter

The proposed model is implemented on Exata-Cyber v2.0 [84]. A MANET scenario is created with 100 mobile nodes scattered in an area of $1000 * 1000m^2$. Important parameters as shown in Table 3.2 have been used for evaluating our proposal with other MRPs. Random WayPoint Mobility model has been considered on which nodes are assigned initial speeds selected from a pre-defined range. Source node generates virtual multimedia traffic for multicast receivers using Multicast Constant Bit Rate (MCBR) [85] traffic generator application with the data rate of 30 packets/sec(with 512 bytes packet size). Simulation time for the single duration has been set to 600 seconds. For fair comparison and exact evaluation of our model, 10 different simulations with different random seed values have been used for the single set of the simulation result. Our proposal Moralism is compared

Table 3.2: Simulation Parameters

Simulation Parameter	**Value**
Simulator	Exata Cyber 2.0
Simulation Time	600 Sec.
Number of nodes	100
Area	1500 Square meter
Node Density	15 square meter
Radio Type	802.11a/g
Data Rate	24 Mbps
Communication Range	420m
Hello Packet Interval	1 Sec
Startup Prediction Time	10 sec
Link Selection Interval	8 sec
Mobility Model	Random Way Point Model
Mobility	3-18m/sec or 10.8-64.8km/hr
Pause Time	0 Sec
Routing Protocol	ODMRP, LSMRP, SMR, MORALISM
Traffic Type	Multicast Constant Bit Ratio(MCBR)
Size of packet	512 Bytes
Total Sent Packet	19967
Multicast Receivers	10
Traffic rate	128kbps, 512kbps, 1mbps, 4mbps

with LSMRP, ODMRP and E-ODMRP on various performance metrics like Data Success Delivery Ratio, Control Overhead, Available Route time.

3.4.2 Performance Evaluation

In the subsection, we are discussing the performance metrics that we have used to prove the novely of our proposed work.

3.4.2.1 Data Success Delivery Ratio

The number of data packets received by Multicast Group receivers on total data packets sent by the multicast source is called as Data Success Delivery ratio (DSDR).

$$DSDR = \frac{\sum \text{Number of Data Packets Received}}{\sum \text{Number of Data Packets Sent}} \tag{3.18}$$

DSDR can range from [0,1], the highest value being 1 when no packet is dripped and all transmitted packets are received. A high value of DSDR is desirable.

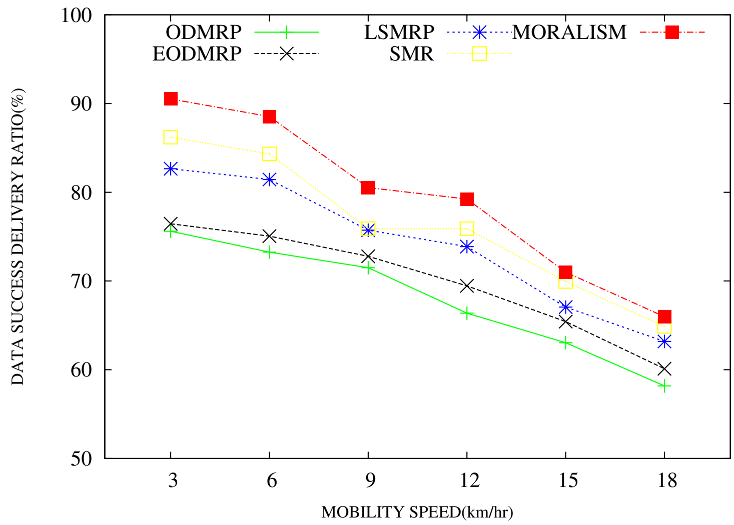

FIGURE 3.11: Effect of node mobility on DSDR (Data Success Delivery ratio)

The Figure 3.11 shows the performance variation in Data Success Delivery Ratio (DSDR) of MORALISM, LSMRP, SMR, ODMRP and EODMRP protocols.

The protocols has compared with variation in node speed from 3 to 18(m/sec). In a static environment, all protocols exhibits similar performance. In some case, existing protocols perform better than our proposal Moralism due to extra routing overhead. In mobility scenario, MORALISM outperforms all protocols, enhancement around 11% to 19%. SMR protocol performs better than LSMRP, because they have applied link stability model using RSSI metirc with mobility prediction mechanism. It falls short of MORALISM because tree based topology used in communicating multimedia data. LSMRP also shows improvement in Data success ratio as compared to ODMRP and EODMRP, because it is estimating stable link for construction of reliable route in place of minimum hop count. EODMRP only dynamically adapts its 'route refresh interval', so it gives approximately equivalent output to ODMRP and depends on network scenarios. Moralism route active duration increases as it predicts the route and node movement in advance resulting in maximum packets being transmitted without any link failures.

The simulator trace files show that MORALISM reduces the number of route failures due to the prediction of a suitable node. The former routes in ODMRP give maximum time unreliable links. In low mobility network scenario, MORALISM protocol exhibits the largest improvement in data success delivery ratio as compared to a high mobility scenario and static environment.

3.4.2.2 Available Route Time (ART)

Available Route Time is calculated as the time elapsed just after route discovery phase till the route expires. In general, routing protocols reconfigure route after the expiry of the route. Multicast routing protocols periodically update their route membership information.

$$ART = Route\_Expire\_time - Route\_Discover\_time \tag{3.19}$$

So, it's required that ART should be greater than 'Route Refresh interval' for better performance of the network.

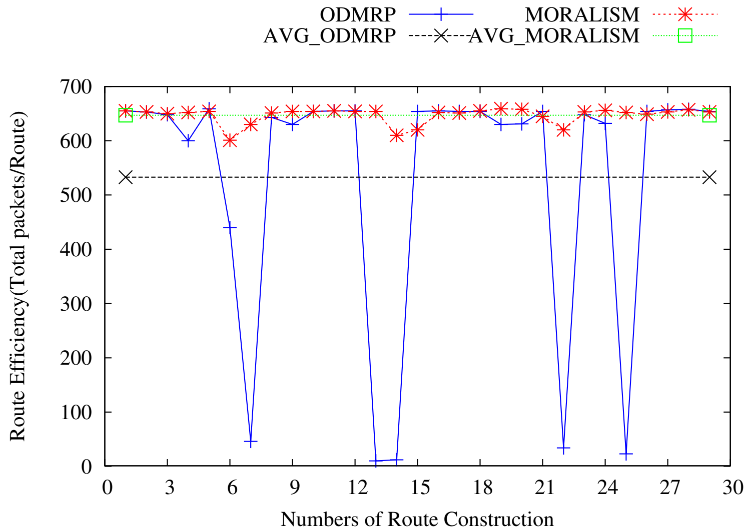

FIGURE 3.12: Effect on Route Efficiency in number of route constructions

Figure 3.12 compares the Available Route Time (ART) in terms of the number of packets of MORALISM and ODMRP in route construction process. In the graph, Avg_ODMRP and Avg_MORALISM have also shown, the average number of packets on multiple routes that reach to the destinations. In MORALISM protocol, the route never fails during RRI, because the selected node is least likely to move out of the communication range of the preceding node. In all protocols it is assumed that link failure is because of mobility and not because of any other reason such as low battery, node failure, network attack etc. In case of ODMRP protocol, the route efficiency falls down at many instances (number of routes are 7, 13, 14 etc.). Route gets disconnected in the initial phase of the construction of path, but MORALISM works well in these cases. For a given number of routes, MORALISM transmits an average of 100 more packets than ODMRP.

3.4.2.3 Average End-to-End Delay

The average end-to-end delay is calculated as the time elapsed between transmitting the data packets from the multicast source and receiving at end receivers. It also carries time elapsed in buffering and processing for the transmission of the data packet. It counts only successful transmissions.

$$Delay = \frac{\sum(Receiving\_time - Sending\_time)}{\sum Total\_Packets} \tag{3.20}$$

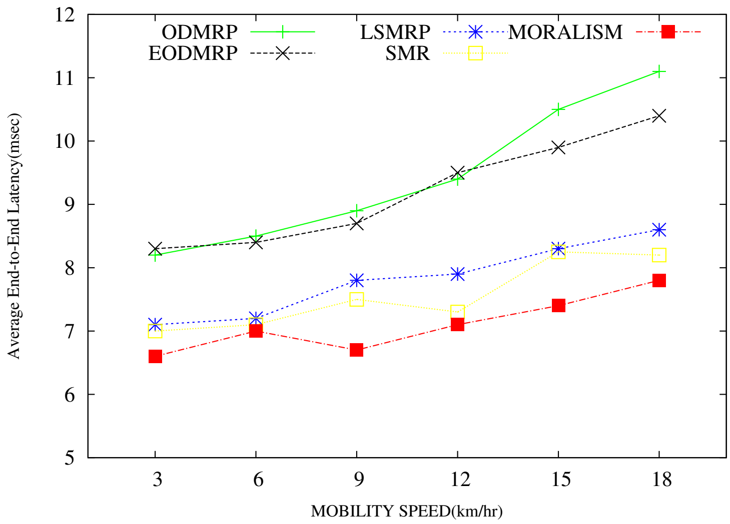

FIGURE 3.13: Effects on Average End-to-End Delay with various mobility speed

The Average End-to-End Latency represents transmission, propagation and queuing delay for the transmission of the packet to multicast destinations. Figure 3.13 shows, the Average end-to-end latency of Moralism, SMR, LSMRP, E-ODMRP and ODMRP versus mobility speed. From the graph, it is evident that latency is reduced in Moralism as compared to ODMRP and EODMRP, both of which perform in similar manner. LSMRP also shows improvement in Average End-to-End latency. As number of route failures as compared to LSMRP are less, Moralism outperforms LSMRP. Moralism also outperforms SMR protcol due to availability of multiple paths from source node to destinations. SMR protocol has a single path from source to destination group; if packets from any node get delayed due to high congestion, the entire route is effected. As node mobility increases, latency increases as well. At node mobility $3m/sec$ and $18m/sec$, corresponding latency improvement is 22% and 29%. In some cases, latency is increasing(declining) e.g. in case of $6m/sec$, because it may get affected by some abnormal route breakage.

3.4.2.4 Control Overhead

A number of control packets are transmitted for route establishment and to maintain group membership information. Control overhead can be calculated by dividing the total number of control packets transmitted by the total number of packets sent.

$$Overhead = \frac{\sum(Number\_of\_Control\_Packets)}{\sum Total\_Sent\_Packets} \tag{3.21}$$

Here, adding a new parameter called prediction overhead; it is a part of control overhead.

3.4.2.5 Prediction Overhead

Prediction overhead is an additional overhead that occurs due to time needed for predicting the node movement.

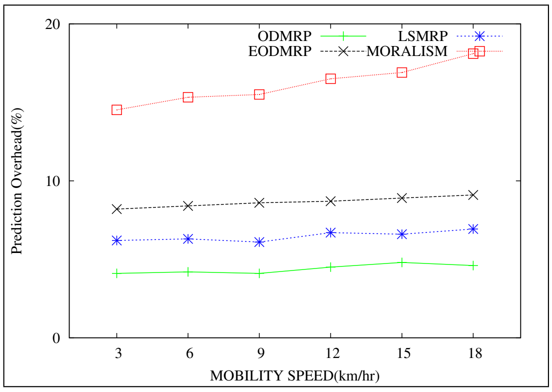

FIGURE 3.14: Prediction Overhead with mobility speed

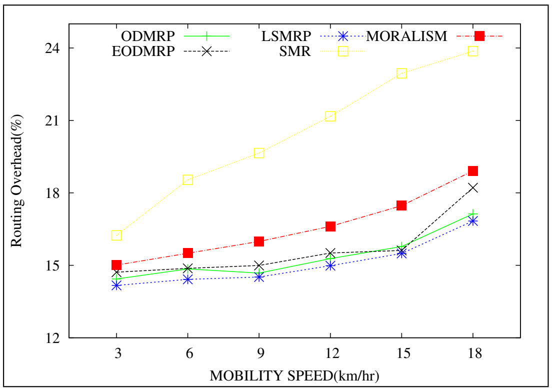

FIGURE 3.15: Control Overhead with mobility speed

A plot of the prediction overhead using multicast routing protocol can be seen in Figure 3.14. Prediction overhead is an additional overhead that occurs because of time required for predicting the TTT of a requesting node in the estimating node's communication range. In MORALISM, prediction overhead is increased by 6%. Prediction overhead is not changing with the increment in node mobility because the number of packets that need be transmitted for prediction is same in all cases.

Similarly, Figure 3.15 shows the totol overhead in the network to successful transmission of data. In this, one more routing protocol (SMR) is added for comparison. SMR protocol is not considered while evaluating performance with respect to prediction overhead. In this comparison, Moralism does not perform well as compared to others. It gives very less overhead from SMR protocol. LSMRP gives less routing overhead as compared to all other protocols, because it does not send any extra packets for route establishment. Moralism and SMR protocol, send periodic packets to calculate total active time in the node communication range. This increases total routing overhead of Moralism protocol. We have not simulated SMR protocol and taken their results according to our scenario parameters [15].

3.4.2.6 Number of Route Failure

In the simulation, routes have constructed various times according to the total simulation time. From the total number of routes, that got break before the time of construction of next new route is counted as route failure.

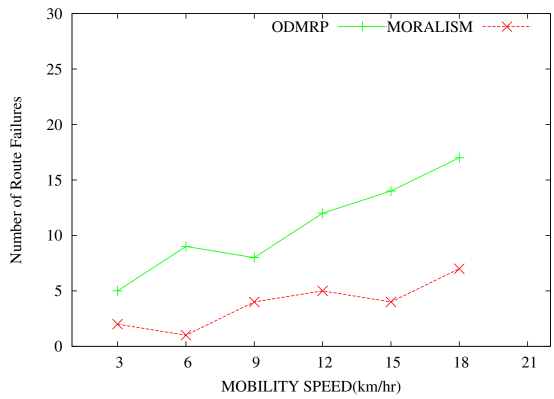

FIGURE 3.16: Number of route failures with mobility speed

The number of route failures is examined with increasing node's mobility speed as shown in Figure 3.16. In general case route failure are increasing with the increase in node mobility due to the fact that forwarding nodes move out from communication range. In ODMRP, FG node selection depends on the first come first served basis. So the frequency of route breakage increases. A single link with lower link quality may also result in cause for route failure. As shown in

Figure 3.16, the number of route failures decrease by about $50-80\%$ in Moralism as compared to ODMRP.

3.4.3 Moralism: QoS on Streaming Data

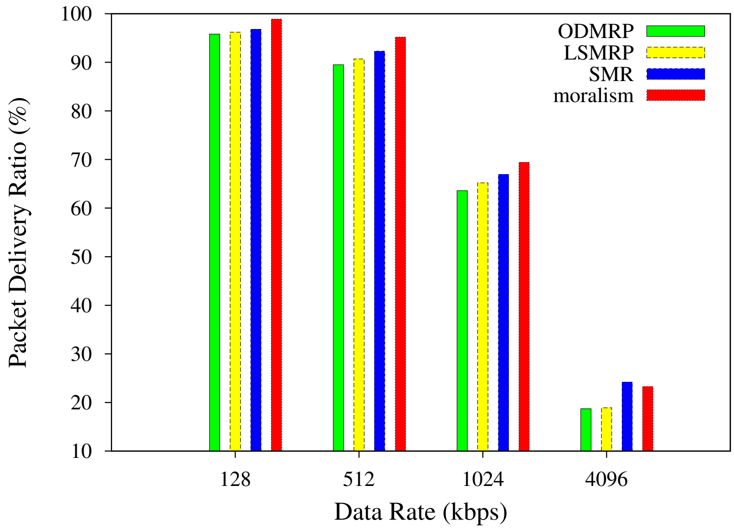

Figure 3.17: Effect of different data rate on DSDR (Data Success Delivery ratio)

Effect of DSDR on various data rates as applicable in multimedia streaming shown in Figure 3.17. To check feasibility of our proposed method on multimedia data, it is tested on different data rates i.e. used in video streaming data. The simulation results are shown on $128kbps$, $512kbps$, $1024kbps$ and $4096kbps$, as can be seen from Figure 3.17, moralism performs better than all ODMRP and LSMRP., after the threshold data rate ($1mbps$), the DSDR rate falls sharply for all algorithms but Moralism performs better. At $4mbps$ data rate, the DSDR ratio is only (10-20)%.

Figure 3.18, shows average end-to-end delay on data rate $128kbps$, $512kbps$, $1024kbps$ and $4096kbps$. For high data rate communication, the end-to-end delay is increased because packets are not able to reach the destination or buffer overflow. For $128kbps$ and $512kbps$ data rates, packets reach to destination without any drop. In proposed approach the delay decreases by (5-10)%.

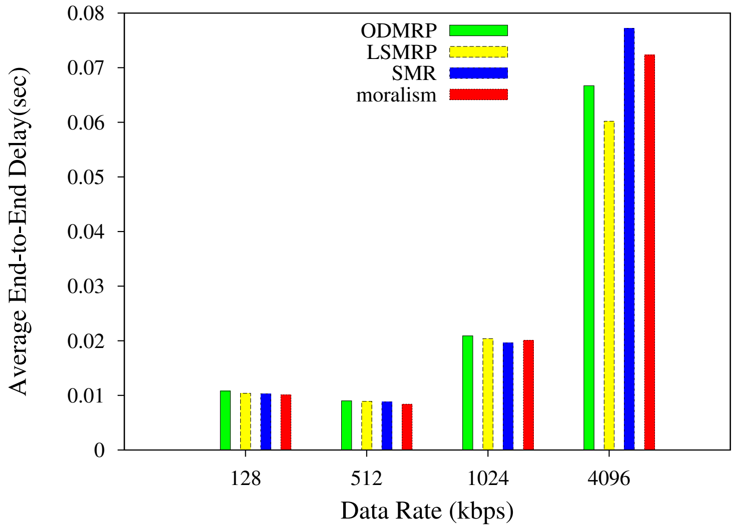

FIGURE 3.18: Effects on Average End-to-End Delay with different data rate

3.4.4 Inferences

Our proposed protocol is compared with existing basic protocols and their enhanced versions. The main findings of this comparison are listed below:

1. Our Proposed approach outperforms the existing protocols (SMR and ODMRP) by predicting the node active time. It helps to make a reliable route for communication.

2. Moralism has compared with existing protocols on different streaming data rate (128$kbps$, 512$kbps$, 1024$kbps$ and 4096$kbps$) to validate the proposed routing technique.

3. In a high mobility scenario, Moralism surpasses its performance in terms of successful transmissions because of the feature of advanced range prediction. If the maximum transmission range is 500m and, the node is travelling with the speed 50m/sec (180 km/hour, permissible speed along highways of USA/EUROPE) with RWP mobility model, it can take maximum 10sec to travel their respective CR. In our case, RRI is assumed to be 20s, that is twice of total travel time. So, the link shall not persist and link failure takes place. To overcome this, one needs a constraint on speed and/or RRI.

4. Moralism will not worked with high mobility scenarios, because the node will move away from the communication range in the required RRI.

3.5 Summary

Link stability has always been a subject of great concern for researchers. In this work, we have discussed some issues and problems related to link stability estimation. A novel method for node mobility prediction is proposed that selects intermediate nodes avoiding link failures. This approach is not concerned with exact coordinates of devices and select the links with maximum route available time. The node travel time in the communication range of requesting node is predicted through a mathematical model. Selected reliable link from the existing set of requesting links reduces route failures. Route failure depends on a single weakest link of the entire route. The proposed method does not require exact position using any fixed device (GPS), and this make it energy efficient.

In this approach, the reliable link is selected for communicating data from one end to other. In few cases, reliable link may lead to unreliable route, that is not estimated in our protocol. In the next chapter 4, link and route stability estimation is used to discover the reliable route for multimedia data transmission.

Chapter 4

Improved multicast routing using link stability and route stability

The growing popularity of multimedia applications and services need to support several quality of service metrics such as high throughput, low energy and jitter, which is a challenging task in MANETs. Due to limited bandwidth, energy constraints, dynamic topology, transmission errors and fluctuating link stability, the links between adjacent nodes are often not reliable and may break due to node mobility. Link breakage initiates the process of re-routing either at the sender node (the node at which the link breaks), or at the source node. In either case, it leads to packet loss, delivery delays and increased control overheads. Hence to attain a minimum Quality of service, routing protocols must address the dynamic network topology. Uncertain and varying movement of nodes necessitates stability of the links between such nodes.

To transmit packets to receiver(s) outside the transmission range of the source, the routing protocol should determine a stable route(s) between source node and destination node, via intermediate nodes acting as routers. Due to dynamic topology and multi-hop routes, often, there is a possibility of a link breakage. To minimize such occurrences, the routing protocols should be able to establish a stable communication path between source and receiver with decreased control overheads, less delay, and better packet delivery ratio (PDR).

In the previous chapter, we presented a link stability based protocol that determines a stable link among all available links to the next-hop from a node and creates a more reliable path for data transmission. In this chapter, the method of link stability estimation is extended to a route stability based protocol that determines an available stable path between source and destination nodes. Most of the proposed routing protocols for route selection are dependent on minimum hop-count and optimize the path length but ignore the stability issues. Consequently, the selected path may not necessarily remain available and route refresh may need to be invoked. Link stability is the ability of link between adjacent nodes to remain established for a definite duration. It fluctuates due to the mobility of nodes, congestion in the network, exhaustion of resources like bandwidth in the network, energy of nodes. Apparently, the path selected using traditional routing protocols is always the shortest path. To minimize hop-count, longer hops are usually selected without considering the edge effect (Section 2). As a result, such paths are likely to be less durable.

Stability of a link is adjudged by parameters such as the relative mobility of the nodes sharing the link, received power, energy of nodes, signal to noise and interference ratio, congestion on the link and the link bandwidth. In this chapter, a method of computing link stability based on the probability of successful transmission of periodic HELLO packets is proposed. In this method ack-free packets are transmitted by nodes periodically at a specified interval of time. Network connectivity can be assessed by periodically sending HELLO packets to neighboring nodes. Based on HELLO packets received successfully at each receiver node, successful transmission probability of each link is calculated and link with maximum probability of success rate has been selected as a previous-hop address for communicating multimedia data. Increased probability of successful transmission indicates that the link may sustain for longer duration and delivers packets more reliably.

In this method, less durable links are avoided to ensure that route is composed of durable links. The reliable route thus formed, results in reduced retransmissions and increased PDR. Using simulation technique to model adhoc networks, it is observed that route may be broken, as unstable links may get included in the route.

One possible solution to this problem is to choose a complete route that is most stable than other requesting nodes. The probability of successful transmission of packets has been employed to determine a stable route. The probability of each transmission for single hop is stored between communicating nodes and successful transmission probability is computed over a complete route. The route with maximum successful transmission probability is taken as the most stable route. Numerous simulation runs support our proposed techniques that perform better as compared to the existing protocols in terms of packet delivery ratio, average end-to-end delay and average route lifetime. In the study, optimization of route length is not taken into consideration, i.e., the path chosen may be of any number of hops.

The rest of the chapter is structured as follows. Section 4.2 discusses the proposed methodology of selecting a stable link and routes, among the set of available links between respective sender and receiver nodes. Section 4.3 describes the simulation set-up and analysis of obtained experimental results. Section 4.4 concludes the chapter with pointers to future work.

4.1 Stability based Multicast Routing Protocol: An Overview

Multimedia data transmitted in real time especially in the military applications such as border surveillance needs to support Quality of Service (QoS) metrics such as throughput, energy utilization, jitter. To support QoS, information like bandwidth, link delays, error rate, loss rate is required, which is difficult to ascertain because of continuously varying links due to dynamic topology, limited availability of resources like energy and bandwidth [86]. To achieve satisfactory QoS, routing protocols in MANETs should be able to deal with high mobility. Various metrics have been proposed to determine a stable link or a stable route to transmit the data packets to the destination successfully.

The fundamental idea behind considering link stability is to facilitate a protocol to select those channels that persist for longer periods of time. Link stability can be evaluated using parameters like the relative mobility of the nodes sharing the link [87], received power, the energy of nodes, signal to interference and noise ratio, congestion on the link and bandwidth of the link. Authors in [88] present a stable path metric called ETX, Expected Transmission Count, which searches high-throughput routes for data transmission. ETX is defined as expected number of transmissions (including retransmissions), a data packet would require to reach its destination node successfully. ETX can be calculated as a reciprocal of the product of the probability of successful packets received by the receiver and probability of ACK packets received successfully. The path with minimum ETX has been considered the highest throughput path. Based on ETX, another stability approach has been introduced, named as LCAR, i.e., Least Cost Anypath Routing [89]. This method focuses on choosing a route such that expected cost of relaying a packet to its ultimate receiver must be minimized. It is formulated for unicast transmissions, and this idea is extended over multicast transmission and named as M-LCAR [90] that stands for Multicast LCAR. A metric called multicast anypath cost is based on ETX and calculates the minimum cost to reach the destination using distributed Bellman-Ford algorithm [91][92]. The route with minimized cost of transmission is considered as a stable, high-throughput route. Although ETX and its extensions provided better throughput, they performed well only in case of static and low mobility scenario.

Another metric named as Mobility Factor (MF) introduced in [93] is used to calculate link stability in dynamic situations. Based on the symmetric difference of neighbors of a node in a specified time interval, generally a HELLO interval, MF is calculated. The node with least value of MF has been considered as a lesser mobile node and is assumed to form a more stable link. To calculate MF, a node has to maintain the history of neighbor nodes along with current neighbor node set. This leads to the problem of resource scarcity. Signal to Interference and Noise Ratio (SINR) [94] is introduced as a link stability metric to estimate a stable link in [95]. SINR is calculated using received signal strength and average noise level, during an idle period of a node. The node with the maximum value of SINR is considered to form stable links. The protocol performed well with link stability estimation, but some weak links might get included in the route construction process as route stability is not considered.

Contact based metric [96] estimates link stability on the basis of encounter rate. The encounter between two nodes happens when a node is in the transmission range of another node. More encounter rate reveals higher relative mobility and higher density of nodes and can be used to predict link stability. The contact-based metric is extended further to determine route stability [70]. A metric named as path encounter rate (PER), is exploited as a route stability metric. It is calculated as the sum of squares of average encounter rate for each node present on a respective route. The route selected with minimum value of PER shows elevated throughput. This metric performed well only in low mobility scenarios.

Received signal strength is also introduced as both link stability and route stability metric [97]. In this method, communication gray zone is first identified and then avoided. In communication gray zone, packet drop ratio is high due to unstable links. Signal strength is used to gather link related information and determine link stability factor employed for computation of route stability factor. The route with the maximum value of route stability factor is considered to be a stable route and selected for data transmission.

In MMRNS [19], authors proposed a multicast protocol for selection of reliable neighbor. They have enhanced the ODMRP protocol by applying link stability parameter (called Reliable Pair Factor (RPF)) using signal strength and node energy of requesting node. RPF is directly proportional to signal strength and residual energy. After estimating RPF for every requesting node, they pruned neighbors according to a threshold and established a reliable route with zero possibility of link failures.

In proposed protocol, the probability of successful transmission of periodic packets is used as a metric to determine link stability. It is assumed that if the probability is greater for a link, that link sustains for longer duration and hence, is stable. The link-related information is aggregated to assess route stability. Link stability information at each hop is taken into consideration to estimate route stability.

PERIODIC Packets In ad-hoc networks, connectivity is determined by sending HELLO packets to corresponding one-hop neighbors. It also update neighbor table periodically because of nodes mobility, HELLO packets are broadcast in the network. Various approaches have been proposed for enhancing the accuracy of network connectivity calculation through HELLO packets. In [98], the efficacy of HELLO packets to check connectivity is determined by implementing AODV protocol.

In traditional HELLO messaging approach, there is pre- or post- condition for sending messages. In addition, HELLO messages are to be sent at constant intervals. This unnecessary sending of packets leads to battery drainage when nodes are not communicating. Periodic HELLO packets create network congestion, consume additional bandwidth, resulting in a drop of control and data packets.

In this chapter, the application of HELLO packets to determine link stability is extended. A HELLO packet is sent at an interval of one second through each node in the network. The probability of successful transmission is calculated as the ratio of a total number of HELLO packets received at receiver node to the total number of HELLO packets sent by sender node at a specific interval of time.

4.2 Proposed Methodology

In this section, the proposed methodology based on network model for link and route stability is described.

4.2.1 Network Model

A mobile ad hoc network can be represented by an undirected and weighted graph $G(N, E)$, where $N = \{n_1, n_2, n_3, ..., n_n\}$ is the set of vertices that depicts mobile nodes building a network and $E = \{e_1, e_2, e_3, ..., e_m\}$ is the set of edges between those vertices that represents uni- or bi-directional links between a pair of adjacent nodes in the network. The network consists of a multicast source S, a set of multicast destinations $D = \{d_1, d_2, d_3, ..., d_p\}$ and a set of intermediate nodes $I = \{i_1, i_2, i_3, ..., i_q\}$ that act as a router. Each node is free to move in a fixed area A, has a limited range of transmission R and is identified by a unique id, i.e., multicast group IP address. A link $e_{u \to v} \in E$ between any adjacent nodes u and v exists when node u lies in the transmission range of node v. Stability of the link $e_{u \to v}$ depends upon relative movement of nodes u and v. The weight on a link signifies its quality like stability, bandwidth, signal strength etc.

In our model, weight represents successful transmission probability (p_e) of a periodic packet. A multi-hop route between a source and its receivers is a subset of a set of all the possible routes $R = \{R_1, R_2, R_3, ..., R_r\}$, that exist between these nodes. When source S desires to transmit data packets to a $d \in D$ via intermediate nodes $i \in I$, each intermediate node determines the value of successful transmission rate and assigns maximum to p_e for all incoming links. Link $e_{a \to b} \in E$ corresponding to maximum value of p_e, for any pair of adjacent nodes a and b, has been considered as the most stable link and added to the route. Furthermore, using values of p_e at each hop in the route, successful transmission probability (p_R) for a route (R) is determined. The consequential route $R_{s \rightsquigarrow d} \in R$ with maximum value of p_R has been picked as the most stable route.

4.2.2 Approach

As discussed in Chapter 2, ODMRP selects the path with minimum hop-count and does not consider dynamic network topology. Shortest path has its own advantages although, it may not select a stable path leading to disruptions and re-route initiations. The number of hops in a route is proportional to the number of transmissions required to transmit a packet to its destination successfully. Each transmission congests the medium, acquires some bandwidth, adds the delay in the network and expends energy. The shortest path cannot be considered as reliable due to the mobility of nodes. To minimize the hop-count, usually longer hops are included in the route, but they are likely to be less durable. One of the reasons for less durability of longer hops may be that the node included in the route is located at the periphery of the transmission range of previous hop node shown in the Figure 4.1; this phenomena is known as "edge effect" [99]. Any movement in the node can increase the possibility of the node to move out of the transmission range of preceding node and hence link failure. Therefore, in high mobility scenarios, it is necessary to choose a stable path than the shortest path.

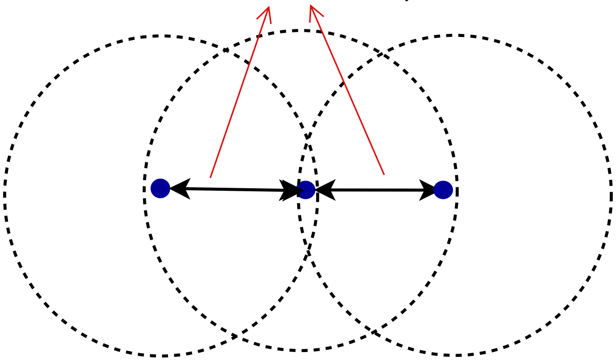

FIGURE 4.1: Edge effect (dotted circle indicates transmission range of a node shown as a circular dot)

Link stability, in our approach, is calculated from the probability of successful transmission of HELLO packets. On the basis of the number of HELLO packets received at each node, probability of successful transmission for that link is calculated. At each link, the probability of successful transmission p_{ij}, where i is the sender node and j is the receiver node. It can be computed using the following formula:

$$p_{ij} = \frac{N_{recv}}{N_{exp}} \tag{4.1}$$

where N_{recv} is the number of HELLO packets received at node j and N_{exp} is the number of HELLO packets expected to be received at a node j. The stability of the link is directly proportional to the probability of successful transmission, i.e., the maximum value of p_{ij} indicates the most stable link.

There are multiple possible paths between source and receiver node. For example, in Figure 4.2, consider a one-hop scenario of a mobile network. Here, node D can receive packets from nodes A, B and C. Weight on each link indicates its probability of successful transmission. Node A is forwarding a JOIN QUERY to node D at time $1ms$. Similarly, nodes B and C forward a JOIN QUERY to D at time $2ms$ and $3ms$ respectively. In conventional scheme of path-finding, only first QUERY received is processed and the respective link is selected. Therefore, JOIN

QUERY received from node A is accepted and processed, and all other queries are discarded, as shown in Figure 3.3(a). Node A is chosen as forwarding node and link formed by nodes A and D is considered suitable for data transmission.

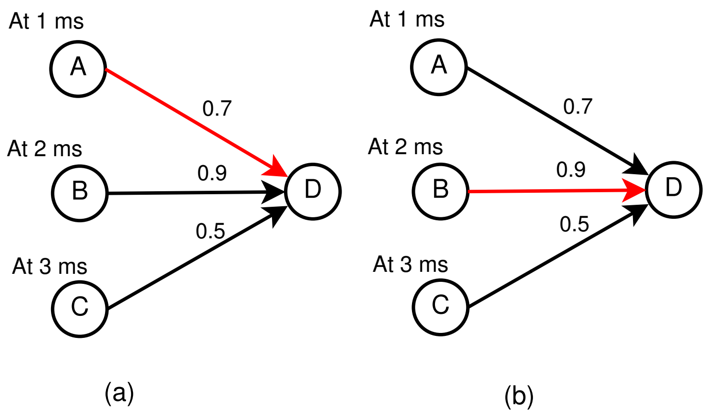

FIGURE 4.2: (a) ODMRP (b) Modified

In our approach, at each j node, p_{ij} of all links are compared, and link with maximum p_{ij} is selected and i node as previous-hop. Mathematically, it can be stated as $p_e = \max(p_{ij})$ and 'previous hop' $= \arg\max(p_{ij})$. Consider Figure 3.3(b), node D buffers all queries it receives, checks for the probability of transmission of a link from each sender node. Node B is chosen as a forwarding node as reception rate from its transmission is maximum among all three and rest two (A and C) are discarded. A link between node B and D is considered to be more reliable for data transmission.

Choice of a route with stable links increases the performance of the protocol. An elevated probability of transmission of packets from node B to D shows that the link is sustained for the longer duration. It can be inferred that node that remains in the transmission range of preceding node for a longer time is selected as a forwarding node. As hop-count is not minimized in our approach, the length of a route may increase. Increased length of route infers that smaller hops are selected, i.e., node remains well below the maximum transmission range of preceding node. Hence, nodes can move freely without breaking the route.

Consider an example as shown in Figure 4.3, where S is a source and R is the receiver along with intermediate nodes forming a mesh structure. The weight on each link signifies its probability of successful transmission and higher probability indicates the higher stability. At next-hop from the multicast source, the source itself is selected as previous-hop, so node A and B select S as previous-hop. Node D receives a query from both nodes A and B and selects node A as next-hop because of the higher probability of transmission. In case, if the probability of transmission coincides, query first received is considered. This process occurs at each node, and the more stable link is selected at each hop. The route $S \to A \to D \to G \to R$ is an example.

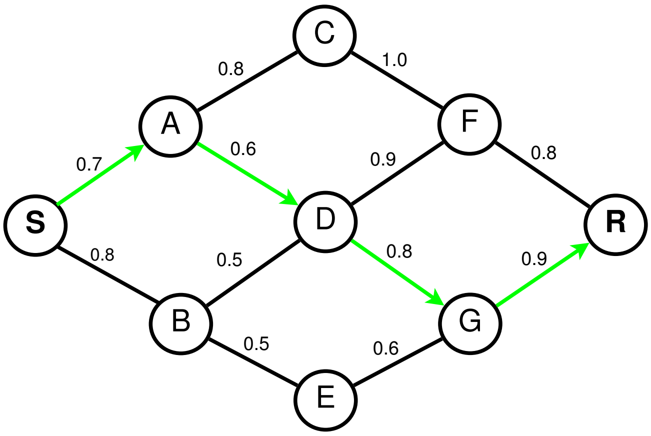

FIGURE 4.3: Route Selection based on Link Stability

Although choosing a stable link raises the stability of route; stability of the route is primarily governed by the least stable link of the route. As can be seen in the Figure 4.3, link $A \to D$ is a least stable link in the route. This may be due to enhanced distance between two nodes A and D, as explained earlier. One possible solution to this issue is to consider the stability of the whole route. The probability of successful transmission for all possible routes is calculated at each node and route with maximum probability is considered as more stable.

Let us look at a network as shown in Figure 4.4. Two possible routes can be observed between S and R. The probability for each link is as shown as weights in the Figure 3.3. Moving from S to A and then from A to R is an independent event, and the overall probability for route $S \to A \to R$ is given as:

$$p^{A}_{S \rightsquigarrow R} = p_{S \to A} \times p_{A \to R} \tag{4.2}$$

Similarly, overall probability for route $S \rightarrow B \rightarrow R$ is given as:

$$p^{B}_{S \rightsquigarrow R} = p_{S \rightarrow B} \times p_{B \rightarrow R} \tag{4.3}$$

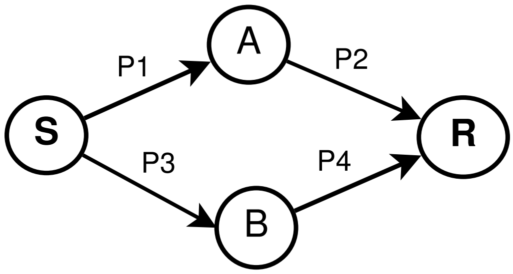

FIGURE 4.4: Probability Estimation Process

Probability at node R is compared and if $p^{A}_{S \rightsquigarrow R} > p^{B}_{S \rightsquigarrow R}$ is true, then route $S \rightarrow A \rightarrow R$ is selected as a reliable route, else $S \rightarrow B \rightarrow R$ is taken as reliable path and, the other paths are discarded. If a route consists of 'n' number of nodes and p_k is the probability of the k^{th} link on the route, then overall probability for the route is given by:

$$p_{route} = \prod_{k=1}^{k=n-1} p_k \tag{4.4}$$

Where p_{route} is the probability of successful transmission of a complete route between source and destination. The value of p_{route} is indicative of the stability of the route. Higher the value, higher is the stability. The maximum value of p_{route} indicates the most stable route.

Consider the same network in Figure 4.5. Here, an edge weight is a 2-tuple consisting of probabilities of the link as well as the route from a source node to current node. Path probability is shown in parenthesis. At the node D, the partial route with maximum probability is selected and rest are discarded. As a result, the partial route $S \rightarrow A \rightarrow D$ is selected at D. Similarly, at a node F, probability of partial route $S \rightarrow A \rightarrow C \rightarrow F$ is greater than that of the route $S \rightarrow A \rightarrow D \rightarrow F$, hence, partial route $S \rightarrow A \rightarrow C \rightarrow F$ is selected at F. The same process takes place at each node and finally at the receiver node, the probability of each route is computed, and a more reliable route is established as a result. The route $S \rightarrow A \rightarrow C \rightarrow F \rightarrow R$ is one such example that has maximum overall probability and contains more stable links.

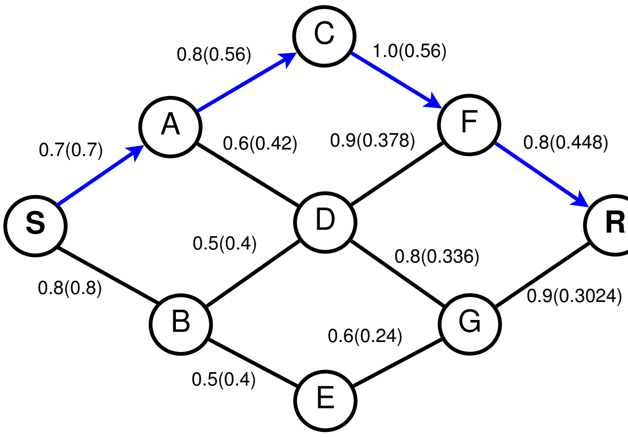

FIGURE 4.5: Route Selection based on Route Stability

4.2.3 Data Structures

The ODMRP protocol has to maintain the following data structures for routing mechanism:

Route Table: Each node creates and maintains routing table on demand. Entry in this table is done when a node receives a non-duplicate query. The table stores the address of the source node that creates JOIN QUERY and address of the last node that propagated JOIN QUERY. It provides information for next-hop during transmission of join replies.

Member Table: This table is maintained by each multicast group receiver. The multicast receiver stores the information regarding source in this table. The source Id and time when the last query received from that source is stored in the table. Within the refresh interval, if no query is received from a source, then its entry is removed from the table.

Forwarding Group Table: If a node is a forwarding group node, it maintains the group information in this table. The table stores multicast group Id and that time when node last refreshed.

Message Cache: Each node maintains this table to detect duplicate control messages. This table stores the source of JOIN QUERY and a unique identifier of the control packet. When a node receives a join query, it first checks this table and decides whether the received packet is duplicate or not. Algorithms such as Least Recently Used (LRU) or First In First Out (FIFO) can be employed to remove stale entries.

Besides, included two tables namely Msg_Cache and $Data\_HELLO$.

Msg_Cache Table: Each node maintains this table (empty initially) to store the information obtained from each query as explained in Algorithm 3. Fields of Msg_Cache are as shown in Table 4.1.

TABLE 4.1: Msg_Cache Table

S. No.	**Fields**
1.	Source Address
2.	Last Hop Address
3.	Sequence Number

This table has been maintained for two reasons. First, to store the address of preceding node, and second, to avoid duplicate entries of a query. Source address at each instant is stored to prevent ambiguous entries in case of more than one source.

Data_HELLO: Each node maintains the $Data\_HELLO$ table to store probability of successful transmission and preceding node to it. Fields of $Data\_HELLO$ are as shown in Table 4.2.

TABLE 4.2: $Data\_HELLO$ Table

S. No.	**Fields**
1.	Last Hop Address
2.	Probability

4.2.4 Methodology

In this section, our proposed approaches (Link Based and Route Based) and their algorithms are explained.

4.2.4.1 Link Stability Based Protocol

Each node generates HELLO packets every second and broadcast packet to next-hop, i.e., the neighbor node. These HELLO packets are ACK-free. If there are 'n' nodes in the network and each node sends HELLO packet at an interval of one second for simulation time 't', then each node sends a total of $(t-1)$ packets and a total of $n(t-1)$ packets in the network. Before sending JOIN QUERY, total number of HELLO packets received at each receiver node during last ten seconds are counted, and then probability at each link between respective sender node and receiver node is calculated using Equation (4.1). Each JOIN QUERY at receiver node through all possible sender node is buffered for the pre-set buffer time. After buffer time is over, link with maximum probability is selected, and the respective sender is selected as the previous-hop address. Detailed steps of our protocol are as follows:

1. Each node generates and sends a HELLO Packet at one second time interval.
2. HELLO packets received at each node are counted, the probability is calculated using Equation (4.1) and stored along with the sender address in $Data\_HELLO$.
3. Source node creates and broadcasts a JOIN QUERY in the network.
4. Intermediate node receives the QUERY and checks whether it is duplicate or not. The node discards duplicate QUERY.
5. For a non-duplicate QUERY, the node buffers the QUERY, stores the respective source address, last address and sequence number in Msg_Cache and sets a timer.

6. After the buffer time is over, the probability for each sender address is compared, and a node with maximum probability is selected as the previous-hop address.

7. If the computed probability is same for two or more nodes, preference is given on first come basis. Node sending in the first QUERY is likely to be nearest, and this link may sustain longer than others.

8. The broadcasting of JOIN QUERY continues until it reaches its final destination.

9. The destination node creates and unicasts the JOIN REPLY after selecting the route.

Algorithm 3 and 4 explain this steps in detail.

Algorithm 3 Buffer Join Query

Require: *Msg_Cache* {Buffer storage for Join Query}
Ensure: Buffer Join Query At Receiver Node

```
Set Msg_Cache = 0
while buffer time is not over do
    Receive query from neighbor and extract Source Address, Last Address and Sequence Number from received Join Query
    if Source Address and Sequence Number exist in Msg_Cache then
        Discard the query packet
    else
        Add above extracted information to Msg_Cache
    end if
end while
```

4.2.4.2 Route Stability Based Protocol

The probability of successful transmission, calculated at each link is further used to calculate the probability for a complete route between source and destination. As explained earlier, the probability of a route is a product of individual probabilities at each link that belongs to that route. For this, each node should store the value of probability calculated so far. HELLO packets are generated at each node and broadcast to the one-hop neighbor node, at an equal interval of one second. Before sending join query, the probability of each link can be calculated using Equation

(4.1) and is stored in the node. Each receiver node buffers the join query for a pre-set time interval, i.e., buffer time. When the buffer time finishes, the probability of current node's link is multiplied by previous hops' node probability. The maximum probability route is selected among all the requested routes and stored along with the respective node. This process is repeated at every node. Detailed steps of our protocol are as follows:

Algorithm 4 Selection of Forwarding Node

Require: $Data\_HELLO$ {storage for the probability of successful transmission of a link calculated using Equation 4.1 at each node along with sender address}
Msg_Cache
FG {Forwarding Group Node}
P {Probability}
Ensure:
Set $FG = 0$
Set $P_{max} = 0$
for each $LastAddress \in Msg\_Cache$ **do**
  if $LastAddress \in Msg\_Cache$ matches with $LastAddress \in Data\_HELLO$ **then**
    $P = Probability \in Data\_HELLO$
    if $P_{max} \lneqq P$ **then**
      $P_{max} = P$
      $FG = LastAddress \in Data\_HELLO$
    end if
  end if
end for

1. Each node generates and sends a HELLO Packet at one second time interval.
2. HELLO packets received at each node are counted, the probability is calculated using Equation (4.1) and stored along with the sender address in $Data\_HELLO$.
3. Source node creates and broadcasts a JOIN QUERY in the network.
4. Intermediate node receives the QUERY and checks whether it is duplicate or not. If duplicate, then discards the QUERY.
5. If not duplicate then each node sets a timer and buffers the QUERY, stores the respective source address, last address and sequence number in Msg_Cache.

6. After the buffer time is over, the probability of partial route at each previous node is extracted, and overall probability of the partial route up-to-current node is calculated using Equation (4.4).

7. At receiver node, the partial route with maximum probability is selected, and the respective value of probability is stored with the current node.

8. If probabilities for two or more nodes coincide, then first received QUERY is considered.

9. The broadcasting of JOIN QUERY continues until it reaches its final receiver.

10. The final receiver creates and unicast's the JOIN REPLY after selecting the route.

The process is illustrated in Algorithm 3 and 5.

Algorithm 5 Selection of Stable Route

Require: $Data\_HELLO$ {storage for probability of successful transmission of a link calculated using Equation 4.1 at each node along with sender address}
Msg_Cache
FG {Forwarding Group Node}
P {Probability}
R_{max} {Maximum probability for a partial route at previous node calculated using Equation 4.4}
Ensure:
Set $FG = 0$
Set $P_{max} = 0$
Set $R_{max} = 1$
for each $LastAddress \in Msg\_Cache$ **do**
  if $LastAddress \in Msg\_Cache$ matches with $LastAddress \in Data\_HELLO$ **then**
    $P = Probability \in Data\_HELLO$
    $P = P \times R_{max}$
    if $P_{max} \lesssim P$ **then**
      $P_{max} = P$
      $FG = LastAddress \in Data\_HELLO$
      $R_{max} = P_{max}$
    end if
  end if
end for

Algorithm Correctness Proof In the proposed algorithms, we are showing the execution procedure. Algorithm 5 is taking input of probability of n requesting nodes that wanted be part of forwarding group (FG) and calculate the probability of stable route. We have provided the example in different input probability in Figure 4.5. Time complexity of the algorithm is dependent on the number of nodes in the stable route i.e. O(n), n is number of requesting nodes.

4.3 Performance Evaluation

Performance evaluation is a major part of this research. Our proposed approaches have compared with existing work for validation of our approach. Packet Delivery ratio, Average end-to-end delay, average Route Lifetime, control overhead and memory overhead have used as performance metrics for evaluation.

4.3.1 Simulation Environment

All simulations have been carried out on EXata/Cyber v2.0 [84] simulator, on a network of 50 nodes over topology area of 1000×1000 square meters. EXata/Cyber software is a combination of the EXata emulation and simulation tool plus Cyber behavior libraries. A multicast group of ten members with one source is simulated. Each multicast member can join the group at any time during the simulation. Node placement is random. As traffic source, MCBR (Multicast Constant Bit Ratio) is used that sends data packets at a rate of 33 packets per second, approximately. Each simulation is made to run for 500 seconds. Our protocol is tested for networks with node mobility ranging from $0 - 30$ m/s. Parameters set for simulation are shown in Table 4.3. The efficiency of our approach is evaluated by comparing its results with those of ODMRP, EODMRP and MMRNS concerning performance metric as detailed below. On this simulation test bed several simulation runs were conducted to obtain statistical valid and consistent results of performance parameter and QoS with different input sets.

TABLE 4.3: Simulation Parameters

Simulation Parameter	**Value**
Simulator	EXata/Cyber v2.0
Simulation Time	500 Seconds
Number of nodes	50
Scenario Dimension	1000 × 1000 sq. meter
Radio Type	802.11a/g
Mobility Model	Random Way-Point Model
Mobility	0-30 m/s
Pause Time	10 seconds
Routing Protocol	ODMRP
Traffic Type	MCBR
Size of Packet	512 bytes
Data Rate	24 Mbps
Total Packets sent	16300 packets
Multicast Group Size	10

4.3.2 Results Analysis

This subsection gives a detail explanation about our results and their inferences. This is explaining the effect of each performance metrics by varying node mobility with previous proposed approaches. Our method is evaluated based on the following metrics:

4.3.2.1 Packet Delivery Ratio

It is defined that the ratio of the total number of data packets received at multicast receivers to the total number of data packets sent by the multicast source. Increased PDR reflects the effectiveness of routing techniques in multicast routing protocols.

In Figure 4.6, we shows PDR versus node mobility for protocols such as ODMRP, EODMRP, MMRNS and link and route stability protocols. Simulation parameters are shown in Table 5.5. It is observed from the Figure that, at zero or no mobility, PDR for ODMRP is relatively high. As the mobility of nodes begins to rise, PDR reduces. It can be inferred that to minimize the total hop-count of a route, longer hops are being selected. As the random movement in nodes increases,

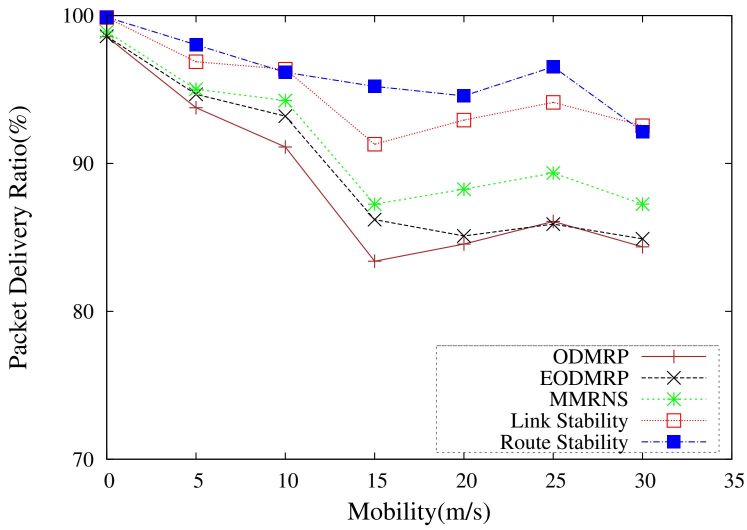

FIGURE 4.6: Packet Delivery Ratio(%) with Mobility(m/sec)

nodes reach at the periphery of the preceding node rapidly. As a result, chances of link breaks are more frequent. In case of EODMRP, as the refresh interval is adapted dynamically and discovery of appropriate forwarder node when any node gets detached from the network before the route refreshes, the network connectivity becomes more dynamic. This leads to improvement in PDR to some extent, as can be seen in the Figure. With the increase in mobility speed, the PDR drops swiftly and becomes almost equivalent to ODMRP. The reason for this drop is that the protocol does not consider link or route stability, as dynamic route refresh interval does not guarantee stability of the link or a route.

MMRNS estimates stable link based on received signal strength and energy of nodes. The Figure 4.6 shows enhanced PDR in MMRNS in contrast to ODMRP and EODMRP because MMRNS considers link stability. With the increase in mobility, the pattern of non-pruned nodes changes which necessitates the creation of different multipath sets. This further increases control overhead and computation overhead which leads to packet drop. As expected, PDR increases in cases of link and route stability based protocols. It can be seen that at zero mobility, PDR rises as compared to ODMRP, EODMRP, and MMRNS. Route stability based protocol performs best among all. As the path is more reliable, more data packets are transmitted successfully before the route refreshes and hence, results in improved

PDR. With increase in mobility, although PDR starts reducing but both of our proposed protocols perform better than other three protocols.

PDR is quite high in case of both link and route stability based protocols in contrast to rest of the three because our protocols chose those links that have the maximum probability to remain connected for a longer duration. Additionally, when a link fails, no extra control packets are relayed in the network, and no additional computation is needed in case of our protocols. It is also observed from the Figure that route stability based protocol shows highest PDR and link stability based protocol lags behind it. This protocol uses link stability information and discovers a route that has the highest probability to remain connected for longer duration and avoids weak links. With the increase in mobility, there is a rapid decrease in PDR in the case of ODMRP, EODMRP, and MMRNS and considerable fall in case of link stability based protocol followed by a steady decrease in the event of route stability based protocol. To summarize, our protocols performed far better than ODMRP, EODMRP, and MMRNS and among our both protocols, route stability based protocol outperforms both of them. The performance of the

Table 4.4: PDR improvement in % compared with ODMRP

Node Mobility	**EODMRP**	**MMRNS**	**Link Stability**	**Route Stability**
0	0.03%	0.33%	1.32%	1.34%
5	0.97%	1.33%	3.32%	4.53%
10	2.29%	3.45%	5.77%	5.54%
15	3.37%	4.63%	9.49%	14.17%
20	0.65%	4.39%	9.91%	11.85%
25	-0.21%	3.80%	9.35%	12.15%
30	0.64%	3.43%	9.71%	9.25%

various routing protocols is summarized in Table 4.4.

4.3.2.2 Average End-to-End Delay

End-to-end delay is defined as the delay between the time when a sender sends a packet and time when multicast receivers receive it. Average of delays of all packets received yields average end-to-end delay. The time elapsed for route creation or recreation is also included in end-to-end delay. For a routing protocol to be efficient, the end-to-end delay must be less.

In the Figure 4.7, we shows a variation of end-to-end delay against node mobility for ODMRP, EODMRP, MMRNS and link and route stability protocols. It is worth noticing, in this case, that the time elapsed for retransmissions (required for packets to get delivered to multicast receiver successfully) and for route reconstruction (when route breaks because of link failures) are all included in end-to-end delay. It can be observed from the Figure that with an increase in mobility,

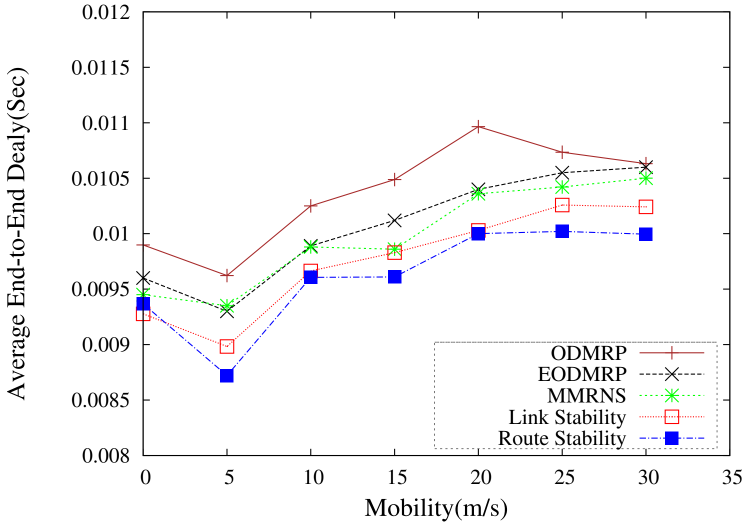

FIGURE 4.7: Average End-to-End Delay(sec) with Mobility(m/sec)

end-to-end delay increases considerably. As discussed earlier, with the increase in mobility of nodes, there are elevated chances of link breakage, resulting in route failure and requiring more frequent route reconstruction. As the route breaks, the probability of retransmissions also rises. Consequently, more time is elapsed in delivering a packet to its destination.

It is observed that end-to-end delay in case of our proposed protocols shows significant decline as compared to ODMRP, EODMRP and MMRNS. Longer delays in cases of ODMRP and EODMRP is due to both the protocols omit the stability concern and discover the paths that, more likely, get disconnected. In the case of MMRNS, end-to-end delay is lesser in contrast to ODMRP and EODMRP because this protocol focused on stable links. While discovering new or different multipath sets, delay increases due to extra computation and control messaging.

Link stability based protocol discovers the path that consists of most stable links; this reduces the route failure possibility. As a result, the overhead of route reconstruction is smaller, and this offsets increase in latency because of selection of the non-minimal but stable path. Hence, overall latency averaged over simulation cycles is smaller than other three protocols.

TABLE 4.5: End-to-End delay improvement in % compared with ODMRP

Node Mobility	EODMRP	MMRNS	Link Stability	Route Stability
0	3.01%	4.53%	6.28%	5.36%
5	3.36%	2.84%	6.65%	9.37%
10	3.52%	3.62%	5.73%	6.28%
15	3.51%	5.99%	6.28%	8.37%
20	5.15%	5.52%	8.53%	8.80%
25	1.71%	2.92%	4.43%	6.65%
30	0.30%	1.23%	3.66%	5.98%

In Figure 4.7, we also shows that delay is least in the case of route stability based protocol. Because this protocol aims at finding the most reliable route and avoids weak links in its path, the probability of route failure in this case, is much lower as compared to ODMRP and even to link stability based protocol, hence the lower rate of route recreation. At 5 m/s, there is a dip in delay. Due to random mobility, nodes may have approached each other, and thus, connectivity may have sustained for the longer duration. It can be seen that at 0 m/s and 20 m/s, the delay is more in the case of route stability as compared to link stability based protocol, but its overall performance leads over link stability metric. The reason is that time to determine route also constitutes an overhead, which is a sizeable portion of time at low node mobilities. The results of the performance of the various algorithm is summarized in Table 4.5.

4.3.2.3 Average Route Lifetime

It is actual duration of route is remain connected before the next route reconstruction occurs. This metric reflects the stability of constructed paths. Longer duration of route indicates more stable path. It is usually measured in seconds and gets adversely affected by an increase in node mobility. For a routing protocol to be effective, it is important that a chosen path must last longer. If the route fails immediately after its creation, all efforts to create route is wasted and yield poor performance.

This value shows the period of usability of a route. The lifetime of a link begins when a node is detected by another node in its transmission range and lasts until the node remains in this range without breaking the route. Active duration of

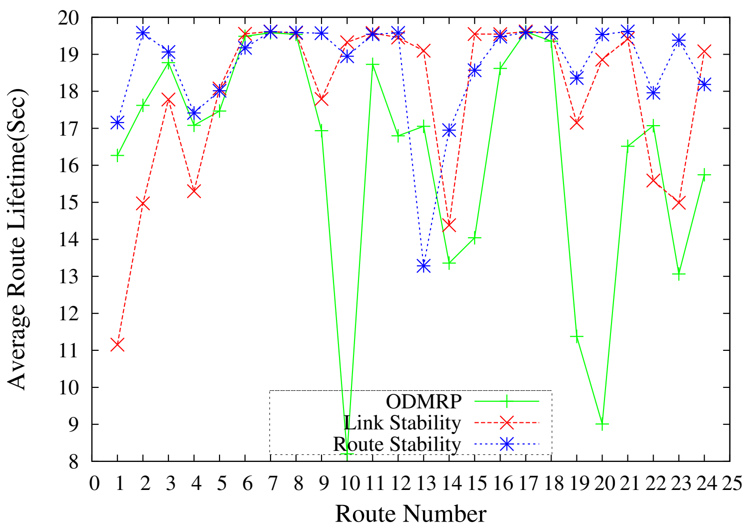

Figure 4.8: Route Active Time with Mobility(14-15 m/sec)

a link or a route depends indirectly upon the mobility of nodes and directly on the range of transmission of nodes. Networks with less transmission range usually have smaller route lifetime. All nodes have same transmission range is assumed in this approach, so the effect of transmission range is not considered. At zero (no) or low mobility, links sustain for a longer duration, due to increased time of encounter of nodes. With the increase in mobility, encounter a period of nodes reduces and hence the average link lifetime lowers.

In Figures 4.8 and 4.9, we show the variation of average route lifetime against node mobility at 14-15 m/s and 29-30 m/s respectively. Sudden ups and downs in the lifetime are due to random mobility of nodes. On comparing the results obtained, it can be observed that the average route active duration decreases considerably as mobility increases from 0 to 15 m/s. Further, increase in mobility affects the lifetime of route but at a low rate. As can be seen from the Figures, average lifetime of all 24 routes formed in both types of protocols is higher in the case of

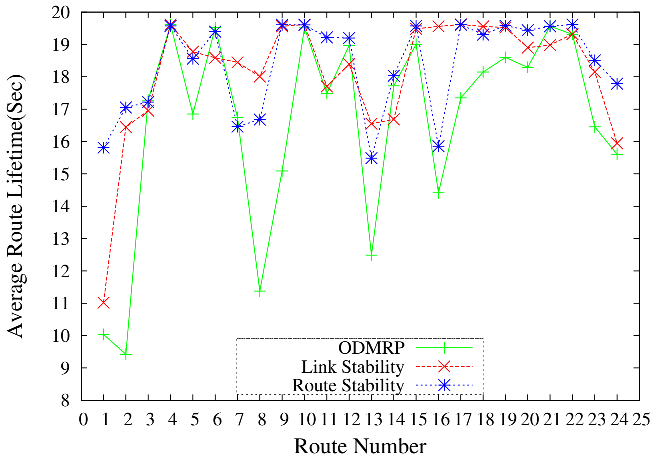

FIGURE 4.9: Route Active Time with Mobility(29-30 m/sec)

node speed at 14-15 m/s as compared to node speed at 29-30 m/s. Both Figures show that our protocol has the highest route lifetime and ODMRP lags far behind it. As already explained, our protocol discovers those paths that have a maximum probability to stay connected for long. It is, then, obvious that route will remain active for the longer duration.

At mobility 15 m/s, the minimum route lifetime reduced to 8 and 9 seconds at routes 10 and 20 respectively, in the case of ODMRP, which has enhanced to 13 seconds in case of route stability. Similarly, at mobility 30 m/s, in case of ODMRP, at 1^{st}, 2^{nd}, 8^{th}, 13^{th} route reconfiguration, route broke immediately due to less stable links. This number reduced to one (1^{st} only) in case of link stability based protocol and all routes sustained for long with a minimum route lifetime of 15-16 seconds in case of route stability. It can be inferred that among our proposed protocol, route stability based protocol leads to link stability based protocol at some mobility conditions.

4.3.2.4 Control Overhead and Memory Overhead

Control overheads are estimates the control packets transmission, required for route establishment in data communication. It is calculated as:

$$Control\_Overhead = control\_packets/(data\_packets + control\_packets) \tag{4.5}$$

In the proposed approach, minor insignificant differences is observed in the control overhead, that is shown in Table 4.6. The results based on node mobility, total number of nodes, and number of destinations are summarized in Table 4.6. Control overhead will almost same in each mobility scenarios because their is no effect of node mobility to the control overhead. In each mobility scenario, total number of transmitted control packets are equal; undependable to link and route failures. In second case (i.e. total number of nodes), JOIN QUERY and JOIN REPLY packet have transmit to each intermediate node, till the packet not reach to destination. So if the total number of nodes is increasing in a particular scenario, it obviously increase the control overhead of network. In third case (i.e. Destination node), generally control packets are same in each scenario because it is multicast networks. Few intermediate node will generate additional control overhead. In proposed technique, their is a difference is occurred due to periodic packets that is sent by each Forwarding group nodes to estimate the reliable node for communication.

Memory overhead is the additional memory required to store temporary data in data communication. It includes various types of information like IP packets, hop-count, signal strength, multicast group address, source address. Here, memory overhead can categories in various subtypes like protocol overhead, data structure overhead, and method call overhead. It can reduce all the overhead by using alternate techniques like bigger packet size, using array in place of link-list data structure and by using single function in the complete program in place of multiple functions. This shows that in our proposed methodology, there is no significant impact (change) on memory overhead in comparison with existing protocols. Single extra variable have taken to store the link probability, i.e. shown in Table 4.6.

TABLE 4.6: Control and Memory Overhead

Effective parameter		**Control Overhead**		**Memory Overhead**	
		Existing	Proposed	Existing	Proposed
Node Mobility	$0m/s$	6.14%	7.97%	$1KB$	$1.1KB$
	$10m/s$	6.32%	8.23%	$1KB$	$1.1KB$
	$20m/s$	6.64%	8.41%	$1KB$	$1.1KB$
	$30m/s$	6.59%	8.44%	$1KB$	$1.1KB$
Number of Nodes	50	6.53%	8.01%	$1KB$	$1.1KB$
	75	9.59%	11.12%	$1.5KB$	$1.65KB$
	100	12.05%	14.65%	$2KB$	$2.2KB$
Number of Destinations	5	3.96%	4.59%	$1KB$	$1.1KB$
	10	6.12%	7.89%	$1KB$	$1.1KB$
	15	9.43%	11.23%	$1KB$	$1.1KB$

In the table, the link and route stability algorithm are not considered separately as there is no significant difference in their overall control and memory overhead metrics.

4.3.3 QoS on Streaming Data

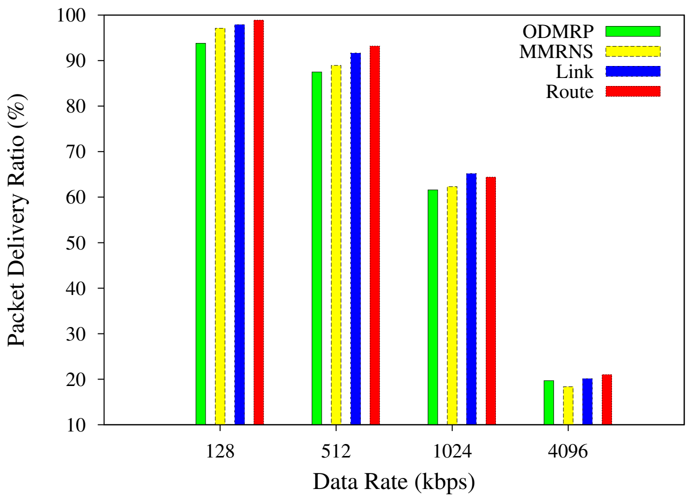

FIGURE 4.10: Effect of different data rate on PDR

Now, the packet delivery ratio has been plotted for different data rate that is used in streaming video [100]. It is giving the comparative analysis of proposed protocols and ODMRP on $128kbps$, $512kbps$, $1024kbps$ and $4096kbps$ data rates and proposed routing protocols give high PDR as compared to ODMRP as shown in

Figure 4.10. For less data rate, the throughput is higher; as data rate is increasing the packet delivery ratio is decreasing. If data rate is increasing from 128*kbps* to 4*mbps*, the PDR is decreasing from 93% to 17%.

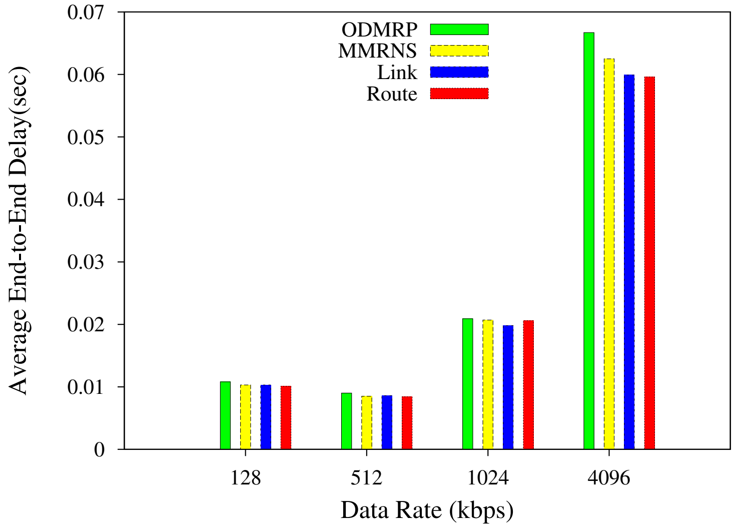

FIGURE 4.11: Effects on Average End-to-End Delay with different data rate

As PDR is shown with different data rates in the above diagram, average end-to-end delay is also presented in Figure 4.11. Delay is getting much higher at high data rate as compared to low data rate because of congestion on the links. Both proposed protocols outperforms the existing protocol, for link and route stability based protocol it is more or less same.

4.3.4 Inferences

1. The proposed protocol discovers a route for data transmission that includes the most stable link at each hop. This idea is further extended to discover a stable route using information of link stability.

2. Proposed protocol is analyzed by comparing the obtained results with that of ODMRP, EODMRP, and MMRNS. The system parameters used for our comparative study are PDR, average end-to-end delay, average route lifetime, control overhead and memory overhead.

3. Route stability based protocol focused on stability of a complete route, while link stability protocol emphasized on the most stable link at each hop, MM-RNS estimates a stable link based on received signal strength and energy of nodes and ODMRP and EODMRP, considered the minimum hop-count path.

4. As the complete route is stable, chances of route failure are least in the case of route stability as compared to other protocols and are highest in the case of ODMRP and EODMRP. MMRNS considers link stability, but the process of route reconfiguration increases computational and control overhead. Thus, it can lead to packet drop and increase in delay. Hence, it is expected that PDR and route lifetime would be highest and end-to-end delay would be minimum in case of route stability based protocol, followed by link stability based protocol and would be least and highest respectively in the case of ODMRP, EODMRP, and MMRNS.

5. On comparing the obtained results, it is observed that route stability based protocol showed the best performance in terms of higher PDR, lower average end-to-end delay, longer route time and a little overheads, followed by better performance in the case of link stability based protocol, MMRNS, ODMRP and EODMRP lagged behind other protocols. In the case of rising node mobility, the performance of our protocols is lowered but still better than rest of three.

6. It can be inferred from our experiments that a dynamically adapted route refresh interval does not guarantee a stable link. Emphasizing on a stable link can improve the throughput but selecting a stable route yields better performance as compared to stable link.

7. While considering link stability, there may be a possibility of involvement of weak links in the route. Because of rapid and unpredictable changes in network topology, this possibility increases. The unstable link in a route increases the chances of a route failure. As a result, all efforts to discover a stable route would be futile. Hence, it is better to consider route stability issues and pick a route that is more durable.

4.4 Summary

In this chapter, a link stability based protocol has been proposed to identify a a stable link among a set of all possible links from the sender to the receiver node. Selecting a stable link at each hop leads to a reliable path. The proposed protocol discovers a stable path that consists of comparatively more stable links. The application of HELLO packets is extended to determine a stable link. The link with the maximum possibility of successful transmissions of HELLO packet is considered to be the more stable and durable link and hence included in the route. This link stability information is then used further to figure out a stable route. To find out a stable route, probability of transmission for a complete route is calculated and the route with maximum probability of transmission is selected as the most efficient route. Comparing the results obtained from various simulations revealed that our protocol outperforms ODMRP, EODMRP, and MMRNS on grounds of Packet Delivery Ratio, Average end-to-end delay and Average route lifetime.

In this proposed work, a single QoS metric is used in estimation of link and route stability for reliable route discovery. A single metric is not able to handle all ups and downs, however, fails to encapsulate nuances of the transmission characteristics. For example, signal strength is used as a QoS metric for route construction, then it is possible that route has high hop-count. In the next chapter 5, a multi-parameter approach is presented to address this issue.

Chapter 5

Multi-constraints link stable multicast routing protocol in MANETs

The chapter introduces a QoS aware routing metric that determines a reliable forwarding node based on Link Stability cost Function (LSF). Most of the routing protocols proposed, so far, are based on hop-count metric. These consider minimum hop count path, i.e. shortest path as the feasible one and ignore the stability concerns. Link stability is the capability of a link to stay connected for a longer duration. Longer the link duration, higher is the stability of a link. Link stability gets affected by node mobility, available bandwidth, residual energy of nodes, etc. These factors may lead to link breakage and route reconfiguration. Therefore, a more stable path should be preferred over a shortest path. In the last chapter, we have estimated link and route stability for route discovery process. A single parameter is not able to find the reliable path for communication process. If a node has high number of neighbors then the node have high choice to select the node for reliable route but it could also generate high disturbance in the communication.

The objective for this chapter is to introduce a QoS aware metric that determines a stable link among all incoming links based on link stability factor. The proposed metric is adaptable to densely distributed networks and assures an economic use of bandwidth. Our proposed algorithm is found to perform better than an existing mesh-based multicast routing protocol, ODMRP.

The main contribution in this chapter is a QoS-aware metric has been proposed to determine a stable link based on link stability factor or LSF. The stability factor has been estimated using contention count, received signal strength and hop count as QoS parameters. Contention count is the number of nodes that lie within the transmission range of any node. It has been determined by sending periodic packets to one hop neighbors. The sender node, in turn, receives periodic packets from all the adjacent nodes and determines the number of its neighbors. The node estimates the received signal strength using cross-layer interaction approach. The node with the maximum value of link stability factor has been selected as the forwarding node. In last, the impact of minimum and maximum contention count on PDR and latency has been investigated. Simulations have been performed on Exata/Cyber v2.0 simulator over a network of mobile nodes with varying mobility. Experimental results obtained from simulations are compared with that of ODMRP, LSMRP and MMRNS, and the comparison verifies that our proposed algorithm is more efficient regarding PDR, end-to-end delay and average route lifetime.

The rest of the chapter is structured as follows. Section 5.1 describes a brief overview of various types of routing protocols, followed by related work concerned with QoS-aware routing. Section 5.2 presents our proposed methodology to find a stable link using LSF as a QoS-aware metric along with the algorithm. Section 5.3 discusses the experimental set-up and analysis of obtained simulation results. Section 5.4 concludes the chapter with pointers to future work.

5.1 Related Work

Due to the highly dynamic topology of the network, routing is a challenging task in MANET. A large number of routing protocols for multicasting has been proposed for MANET with an aim to discover a reliable path for data transmission between source and destination with reduced transmission overhead and optimized resources consumption. On the basis of the way how routing information is obtained and maintained, multicast routing protocols are categorized as Proactive, Reactive, and Hybrid [101], [22]. Mesh-based protocols are resilient to link failures as they maintain redundant paths between source and destination by forming a mesh structure. The major drawback of mesh-based approach is that redundant control or data packets travel along the network as these packets are broadcast along the mesh of paths. If the network is large in size or it has high mobility then overhead increases and throughput decreases. Reactive mesh-based protocols are efficient than proactive as the process of route discovery initiated on demand and avoid unnecessary routing updates [23]. Some of the reactive mesh-based routing protocols proposed for MANETs are On-Demand Multicast Routing Protocol (ODMRP) [16], [13], [36], Enhanced-ODMRP [17], BODS [26], CQMP [27], etc. The main advantage of ODMRP is that it produces higher throughput even under high mobility conditions. The drawback of this protocol is high overhead with network size. With the frequent re-routing, control overhead increases further. Therefore, more stable link should be given preference.

Various QoS aware routing metrics have been proposed to determine stable link. The ultimate goal of all stability based protocols is to discover the long-lived routes, the difference lies in the algorithms to estimate stability. Paper [102] proposed residual lifetime of a link as a stability metric. Residual lifetime of a link is a function of mobility speed and pattern, age of current link and its value has been determined as average lifetime of all the incoming links having duration above A minus $Avg(A)$, where A is the age of the current link. However, to calculate residual lifetime of a link, effect of speed and mobility pattern of nodes on residual lifetime is first investigated and then residual lifetime is determined, which increases computational complexity on a node. Path Encounter Rate (PER) has been considered as stability metric in paper [70] that is based on the concept of encounter. Encounter between any pair of adjacent nodes happens if those nodes are in transmission range of each other. The key idea behind the estimation of link stability is prediction of node mobility. New encounters to a node are recorded per unit time and is termed as Average Encounter Rate (AER) that signifies relative speed of node with respect to its adjacent nodes. Based on AER, PER is calculated and the path with minimum value of PER has been deemed as stable path. The path selected includes node with minimum mobility and density. It is clear that less mobile nodes form more stable links but nodes with less dense neighborhood have less chance of redundant paths to receiver which may reduce throughput because of routes being disconnected and refreshed. The scaling of throughput with increase in number of nodes in the network has been demonstrated in paper [103]. Following the model presented in [104], they identified deterministic properties regarding the location of nodes in respect of throughput. The paper also analyses the properties for node distribution in the network that can influence the throughput growth.

Impact of node density on throughput and delay has been discussed in paper [105]. This paper analyses the relation between hop progress and node density and concludes that higher node density results in reduced hop count. At the same time, higher node density induces contention between neighbor nodes. Routing algorithms in MANET must be capable to cope with three challenges such as contention, congestion and connectivity [106]. The paper compares routing performances of three types of routing protocols such as DSR, AODV and TORA. These protocols show increase in PDR with rise in number of nodes in its transmission range and concludes that increase in number of nodes provides better connectivity in the network. A similar compared analysis of effect of node density on both proactive and reactive routing protocols has been given in paper [107]. Both types of protocols, i.e. DSDV and AODV, show increase in PDR and overhead and decrease in control packets in the network with increase in node density. Connectivity in the network depends upon the number of nodes per unit area (node density) [108]. Authors derive some mathematical expressions for node degree distribution in MANETs to estimate availability of a link. Degree of a node is the number of neighbor nodes within its transmission range. In MMRNS [109], authors present a multi parameters QoS technique to choose reliable neighbor nodes. Authors have estimated remaining residual energy and RSSI values of one-hop neighbors. On the basis of these parameters, Reliable Pair Factor (RPF) is calculated and less reliable nodes are discarded.

5.2 Proposed Methodology

In this section, we present a new metric called LSF (Link stability Factor) that is used for assessing QoS of link/route in proposed routing solution.

5.2.1 Network Model

A mobile ad hoc network can be represented by a undirected and weighted graph $G(N, E)$, where $N = \{n_1, n_2, n_3 \cdots, n_n\}$ corresponds to the set of nodes creating a network and $E = \{e_1, e_2, e_3 \cdots, e_m\}$ corresponds to the set of uni- or bi- directional links connecting those nodes. A mobile network consists of a multicast source S, a set of multicast receivers $D = \{d_1, d_2, d_3 \cdots, d_p\}$ and a set of intermediate nodes $I = \{i_1, i_2, i_3 \cdots, i_q\}$. Each node in the network is recognized by a unique ID called as node IP address, has the limited range of propagation 'R'. The number of nodes present in the transmission range of any node $n \in N$, excluding itself, is termed as *contention count* and is denoted by ρ. On the basis of the contention count, received signal strength and hop count, link stability factor (LSF) for a link has been calculated.

When any node u enters the transmission range of the node v, a link $e_{u \to v} \in E$ exists between those nodes and it sustains until u and v remain in the transmission range of each other. Stability of link $e_{u \to v}$ depends upon relative motion, available bandwidth and residual energy of nodes u and v. In our model, weights on the edges represent the value of LSF corresponding to the link. When node S intends to deliver data packets to any receiver $d \in D$, each intermediate node $i \in I$ compares the value of LSF for all incoming links to select reliable forwarding group member. Link $e_{a \to b} \in E$, in between any pair of adjacent nodes a and b, with maximum LSF value has been considered as the most stable link and added to the route.

Table 5.1: Symbols for Mathematical Formulation

Symbols	Value
N	Set of Mobile Nodes
n	Number Nodes
E	Set of links
m	Number of links
S	Source
D	Set of multicast Receivers
p	Number of Receivers
I	Set of Intermediate node(FG)
R	Propagation Range
CC/ρ	Contention Count
PPKTS	Periodic Packets
SS	Signal Strength
HC	Hop Count
LSF	Link Stability Factor
RSS	Received Signal Strength
$PPKT_{table}$	Contention Count Cache
$QPKT_{table}$	Query Packet Cache
QoS	Quality of Services
MRP	Multicast Routing Protocol
ARL	Available Route Lifetime
PDR	Packet Delivery Ratio
EED	End-to-End Delay

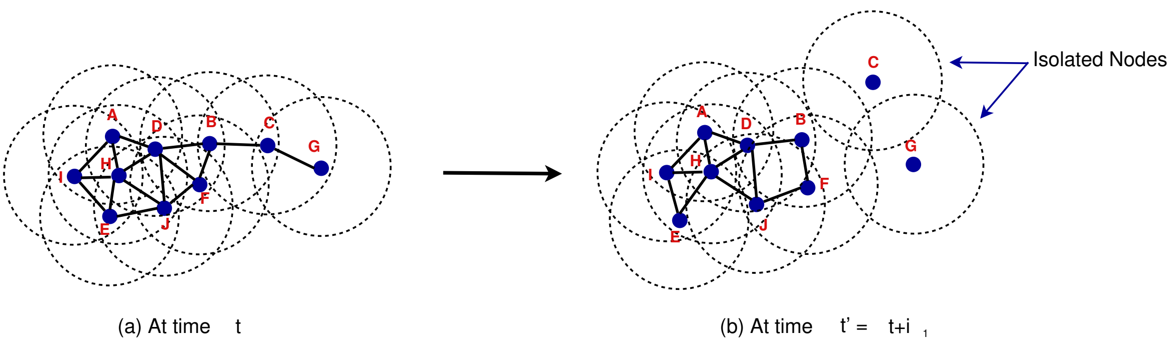

Figure 5.1: Modeling the topology of a MANET (a) Isolation of nodes

5.2.2 Proposed Technique

In this section, we propose a new QoS metric called LSF. This metric is a multi-objective cost function and is constructed from

1. Contention Count (CC)
2. Hop Count
3. Signal Strength

In the following subsection, we explain why each of the above component is needed, what should be the value of the component for better link/route quality and how does this affect overall metric.

5.2.2.1 Contention Count

Apart from node mobility, primary issue with MANET is QoS provisioning because of limited availability of bandwidth for wireless links. When mobile nodes are densely distributed in the network, a large number of nodes could possibly be present in the transmission range of a node. Every node in the transmission range of any node is potential candidate for contention and sharing of bandwidth for transmission. More neighbor nodes incur more contention for bandwidth among nodes. As the transmission medium is wireless, bandwidth available for transmission is less than that available for wired transmissions and any contention/sharing reduces the available bandwidth.. Since the wireless transmission relies on shared medium, MAC protocol coordinates the transmission from all mobile nodes in the network through explicit or implicit control messaging. This control messaging consumes additional bandwidth. Hence, to find a reliable path for transmission, available bandwidth with a node should be taken into consideration.

The primary goal of our proposed protocol is to discover a path that is not only the shortest but also has possibly the maximum bandwidth available for transmission such that the link availability in the network can be optimized. It is clear from the above description that presence of large number of nodes in a node's transmission range incur competition for bandwidth. It can be inferred that smaller contention count can reduce the competition for bandwidth and would provide a more reliable path. At the same time, a very low number of neighbors can reduce connectivity in the network which can trim down the throughput due to less number of paths available between source and destination. In addition, the node can be detached from the network. In Figure 5.1, we portrays an adhoc network with nodes having same range of propagation 'R' and are free to move randomly. Figure 5.1(a) depicts the topology of a well connected network at any time 't', i.e., a node is able to communicate with each node in the network. As illustrated, after a specific time interval 'i_1', the node C moves to a new location (Figure 5.1 (b)). This movement breaks the links $B \leftrightarrow C$ and $C \leftrightarrow G$ as the node C moves out of the range of both the nodes. Both the nodes C and G get isolated from the network. If the node G would have been one of the multicast destinations, there would not have been any route available to the destination.

Due to least number of neighbors, the connectivity among these nodes has been lost. In contrast, consider the same scenario in Figure 5.2 (a), in which a node D moves to a new location after a specific time interval 'i_2' (Figure 5.2 (b)). Due to this movement, links $D \leftrightarrow J$ and $D \leftrightarrow F$ fail. The node D remains connected to the network because initially, it had five neighbors. After its movement, it still has three more neighbors that ensure its connectivity. Similarly, node J changes its position and breaks its links with nodes H and D but its connectivity remains unaffected as it can still communicate with nodes E and F.

From the discussion so far, it can be concluded that the least contention count for a node can reduce path availability between source and destination and larger contention count increases competition for bandwidth between the nodes. Hence, instead of selecting first incoming node as forwarding group member, consider all adjacent nodes and selected the node with most favorable number of neighbor nodes as forwarding group member so that connectivity of the network can be well maintained and contention for bandwidth also reduces.

5.2.2.2 Received Signal Strength

Received signal strength has been used to predict the node with optimum number of neighbors. The median contention count is estimated using the maximum and minimum number of neighbors possible in the transmission range of respective requesting node. The node having contention count closer to the median value and having appropriate received signal strength would be selected as forwarding group member.

5.2.2.3 Hop Count

It has been observed that in the process of selection of most stable link, among all the incoming links, there may be a possibility that the resulting route is longer than the usual. The number of hops in a route is directly proportional to the number of retransmissions required by a packet to reach the destination successfully. Each additional retransmission consumes additional bandwidth and energy and increases transmission latency and error rates. To avoid the unnecessary consumption of bandwidth and energy, try to minimize the length of the route along with the discovery of a reliable route.

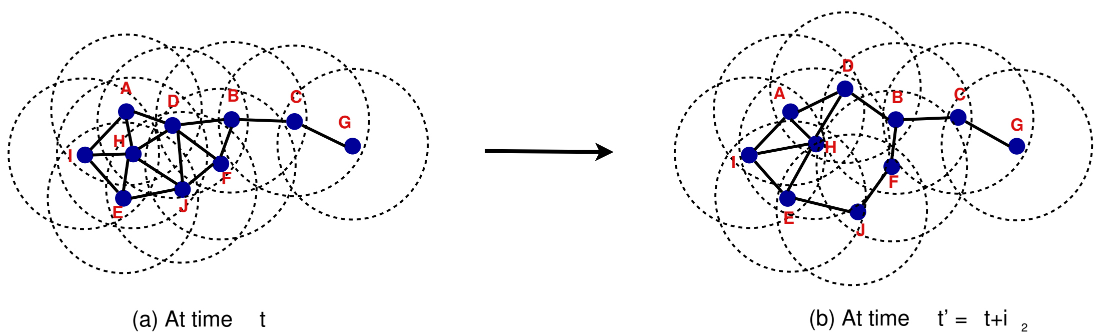

FIGURE 5.2: Modeling the topology of a MANET (b). Connectivity among nodes

The received signal strength, contention count and hop count have been mapped into link stability factor (LSF) to estimate the stable link for a durable route. Following sequence of operations have been executed to calculate LSF:

1. Determination of Contention Count

2. Estimation of Received Signal Strength (RSS) and Hop Count

3. Multi-objective Optimization by Normalization

4. Calculation of LSF

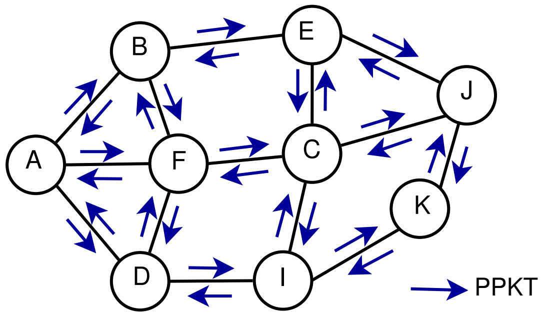

FIGURE 5.3: $PPKT$ Broadcast in the Network

5.2.2.4 Contention Count Estimation

To predict reliability, the node should possess knowledge about its neighbor nodes as well as received signal strength. The neighbor count can be determined with help of periodic packets. Periodic packets are simple packets that are employed to check connectivity in the network. Use of periodic packets transmission to collect information regarding neighbor nodes. As can be seen in the Figure 5.3, all the nodes in the network broadcast periodic packets ($PPKTs$) in its transmission range. As all the nodes broadcast the $PPKT$s, all the nodes, in turn, would receive the $PPKT$s from adjacent nodes too. For example, in the figure it can be seen that a node F broadcasts $PPKT$ to its adjacent nodes A, B, C and D and receives $PPKT$s from these nodes. On receiving the $PPKT$s from adjacent nodes, the receiving node makes entry of the respective sender node address in a contention set. The contention set is maintained by each node in the network and it stores the addresses of all adjacent nodes. The neighbor nodes for node F can be given by the contention set C_F:

$$C_F = \{A, B, C, D\} \tag{5.1}$$

Let $S = \{n_1, n_2, n_3..., n_i\}$ be the contention set of a node N, where n is the neighbor node and i is an integer. Then contention count (ρ_N) of a node N can be represented as:

$$\rho_N = |S| \tag{5.2}$$

where $|S|$ signifies the cardinality of contention set S. According to the Equation (5.2), contention count (refer to Figure 5.3) for node F is 4 and similarly all the other nodes can calculate their contention count.

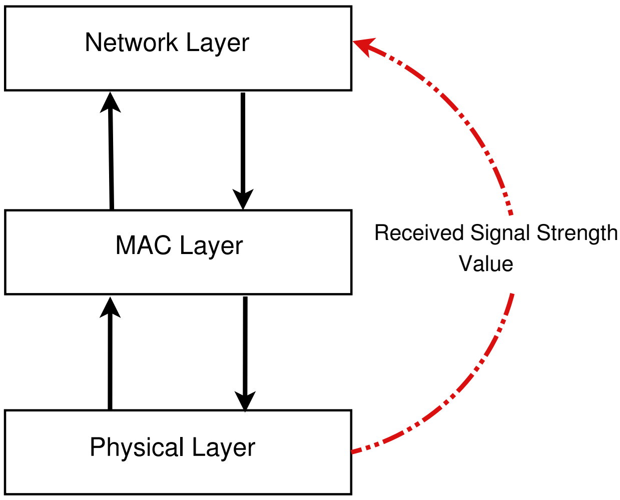

FIGURE 5.4: Cross-layer Interaction

5.2.2.5 Estimation of Received Signal Strength and Hop Count

The signal strength signifies the quality of the link between two adjacent nodes. Larger signal strength indicates lesser power loss (e.g. in the form of energy dissipated in the air) during the transmission and the quality of the link is considered to be strong and stable. It can be concluded that the received signal strength increases when any pair of adjacent nodes move towards each other and vice versa. Signal strength can be calculated as:

$$RSS = \frac{received\_power_{packet}}{noise} \tag{5.3}$$

A cross-layer approach [110–112] has been implemented to determine the magnitude of the signal strength at network layer. Each node in the network monitors the received signal strength from preceding nodes. The value of received signal strength on each packet transmission can be calculated at physical layer and transferred to the network layer through cross-layer interaction as shown in Figure 5.4. The signal strength is measured and stored at a receiving node.

The hop count is the number of hops traveled by a packet so far. Hop count of a packet increases by 1 on its every valid reception. It can be extracted from the control packet received. Hop Count use for calculate the number of intermediate node in the path. High hop count increases Average end-to-end delay (AEED) for transmitting streaming multimedia data, because it increases number of transmission in intermediate node.

5.2.2.6 Multi-objective Optimization by Normalization

For a link to be stable, its received signal strength must be maximum, contention count has to be a middle value and hop count must be minimum. Here, we have to optimize more than one objective that are conflicting. All these objectives cannot be satisfied with either a minimum or a maximum value simultaneously, so trade-off is needed. These type of problems are generally known as *multi-objective optimization problems*. Important issue in mapping these three parameters into one factor is the estimation of weights for multiple objective function optimization. The weighted sum method is unable to ensure and handle if an objective largely dominates the other. To avoid this situation, normalization method has used on all the three objectives. This is done in order to avoid any one of the objectives from dominating the other two. Various methods for normalization have been proposed in the literature. In the following considerations, let $f_i(x)$ be the objective to be normalized, $f_{i_{min}}$ and $f_{i_{max}}$ be the minimum and maximum values among a set of objective and $i = 1, 2, 3..., n$ be the number of elements in an objective set.

(a) ***Lower Bound Normalization:*** This approach divides each of the component objective by the minimum value attainable for that objective. It bounds the lower value to zero and upper value is left unbounded.

$$f_L = \frac{f_i(x) - f_{i_{min}}}{f_{i_{min}}} \tag{5.4}$$

(b) ***Upper Bound Normalization:*** This approach divides each of the component objective by the maximum value attainable for that objective. It bounds the upper value and lower value is left unbounded.

$$f_U = \frac{f_i(x)}{f_{i_{max}}} \tag{5.5}$$

(c) ***Upper-Lower Bound Normalization:*** This approach provides both upper and lower bound to the objective and can be calculated as:

$$f_{UL} = \frac{f_i(x) - f_{i_{min}}}{f_{i_{max}} - f_{i_{min}}} \tag{5.6}$$

In this type of normalization, the objective lies in between the range of 0 and 1, thus minimizes the chances of domination over other objectives.

5.2.2.7 Link Stability Factor

In the LSF, Upper-Lower Bound on signal strength and contention count and an Upper Bound on hop count have been applied. The normalized values of received signal strength, hop count and contention count have been mapped into a link stability factor (LSF) and using LSF, the stability of an incoming link has predicted. As discussed earlier, signal strength is directly related to the link stability and hence

$$LSF_i \propto SS_{norm_i} \tag{5.7}$$

where SS_{norm_i} is the normalized received signal strength at a node. For a protocol to be efficient, it must select a stable link while minimizing the route length. Therefore, for an efficient route, its hop count should be minimum.

$$LSF_i \propto \frac{1}{HC_{norm_i}} \tag{5.8}$$

where HC_{norm_i} is the normalized hop count at any node. From Equation (5.7) and (5.8), LSF_i can be written as:

$$LSF_i \propto \frac{SS_{norm_i}}{HC_{norm_i}} \tag{5.9}$$

The contention count should neither be too high nor be too low such that it can provide better connectivity in the network and at the same time, more contention-free route. In a network, the preferred value of contention count should be close to central tendency (or median). The median contention count (CC_{med}) is calculated using the following formula:

$$CC_{med} = \frac{CC_{norm_{max}} + CC_{norm_{min}}}{2} \tag{5.10}$$

where $CC_{norm_{max}}$ and $CC_{norm_{min}}$ are maximum and minimum normalized contention count. To select the node with median count from the set of contention count of various adjacent nodes, the difference between each element of contention set and median contention count must be minimized. This is done because there may be a possibility that the estimated median value may not coincide with any element in the set. To avoid this possibility, the value of contention count has taken with minimum difference. The difference can be calculated according to the following Equation:

$$CC_{diff_i} = |CC_{norm_i} - CC_{med}| \tag{5.11}$$

The absolute value of CC_{diff_i} is taken in order to avoid selection of contention count lesser than median count, so that connectivity in the network can be well maintained. Now, to get a maximum value of LSF using median contention count, the difference between LSF and median contention count must be maximum. Hence, using Equation (5.9) and (5.11), LSF_i can be calculated as:

$$LSF_i = \frac{SS_{norm_i}}{HC_{norm_i}} - CC_{diff_i} \tag{5.12}$$

Using Equation (5.11) and (5.12), LSF_i can also be written as:

$$LSF_i = \frac{SS_{norm_i}}{HC_{norm_i}} - |CC_{norm_i} - CC_{med}| \tag{5.13}$$

Each node calculates the value of LSF for all incoming links and the node with maximum value of LSF would be selected as forwarding group member. It is believed that the node with maximum LSF is able to create more stable link and can be added to the route. As hop count has been taken into consideration, the resulting route may be of optimized length.

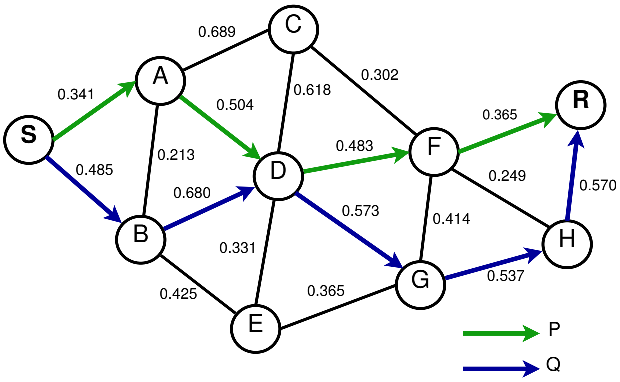

FIGURE 5.5: Shortest route (P) vs. Stable route (Q)

The complete mechanism for route creation, employing our approach, has been illustrated in Figure 5.5. Weights on the edges correspond to the value of $LSFs$ calculated. As can be observed in the Figure, a number of shortest paths exist between source (S) and one of the multicast receivers (R), but may not be the feasible ones because of less stable links en-routed. One such route is demonstrated by $P_{S \rightsquigarrow R}$. According to our approach, stable route has been determined using hop to hop stability based on LSF. The incoming node with maximum value of LSF is selected as next hop address at each hop, as shown in the Figure. One of the consequential route is depicted by $Q_{S \rightsquigarrow R}$.

5.2.3 Methodology

In the conventional scheme of route discovery by ODMRP protocol, the focus is merely on minimum hop count. To minimize the hop count, usually longer hops are selected [99]. It may be possible that the selected link is not a good quality link and can break in near future due to mobility. An approach is proposed in which instead of processing first received query packet, the receiver node receives query packets from all possible senders and estimates their LSF using received signal strength, contention count and hop count as parameters.

The node that aims at determining its contention count creates a $PPKT$ and broadcasts it to all the nodes in its transmission range. All the broadcasting nodes, in turn, receive $PPKTs$ from their respective adjacent nodes. The $PPKTs'$ receiver nodes then create a table ($PPKT_{table}$) and update source addresses for all received $PPKT$s. For example, considering the same network in Figure 5.3, structure of $PPKT_{table}$ for node C can be visualized as shown in Table 5.2.

Table 5.2: Structure of $PPKT_{table}$

Source Address	**TimeStamp**
E	t_1
F	t_2
I	t_3
J	t_4

Then, contention count at each node can be calculated using Equation (5.2). When the multicast source intends to send data packets to any receiver, it originates join query and broadcasts it in the network. Intermediate node receives the query packet and checks whether it is duplicate or not. Node discards the packet if it is duplicate. The non-duplicate join query from all the neighbor nodes is buffered at intermediate nodes for a specified duration of time termed as *buffer time*. The receiver node creates one more table ($QPKT_{table}$) and stores respective values for a received packet in the table. The various fields of $QPKT_{table}$ are as shown in the Table 5.3.

Normalized values of received signal strength and contention count have been calculated using Equation (5.6) and normalized hop count is calculated by Equation (5.5). When the buffer time finishes, using respective normalized values of received signal strength, contention count and hop count, Link Stability Factor is

TABLE 5.3: Structure of $QPKT_{table}$

S. No.	Packet Attributes
1.	Source Address
2.	Last Hop Address
3.	Sequence Number
4.	Received Signal Strength
5.	Contention Count
6.	Hop Count
7.	LSF

calculated for all incoming links. The receiver node compares value of LSFs for all sender addresses and selects the node with maximum value of LSF as next hop address.

As can be seen in the Figure 5.6, nodes A, B and C send query packets to node D. ODMRP selects node A as next hop address as it reaches to node D first. In our proposed protocol, instead of processing first received query packet from node A, node D buffers all the queries and using Equation (5.13), it calculates LSF_A, LSF_B and LSF_C for incoming nodes A, B, and C respectively, as explained above. In the figure, weights on the edges signify corresponding LSFs calculated. D compares the LSFs and selects node C as next hop address. If have a look at LSF values, node A has least LSF and node C has maximum LSF which indicates that the link $A \rightarrow D$ is a weak or unstable link while link $C \rightarrow D$ is a stable link.

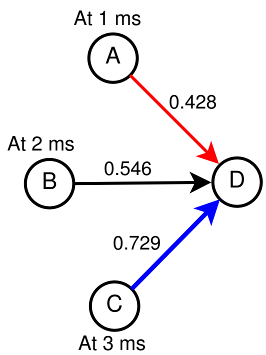

FIGURE 5.6: Estimation of Forwarding Group Member

After selecting and updating the next hop address in join query packet, the node rebroadcasts the join query and the same process repeats at each intermediate node until the query packet reaches the multicast receiver. When the query reaches multicast receiver, it creates join reply and broadcasts it. On receiving the join reply, the receiver node checks the entry of next hop address. If that entry matches with its own, it sets itself as forwarding group member and rebroadcasts the join reply. The join reply reaches the multicast source via forwarding group members and the multicast source selects the route accordingly. The complete process has been illustrated in Algorithm 6 and 7.

5.2.4 Algorithm

In Algorithm 6, we describes our mechanism to estimate the contention count of a node. $PPKT$ is the periodic packet, a node broadcasts to get information about neighbor nodes. $PPKT_{table}$ is maintained by each node and it stores the source addresses of all the $PPKTs$, it receives. If a node receives a $PPKT$, it stores the source address of respective packet and current timestamp in $PPKT_{table}$. The current timestamp is included in order to check the validity of received $PPKT$. The $PPKT$ receiving node calculates its contention count using Equation (5.2). The node also estimates its Received Signal Strength. When a node receives first join query, it sets timer and buffers all the queries it receives, until the timer expires. The node extracts the Source Address and Sequence Number from the query and compares them with all the entries in $QPKT_{table}$. $QPKT_{table}$ is maintained by each node to store information regarding each received non-duplicate join query. It is maintained for two reasons; first, to keep record of all queries it receives and second, to check if the received query is duplicate or not. If the corresponding entry matches with any entry in $QPKT_{table}$, the received packet is regarded as duplicate and thus, the node discards the packet. The node stores all the values, as illustrated in steps 17 to 22, in $QPKT_{table}$, if it receives a non-duplicate query.

Algorithm 7 discusses our mechanism to determine an appropriate forwarding group member. For each entry in $QPKT_{table}$, normalized values of RSS, hop count and contention count is calculated. Using normalized values of contention

Algorithm 6 Creation of $PPKT_{table}$ and $QPKT_{table}$

Require: N {Node}
I {Neighbor node}
ρ {Contention Count}
$QPKT_{table}$ {Query Packets Cache}
$PPKT_{table}$ {Contention Count Cache}
$Timer$ {Buffer time for Query Packet}
Ensure:
Set $\rho = 0$
N broadcasts $PPKT$
if I receives non-duplicate $PPKT$ **then**
    $PPKT_{table}(SourceAddress) \leftarrow SourceAddress$
    $PPKT_{table}(TimeStamp) \leftarrow CurrentTime$
end if
I calculates ρ using Equation (5.2)
I estimates Received Signal Strength (RSS)
if N receives first join query **then**
    Sets Timer
end if
while $Timer$ not over **do**
    Receive join query from neighbor node and extract SourceAddress and SequenceNumber from query
    if Source Address and Sequence Number exist in $QPKT_{table}$ **then**
        Discard the packet
    else
        $QPKT_{table}(SourceAddress) \leftarrow SourceAddress$
        $QPKT_{table}(LastHopAddress) \leftarrow LastAddress$
        $QPKT_{table}(Sequence) \leftarrow SequenceNumber$
        $QPKT_{table}(Contention) \leftarrow \rho$
        $QPKT_{table}(RSS) \leftarrow RSS$
        $QPKT_{table}(HopCount) \leftarrow HopCount$
    end if
end while

count, median contention count has been calculated. Further, value of LSF for all the incoming links is calculated using Equation (5.13) and then all $LSFs$ are compared to find out maximum value of LSF. The last hop address corresponding to maximum LSF is selected as forwarding group member and the link with maximum value of LSF is regarded as the most stable link and is added to the route.

Algorithm Correctness Proof: We can have the correctness proof of any algorithms with the help of different sets of inputs. If the algorithm works well for every case then we can say that our algorithm is correct. To prove the correctness for the proposed algorithms, we have provided one example in Table 5.4, for

Algorithm 7 Selection of Forwarding Group Member

Require: N {Node}
FG {Forwarding Group Member}
LSF_{max} {Maximum Link Stability Factor}
RSS_{norm} {Normalized RSS}
ρ_{norm} {Normalized Contention Count}
ρ_{med} {Median Contention Count}
HC_{norm} {Normalized Hop Count}
$QPKT_{table}$ {Query Packets Cache}
$Timer$ {Buffer time for Query Packet}
Ensure:
if $Timer$ expires **then**
  Set $LSF_{max} = 0$
  for each $LastAddress \in QPKT_{table}$ **do**
    Calculate RSS_{norm} and ρ_{norm} using Equation (5.6)
    Calculate HC_{norm} using Equation (5.5)
    Calculate ρ_{med} using Equation (5.10)
    Calculate LSF using Equation (5.13)
    $QPKT_{table}(LSF) \leftarrow LSF$
  end for
  for each $LastAddress \in QPKT_{table}$ **do**
    if $LSF_{max} \lneq LSF \leftarrow QPKT_{table}$ **then**
      $LSF_{max} = LSF \leftarrow QPKT_{table}$
      $FG = LastAddress \leftarrow LSF_{max}$
    end if
  end for
end if
N flush entries in $PPKT_{table}$ and $QPKT_{table}$

TABLE 5.4: Input set for the proposed algorithm

Contention Count	**RSSI**	**Hop Count**	$N_{ContentionCount}$	N_{RSSI}	$N_{HopCount}$	**LSF**
23	10.363956	1	0.6	0.012132	0.5	-0.075736
24	16.055869	2	0.7	0.201862	1	0.001862
27	10.143511	2	1	0.004784	1	-0.495216
22	16.472802	2	0.5	0.215760	1	0.21576
19	14.421476	2	0.2	0.147383	1	-0.152617
20	28.329875	2	0.3	0.610996	1	0.410996
17	18.335973	2	0	0.277866	1	-0.222134

this input, the algorithm is working completely fine, even we have checked for the worst and best case. In terms of time complexity, it will take O(n), for any case, maximum number of iteration for the node is the number of neighbour nodes for estimating node.

5.3 Performance Evaluation

In this section, the simulation parameters, tool and result analysis discussed.

5.3.1 Simulation Environment

All simulations have been performed on Exata/Cyber v2.0 simulator. The mobile ad hoc network consists of 60 mobile nodes, scattered at random, over an area of 1000 x 1000 sq. metres. MCBR (Multicast Constant Bit Ratio) has been taken as traffic source to generate the traffic with a rate of 33 packets per second. Each simulation experiment is made to run for 600 seconds at different seed values. One source node and ten destination nodes are selected randomly. The performance has been monitored under various mobility conditions. Each multicast member can join or leave the group at any time during the simulation. Rest of the parameters configured for the simulation are given in Table 5.5. To check the effectiveness of our protocol, our results are compared with that of ODMRP.

Table 5.5: Simulation Parameters

Simulation Parameters	**Value**
Simulator	EXata/Cyber v2.0
Simulation Time	600 Seconds
Number of nodes	60-100
Scenario Dimension	1000×1000 sq. meter
Radio Type	802.11a/g
Mobility Model	Random Way-Point Model
Mobility	5-30 m/s
Pause Time	10 seconds
Routing Protocol	ODMRP, LSMRP, MMRNS
Traffic Type	MCBR
Size of Packet	512 bytes
Data Rate	24 Mbps
Total Packets sent	19634 packets
Multicast Group Size	10-20

5.3.2 Performance Evaluation

In the subsection, we analyze different performance parameters on proposed and existing protocols. The performance of our proposed protocol has been analyzed on the basis of following metrics:

5.3.2.1 Packet Delivery Ratio

Packet Delivery Ratio (PDR) can be defined as the ratio of total number of data packets received at multicast receivers to the total number of data packets sent by a multicast source. PDR is related directly with the efficiency of a multicast routing protocol, i.e., higher the PDR, highly efficient is the protocol. PDR can be calculated as:

$$PDR = \frac{\sum N_{rec}}{\sum N_{sent}} \tag{5.14}$$

where N_{rec} is the number of data packets received at multicast receivers and N_{sent} is the number of data packets sent by multicast source.

Figure 5.7 shows the variation of packet delivery ratio with nodes mobility speed for ODMRP, LSMRP, MMRNS and our proposed protocol(i.e. median contention count). Mobility of nodes has been kept in between 5 and 30 m/s (18-108 km/hr) with an increment step of 5 m/s. It has been observed that PDR, in both the protocols, reduces with increase in node mobility. This is due to random and rapid movement of nodes, which makes the more prone to breakage.

In case of ODMRP, with less mobility, PDR is very high and it decreases rapidly with increase in node mobility. This is due to the fact that ODMRP may be choosing longer hops in order to minimize hop count or delay. At least mobility, nodes are less mobile and stays in the transmission range of preceding node for longer. With increase in mobility, nodes frequently move out of the transmission range of preceding node and the link is considered to be broken. In LSMRP and MMRNS, PDR increases due to selection process of stable link at the time of transmission time, maximum signal strength link is chosen for data transmission.

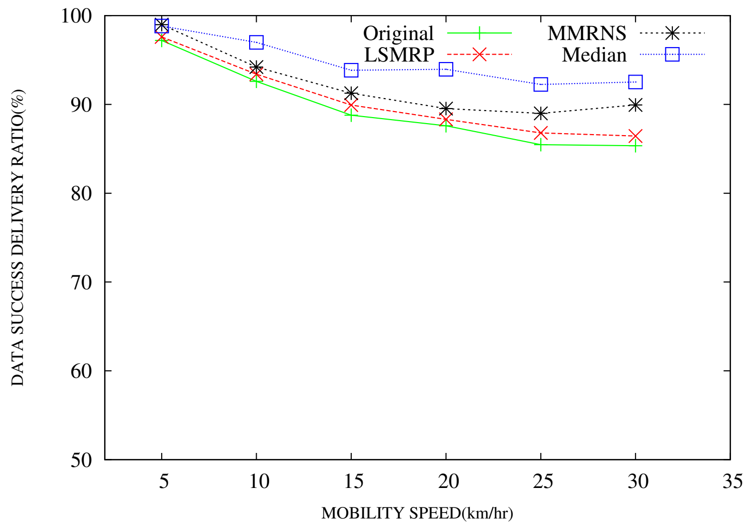

FIGURE 5.7: Packet Delivery Ratio(%) with Mobility(m/sec)

It is also not achieving maximum throughput because maximum signal strength links may transmitting in highly dense areas. In our proposed protocol, PDR rises to a great extent because a shortest as well as stable link has been chosen for transmission. As a result, nodes remain connected for longer duration and reliability for data transmission increases. The link has been selected mainly on the basis of contention count, which ensures well connectivity in the network and received signal strength which guarantees a fair quality link. With increase in mobility, PDR reduces in our protocol too but the decrease is gradual as compared to that of ODMRP and others. This is because our protocol avoids those links that may break in near future and inserts those links in the route that may sustain for longer duration and provides better connectivity.

5.3.2.2 End-to-End Delay

End-to-End Delay (EED) is the time elapsed between sending the data packet and receiving the same at receiver's end. The time taken in route creation and recreation and queuing of packets is also added to end-to-end delay. It is indirectly related to the efficiency of a multicast routing protocol. For an efficient protocol, end-to-end delay must be less. It can be calculated as:

$$EED = T_{rec} - T_{sent} \tag{5.15}$$

where T_{rec} is the time when a receiver node receives a data packet and T_{sent} is the time when the source sends that data packet.

Figure 5.8 shows the variation of end-to-end delay with increase in node mobility for ODMRP, LSMRP, MMRNS and our proposed protocol. It is clear from the obtained results that end-to-end delay for ODMRP is higher than that of our proposed protocol. In case of ODMRP, there exists a mesh of forwarding nodes in between source and destination. The protocol ignores the link stability issues due

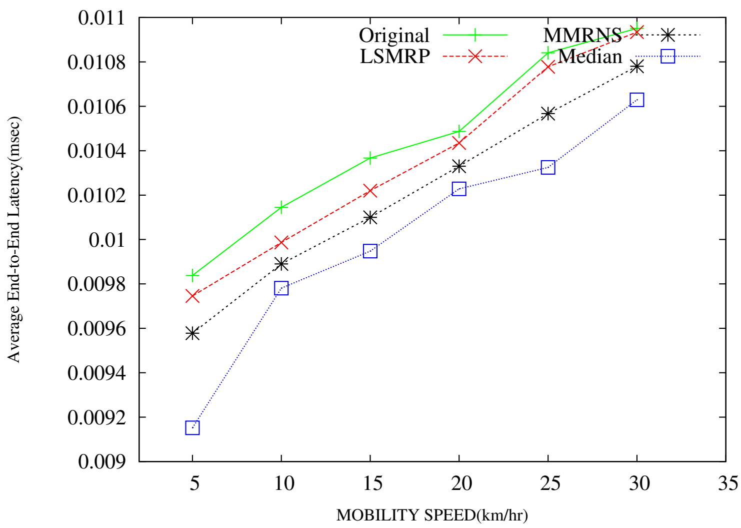

FIGURE 5.8: Average End-to-End Delay(sec) with Mobility(m/sec)

to which there is increased possibility of link failure and this possibility increases with increase in node mobility. With each link failure, probability of retransmission of data packets increases due to switching over to alternate route. The time elapsed in route reconfiguration and data retransmission is also included in delay, hence, end-to-end delay is enhanced in case of ODMRP. LSMRP and MMRNS also face the same problems of retransmission and resultant delay. LSMRP protocol delay is less than ODMRP because it is trying to reduce some number of link failures by selection of stable links. In MMRNS, end-to-end delay is reducing as compare to

LSMRP, but not much effective because of energy is not an issue in our scenarios. Their is not a single link get failed due to energy problems.

In case of proposed routing protocol, more stable links are selected based on appropriate signal strength and contention count. The parameters ensure fair quality link thus chances of link failure reduces which, in turn, reduces transmission delays. In addition, our protocol discovers shortest reliable path and short path guarantees lesser hop counts, which further reduces the number of required retransmissions to deliver the data packet to its final destination successfully. Hence, end-to-end delay is much lower in our protocol as compared to ODMRP. With increase in node mobility, the end-to-end delay increases in both the protocols, but our protocol performs well as compared to ODMRP.

5.3.2.3 Average Route Lifetime

Average Route Lifetime (ARL) begins when a node gets detected in the transmission range of successive node and lasts until the link breaks. Generally, a link is considered to be broken if it is no longer detected by another node in its transmission range for a certain period of time. Higher ARL depicts higher stability of constructed routes, hence, it should be maximum (near to RRI (Route refresh interval)) for efficient routing. ARL gets affected adversely with increase in node mobility. ARL can be explained by average route lifetime spend form route establishment (RE) to route failures (RF).

$$ARL = T_{RF} - T_{RE} \tag{5.16}$$

where T_{RF} is the time when a link or route got broken and T_{RE} is the time when the route got established for transmitting data packets.

Average Route lifetime depicts the period of connectivity of a route. When a node enters the transmission range of any other node, the lifetime of a link begins and it lasts till the node remains in the transmission range of another node. It is obvious that if the mobility of the node is higher, lifetime of the link would be short as node may reach out of the transmission range of the successive node due to high

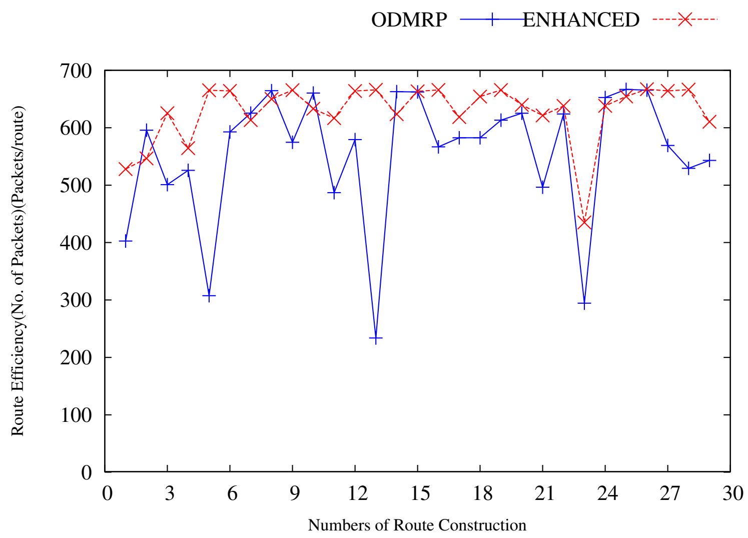

FIGURE 5.9: Average Route Lifetime with Mobility(24-25 m/sec)

mobility. The average route lifetime at each route reconfiguration at mobility 25 and 30 m/s has been portrayed in Figure 5.9 and 5.10 respectively. The Figures show the compared duration for which the route remains active, i.e., increased active lifetime of complete route in our protocol as compared to ODMRP. The resulting routes to all the destinations, in case of our protocol, comprised of stable links. As the stable link ensures that it has the maximum probability to stay

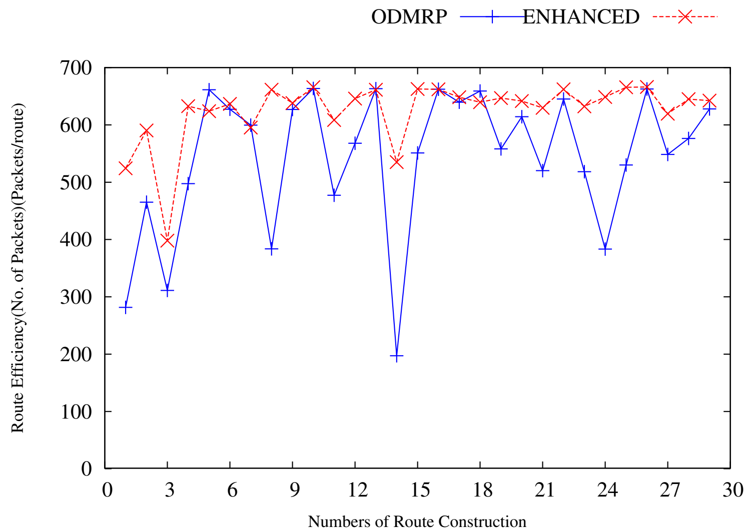

FIGURE 5.10: Average Route Lifetime with Mobility(29-30 m/sec)

connected for longer duration, resulting routes also survive for longer duration. It has been interpreted from the simulation results that with increase in mobility, overall ARL decreases because node mobility increases frequency of link failure. As can be observed from the Figures that at high mobility ARL for our protocol is still elevated at most of the route reconfiguration.

5.3.3 QoS on Streaming Data

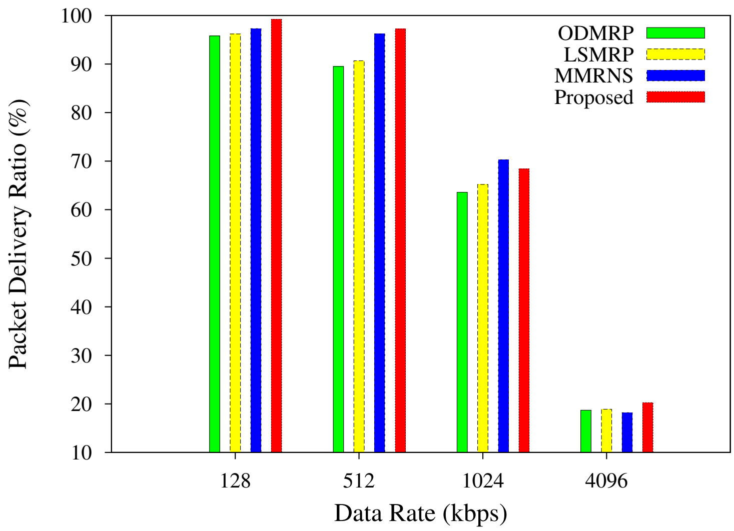

FIGURE 5.11: Effect of different data rate on PDR

Effect of packet delivery ratio on various data rates is shown in Figure 5.11. For video streaming data, we have tested our simulation environment with different data rates. The simulation results have been shown on $128kbps$, $512kbps$, $1024kbps$ and $4096kbps$. The proposed protocol is showing higher PDR as compared to existing protocols. This figure is presenting the packet delivery ratio on different data rate or the maximum data rate that our simulator support for communication of video data.

Figure 5.12 demonstrate the end-to-end delay of proposed and existing routing protocols on various data rates. The reason of up and down is already discuss in the regarding section of performance metric. This is representing the suitable data rate for transmitting video data with lower end-to-end delay and higher PDR. The range of data rate $(128 - 512)kbps$ is reliable for flawless communication because of no congestion.

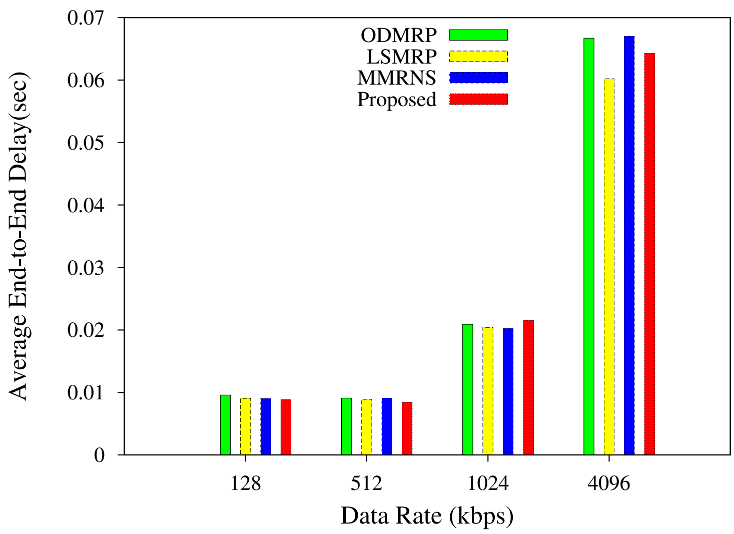

FIGURE 5.12: Effects on Average End-to-End Delay with different data rate

5.3.4 Effect of Contention Count

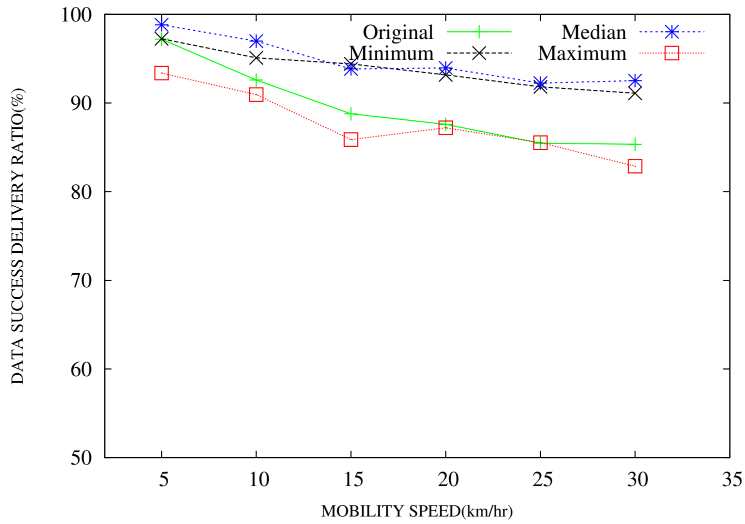

FIGURE 5.13: Packet Delivery Ratio(%) with Mobility(m/sec)

The effect of minimum and maximum contention count on data transmission has been studied and compared to the obtained results with our protocol. In first case, the node has been selected with minimum contention count as forwarding node and in second case, the node by means of maximum contention count is selected as forwarding node. Evaluation of results has been done on the basis of PDR and EED. Figures 5.13 and 5.14 show the variation of PDR and EED, respectively, with increasing mobility in case of both maximum and minimum contention count and their comparison with both ODMRP and our protocol.

In case of maximum contention count, the PDR is much lower even in comparison to ODMRP. This is because due to higher contention count, competition in between nodes for bandwidth is higher and this competition, in turn, affects the data transmission. As compared to the wired medium, the available bandwidth is less in shared and wireless medium and each node, that lie in the transmission range of any other node, consumes equal amount of bandwidth for data transmission. It can be inferred that large contention count at a node incurs more contention among nodes for bandwidth. Due to this contention, quality of link degrades and data transmission reduces. In case of minimum contention count, PDR improves as compared to ODMRP. This is due to less contention count which ensures less competition among nodes. Although least contention count provides better link quality but at the same time, it reduces connectivity in the network.

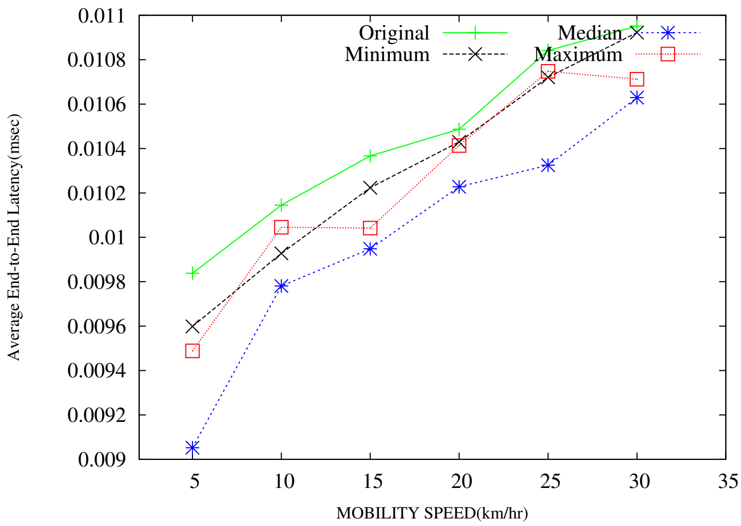

FIGURE 5.14: Average End-to-End Delay(sec) with Mobility(m/sec)

Therefore, a node has been selected with median contention count as forwarding node. In case of median contention count, as can be seen in the Figure 5.13, PDR has been increased to maximum as compared to other three cases viz. ODMRP, minimum and maximum contention count. At mobility speed 15 m/s, may be the nodes selected as forwarding nodes have most appropriate contention count, i.e.

minimum, so PDR is maximum for minimum contention count at this mobility. In Figure 5.14 shows minimum EED in case of our protocol.

5.3.5 Inferences

1. Through the proposed protocol a stable path based on LSF is discovered. LSF has been calculated using parameters like contention count, hop count and signal strength. A median contention count has been selected such that connectivity remains well maintained in the network and also contention-free route can be made available.

2. Our proposed protocol and ODMRP have evaluated results on the basis of performance metrics like PDR, EED and ARL. It has been observed from obtained experimental results that our protocol outperforms ODMRP in all cases.

3. In case of maximum and minimum contention count, EED is decreased as compared to ODMRP but is still much higher than our protocol. One more advantage of our protocol is that it discovers the path that are reliable as well as shortest too. As the shortest path guarantees lesser hop counts, it ensures reduced EED due to reduced number of retransmissions that are required for successful delivery of data packets to the destination. Hence, in our case, EED is minimum as compared to other cases.

4. It has been observed from the above results that contention count impacts the efficiency of a routing protocol significantly. As discussed earlier, there are limited available resources with a node and each node that lies in the transmission range of successive node demands for equal amount of resources. If a large number of nodes are there in transmission range of a node, it suffers competition for resources and would yield poor performance. Obviously, a least contention count would reward resources availability, but the connectivity in the network would be compromised. There are chances that an active node gets detached from the network.

5. Observation of results for PDR show that a stable and reliable path can be discovered based on appropriate contention count. Additionally, results for

EED for all cases ensure that reduced hop count is an added advantage to the protocol.

5.4 Summary

In this chapter, median contention count is taken as a basis for determination of link stability. A novel protocol has been proposed that determines LSF for each link and considers the link with maximum LSF as most stable link. The estimation of appropriate contention count depends upon received signal strength, also hop count is minimized and these three parameters are mapped into one factor, i.e. LSF. The maximum value of LSF at any node suggests that the node comprises appropriate contention count and fair received signal strength. Additionally, tried to minimize the route length to further enhance the efficiency of our protocol.

Our results have been compared with the cases of minimum and maximum contention count. It has been concluded from the simulation results that contention count at a node influences the efficiency of a multicast routing protocol substantially. Large contention count at a node increases competition for available resources and smaller contention count reduces connectivity in the network. An appropriate contention count would enable well connectivity and availability of resources, like bandwidth, in the network. In the next chapter 6, applicability of our proposed works has been presented in real life scenario with FANETs devices.

Chapter 6

Communication Model of UAVs: A Case Study

"Communication in the sky" is a trend because of increased deployment of of Unmanned Aerial Vehicles (UAVs) that make use of wireless communications. UAVs have diverse applications in civil and military domains. A swarm of UAV system is able to finish the operations more reliably and economically than single UAV.

Currently, Mobile adhoc networks (MANETs) routing is used for communication in UAV networks. The standards for the communication system are yet to be developed. UAVs are deployed for topological coverage locating debris of aeroplane crashes, suspicious activities through anomalies in geographical terrains, rescue missions, mapping of hostile territories etc.. UAVs are equipped with cameras for taking pictures that are continually streamed to the base station. In addition to that, UAVs need to communicate among themselves to maintain geometry of swarm formation. Streaming such a voluminous information requires a protocol that can meet requirements of high bandwidth, high mobility devices, varying link stability and high energy consumption compared to adhoc networks. It leads to abruptly breaking communication in between UAV-to-UAV and UAV-to-ground. In this chapter, the link stability issue is discussed in UAV communication systems. Link stability is required for reliable communication. The performance of Flying adhoc networks (FANETs) communication is evaluated with different scenarios on EXata/Cyber 2.0 to analyze the performance are suggested. All proposed approaches (Chapter 3,4 & 5) are simulated over the UAV configurations to show the effects on performance metrics.

6.1 Introduction

Unmanned Aerial Vehicles (UAVs) is a flying non-human vehicle also known as Drone. It can be remotely supervised (instructed by an operator at a base station) or can operate autonomously depend on pre-planned programs.

The growing requirement of UAVs in the military and other areas has made it an extensive research topic. After second world war the unmanned aircraft were controlled by radio signals and other aircraft. The remotely piloted aircraft (unmanned) with high mobility and low cost of deployment are in extensive use since last few decades. Use of single large UAV is less feasible and more costly than small multi-UAVs Systems. In such a system, UAVs are either connected to ground base stations or to satellites, communication between UAVs can be infrastructure based but each UAV need to have complex hardware connection with ground base stations or satellites. The solution to this problem is ad-hoc communication network between UAVs in this network a subset of UAVs is connected to ground stations or satellites. The FANETs (UAVs using Ad-hoc network) has intermittent links, rapid topology changes and challenging communication link stability between the nodes due to their high mobility as compared to MANETs and VANETs.

Communication between UAVs also gets affected by different types of terrain and obstacles which make communication among UAVs challenging in the multi-UAV system. UAVs may have either star topology or mesh topology. Both topologies have their respective pros and cons.

The motivation of this chapter is to elaborate the communication issue in UAV networks and provide techniques to overcome the problems. UAVs are highly in use due to their unique characteristics and features that provide service to the users as per their requirement. More than half population of the world lacks internet access but with a purchase of Titan Aerospace in April 2014 [113], Google could bring millions of more people online. Amazon announced that it aimed to begin delivery by using UAVs. By this, a product is delivered to customers in 30 minutes. Facebook also showed interest in UAVs and there was news that Facebook spent $60 million on buying Titan Aerospace, so it need to evaluate that how much UAVs are in use in many applications. So it is necessary to ensure the communication issues to UAVs and research for solutions related to these issues such as mobility of UAVs, intermittent communication links, dynamic topology.

In this chapter, the scenarios for air communication from multiple sources to multiple destinations are suggested. The performance metrics of FANETs are analyzed with defined simulation parameters. We have described various issues in the FANETs communications due to their extended features from adhoc networks. A 3d scenario is provided for surveillance of border area by UAV devices and transmitting streaming data to destination nodes with the help to UAV and UGV [114] nodes.

The rest of this chapter is organized as follows. Section 6.2 presents the overview of previous approaches on the FANETs. Section 6.3 presents, the communication between UAV devices and requirement of reliable communication. Simulation parameter and various scenario are proposed in Section 6.4. Results analysis are presented in Section 6.5 followed by concluding remarks in Section 6.6.

6.2 Related Work

Flying Adhoc Networks (FANETs) is an ad-hoc network of UAVs or a group of small UAVs [9]. FANETs have been developed for new usages in the civilian and military scenarios. Drones can deliver death on the battlefield, life saving drugs to remote areas and can also be used for delivering presents and drone base photography. Some of the applications in which UAV have been used for are [1] as follows:

1. Protecting Wildlife

[1]http://news.nationalgeographic.com/news/2013/12/131202-drone-uav-uas-amazon-octocopter-bezos-science-aircraft-unmanned-robot/

2. Down on the Farm
3. Hurricane Hunting
4. 3-D Mapping
5. Search and Rescue
6. Remote Sensing
7. Traffic and weather Monitoring
8. Disaster Management and firefighting
9. Border Surveillance
10. Transmission in ad-hoc networks

There are various protocols for FANETs proposed by Physical, MAC, Network, Transport layer [115]. The physical layer conditions should be well defined for effective communication in FANETs. The issues related to FANETs are weak link quality due to high mobility of nodes and also the packet latency is a design issue of MAC layer with FANETs.

The FANETs devices have a high mobility, so the existing routing methods are not effective and need a routing method based on the location information of these UAVs nodes. In highly dynamic environment FANETs need good Transport layer protocols for better results. In FANETs, communication reliability, congestion control, and flow control are controlled by Transport layer which is important issues in communication. A swarm of small UAVs benefited more than a single large UAV if one node is failed or discharge in UAVs swarm then other nodes can fill the gap and the communication is not affected. In case of single large UAV the communication get affected by failure of a single node. So multi-UAVs Systems are more useful than large single UAV system. UAVs fall into one of these following functional categories:

i Target and Enticement.

ii Reconnaissance provide battlefield intelligence.

iii Research and Development for technology improvement.

iv Civil and commercial UAVs used for information collection, aerial photography, agriculture.

v Logistics cargo delivery.

vi Encounter provides attack capability in high military missions.

6.2.1 Issues Related to UAVs Networks

UAVs have high demand in the area of border surveillance[28], wind estimation [116], relay for communication and Adhoc networks [117], disaster monitoring [118]. Although they are high in demand, they are not completely acceptable in the world of networks due to many research issues related to them. There are various challenges in UAV communication as compared to MANETs. Some crucial parameters for comparison are high node mobility, regular patterns of mobility, low node density, fast topology change and high computational power. Summary of comparison has been included in the table 6.1.

Constraints	**MANETs**	**FANETs**
Node mobility	Low	Very high
Mobility model	Random	Regular, but special models for autonomous systems
Node density	Low	Very low
Topology change	Slow	Fast
Line of Sight	Not available	Available
Power consumption	Energy efficient	Energy efficiency for mini UAVs
Computational power	Limited	High

Table 6.1: The comparison of FANETs and MANETs

So strong communication between UAV-UAV (can use 802.15.4n) and between Ground Control Station (GCS) and UAVs (can use 802.11n) for information transfer is an essential requirement. Routing for UAVs can be position based routing, hierarchical routing, proactive routing or reactive routing. For disaster affected area or military uses, area coverage is an important issue for UAV network. Since the efficiency of area coverage solution depends on the coverage percentage i.e. the ratio between how much area is given and how much area is covered by UAVs.

For successful completion of military operations area coverage approach should be efficient. According to the current UAVs uses in the mobile communication area, enhance the capacity of the network.

UAVs network system can be heterogeneous or homogeneous. Although homogeneous systems are highly in use, but the future use of the heterogeneous systems are higher due to the use of different configuration UAVs in single system. In disaster affected area UAVs are used due to their rapid network formation and they provide communication as faster as possible, the network is known by Unmanned Aerial Vehicles-Wireless Mesh Network (UAV-WMN). Each user of this network is also a provider, forwarding data to the next node. The networking infrastructure is simple and decentralized due to each node need only transmit as far as to the next node. In UAV-WMN, this WMN uses UAVs as nodes for communication. One of the most concerned issues is how many numbers of UAVs are required for a particular mission. There are various issues related to tracking of target by UAVs like target is static or moving, if it is moving speed is constant or continuously changing. The UAVs need to move from source to destination for this the main requirement is the path from source to destination should be smooth, flyable, obstacles and terrain free. Path planning is an important issue related to every mission of UAVs. It affects mission delay and efficiency of results. There are various uses of UAVs as communication relay so issues related to a downlink communication and uplink communication in various domains should be point of consideration.

In military and civilian area's, UAVs use both centralized network and decentralized network systems with their respective pros and cons, so the issues related to network centralization or decentralization are considerable. Many simulators and emulators are proposed for UAVs simulation and emulation. In UAVs simulation and emulation the main consideration is requirement of radio propagation model suitable to network, issues related to various model need to be discussed. Energy and power efficiency issues are one of the most important issues related to UAV network. It decides how longer a UAV maintain communication link in space and after a specific time when battery is discharge, UAV should leave the system and come to the station to recharge itself.

In military and disaster recovery scenario, the most important issue is how well UAVs monitor the provided area. Many tasks which are dangerous and difficult for human can be performed by UAVs very easily. In military, UAVs are used for aerial reconnaissance which observes a region to locate an enemy which is required. In area coverage by UAVs corporation is challenging, how well they interact with each other and if a node failure occurs due to some reasons then how well other nodes maintain the network and communication among them [119]. There are various area coverage issues related to UAVs network.

- Connectivity
- Obstacles and Terrain
- Ability of coverage
- Mobility and Lifetime

Considering the coverage and rate performance of a scenario using Unmanned Aerial Vehicle (UAVs) as flying base station which provides fly wireless communication and transmitted data through downlink to users in presence of Device to Device (D2D) communication links. In this scenario, there are two types of users, downlink users (DUs) which are communicating with UAVs, D2D users communicating with each other.

6.3 UAVs Communication Model

Single UAV device is used in communication applications from decades. Because of their limitations like limited range, lack of multi-hop network, cost of making one big UAV, centralized access. In Figure 6.1 have shown single UAV device communication with main node (Head Quarter (HQ)). In this scenario, UAV is on border surveillance for intruder detection from RED to GREEN. UAV device continuously surveillance the allotted border area and transmitting the streaming data to HQ. Due to security reason, it is not possible to apply HQ to nearby the border area, so need to place it to the secure region. Now the direct communication

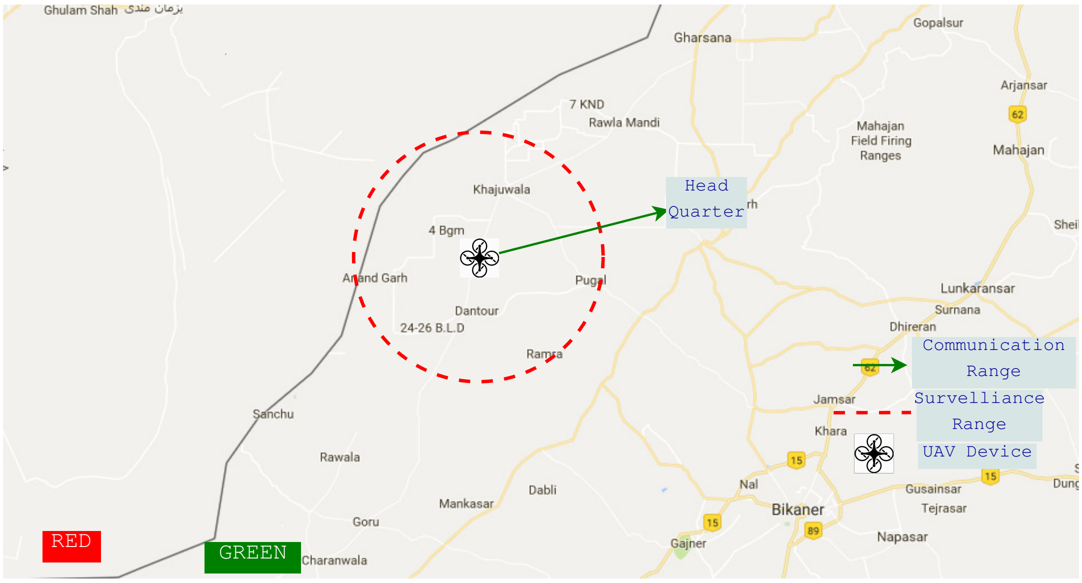

FIGURE 6.1: UAV device transmitting video streaming to Head Quarter

is not possible to communicate directly to HQ, because of limited communication range (red circle) of UAV device.

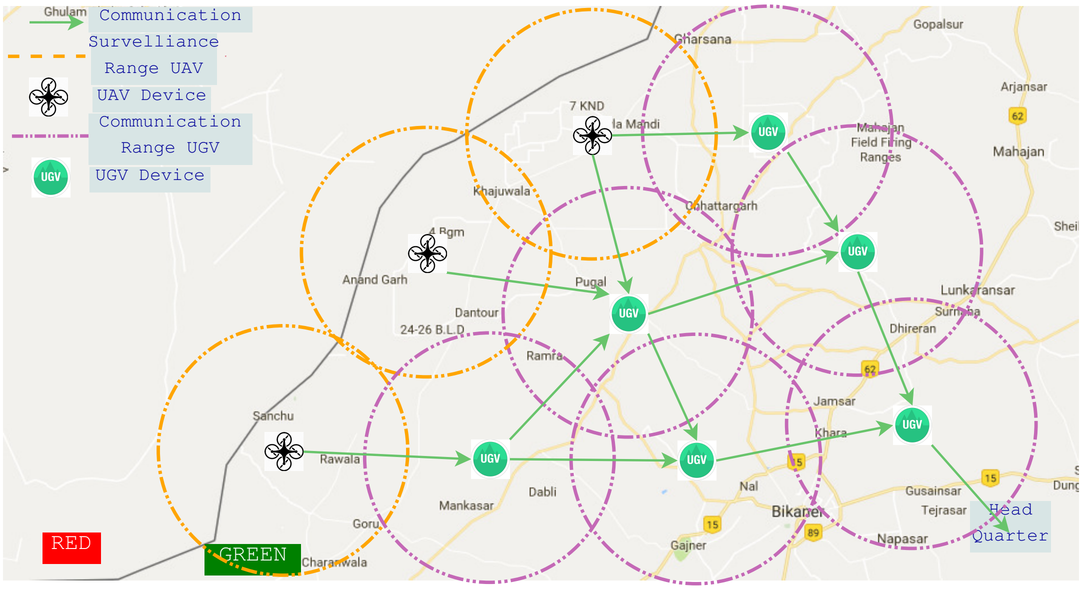

FIGURE 6.2: UAV devices communicating surveillance Data to Head Quarter

In Figure 6.2, another scenario of multiple UAV and UGV (Unmanned Ground Vehicle) nodes communicating data to multiple HQ. This scenario can be represented by MIMO system. In this scenario, swarm of UAVs has placed for surveillance the complete border area. UAV device has higher transmission range (bandwidth) as compared to UGV device for transmitting data to long distance with high reliability. A swarm of mini-UAVs is placed nearby the border of green and red zone for complete surveillance. A swarm of UAVs has various advantages over single UAV system, such as distributed system (single node failure will not breakdown complete system), cost reduction, efficient, reliable and packet transmission to unlimited range.

UAV devices are doing multitasking by surveillance's and transmitting capture data to the nearby relay nodes. Intermediate nodes forward the data to next hop nodes that is near to destination device. For this communication, first it is required to establish a reliable path, that will not be abrupt during the fixed time interval. Ground vehicles are continuously moving in the area with their fixed velocity to transmit the data. The reliable forwarding nodes have to find that are persistent during the communication time. Node mobility, energy reduction, out of transmission range, low signal quality, high bit error rate, high congestion, these are reasons for link failure that leads to route failure. For this, need to estimate reliable link for the communication between source to destinations nodes.

6.4 Simulation Environments

Simulations have been run on EXata/Cyber v2.0 [84] simulator, 56 node network over 1.5 sq. km. terrain dimensions. All simulation parameters are listed in Table 6.2. In this simulation, nodes are placed with few heights around 500 meters and data is transmitted from multiple sources to multiple destinations (Multicast Group). A path is created from multiple sources to multiple destinations for the duration of Route refresh interval [13]. During the simulation around 20k packets send to receiver from each source UAV with the MCBR traffic generator. A number of simulations are run on multicast routing protocol to analyze the effects on the performance metrics, also performed ten numbers of simulations (i.e. different seed value) for validating the each result.

Simulation Parameter	Values
Simulator	EXata/Cyber v2.0
Simulation Time	500 Seconds
Scenario Dimension	(1-10) Sq.km.
Height of Node	0-500m
Transmission Range	500m
Mobility Model	Random mobility model
Mobility	10-30 m/s
Routing Protocol	ODMRP [34], LSMRP [95]
Traffic Type	Multiple MCBR [85]
Size of Packet	512 bytes
Maximum Data Rate	2-54 Mbps
Multicast Group Size	2-5
Number of nodes	(10-50)

Table 6.2: Simulation Parameters of FANETs

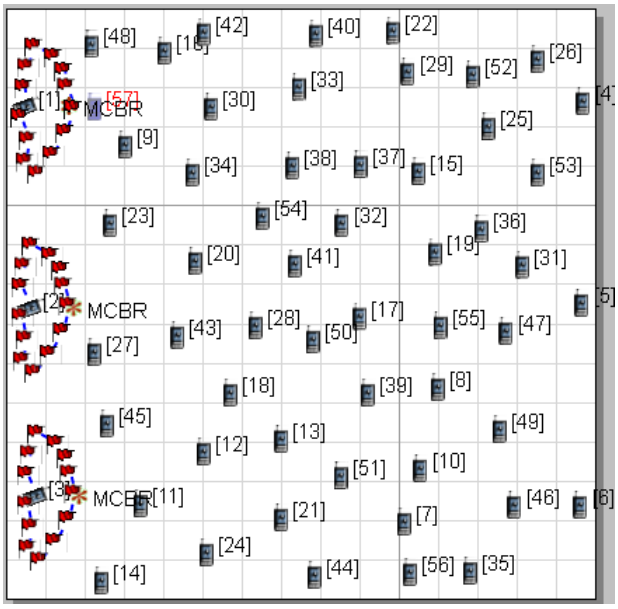

Figure 6.3: Nodes positioning in the Scenario 2D Plane

6.4.1 Scenario Configuration

In Figures 6.3 and 6.4, scenarios for both 2D plane and 3D plane used for simulation in the EXata/Cyber 2.0 are presented. In this example, three sources and three destinations have taken over 1500$sq.m.$. All sources are placed at a with height around 100-500 meters and red flags are showing their mobility patterns. Source nodes have to surveillance the area by moving in the particular area (red flag) and transmit the data to destination nodes. Three nodes (4,5 and 6) on the right side of Figure represent fixed destination nodes. For lack of direct communication between sources and destinations, fifty intermediate mobile nodes are placed to forward the data.

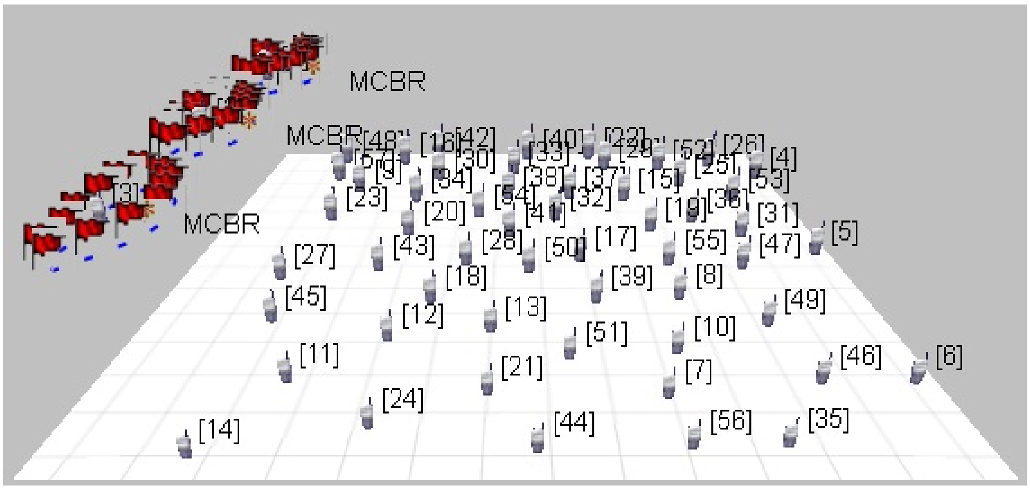

FIGURE 6.4: Nodes positioning in the Scenario 3D plane

6.5 Results

In this section, performance metrics analyze on different receivers with above-defined simulation parameters.

Packet Delivery Ratio: Total number of successfully received packets over total number of sent packets between source to destination is called packet delivery ratio (PDR). In Figure 6.5, the effect of our scenario configuration on packet delivery ratio at different receivers is shown. In this, PDR is around $72 - 84\%$. It totally depends on nodes position in the scenario because some receiver may be getting complete path easily with fewer node variations. Single Destination receiving data from multiple sources at same data rate, because of that some packets drop.

Average End-to-End Delay: This is the time required for communicating a packet across network from a source to a destination. Figure 6.6, shows the differences in End-to-End delay of packet to various destinations. The delay is varying from $8-11$msec. Due to simultaneous arrival of the packets from different sources

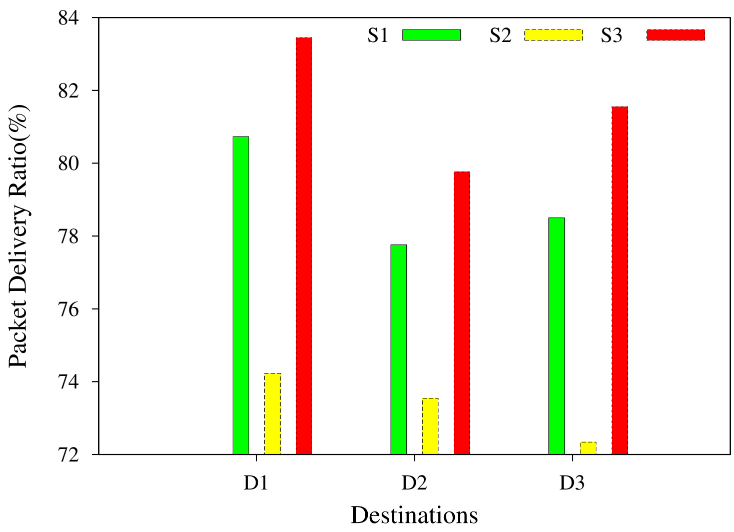

FIGURE 6.5: Packet Delivery Ratio on various Destinations

to same receiver node the delay is increasing. At the end nodes, some intermediate nodes sending duplicate packet again after timeout.

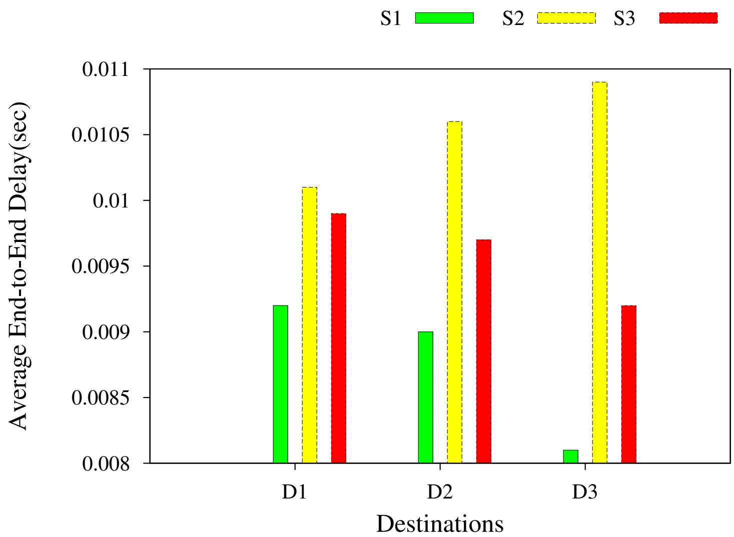

FIGURE 6.6: Average End-to-End Delay on various Destinations

Coverage v/s Communication Reliability: In Figure 6.7, the curve has been plotted for reliability versus coverage area. Reliability is shown in the range [0-1]. Initially, reliability is low and improves as coverage increases.

After the threshold coverage area, reliability is going down or slope is constant due to various reasons such as node contention, congestion or hidden terminal problem in the wireless network. Now node will affect other nodes communication range due to high coverage area.

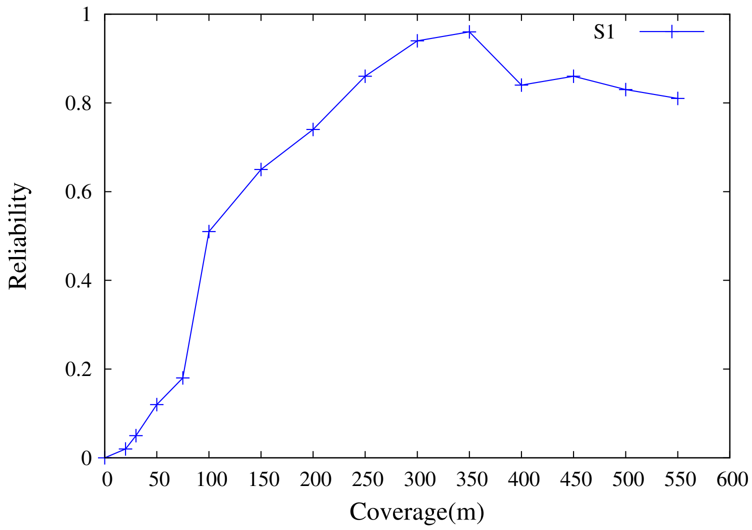

FIGURE 6.7: Communication Reliability by increasing Area Coverage

6.5.1 Proposed Routing Protocols Comparisons

In this thesis, three contributions have been proposed in the chapters 3, 4 and 5 respectively. Here, we are representing the comparison between the proposed routing protocols with simulation configurations of UAV networks. All the parameters have been set according to the requirements of UAV networks. In Figure 6.8 and 6.9, a comparison of PDR and average end-to-end delay is shown.

The PDR is higher in all proposed approaches as compared to existing routing protocols. First two proposed protocols (Moralism and route stability) are getting higher PDR, but last one proposed protocol (MCLSPM) get higher PDR because of multi-objective approach that helps to identify a stable route of longer duration. In first routing protocol, the pdr is going down after a threshold mobility, because it is not suitable for high mobility scenarios.

The average end-to-end delay is reducing in the proposed routing protocols because the reconfiguration cost is reduced. It is directly affecting the average time of a packet traveling from source node to destination node. In UAV networks, the

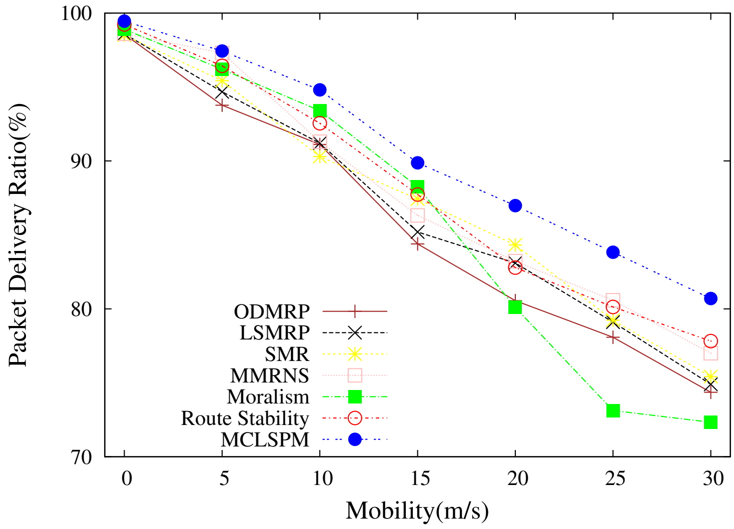

FIGURE 6.8: Packet Delivery Ratio (%) by increasing node mobility

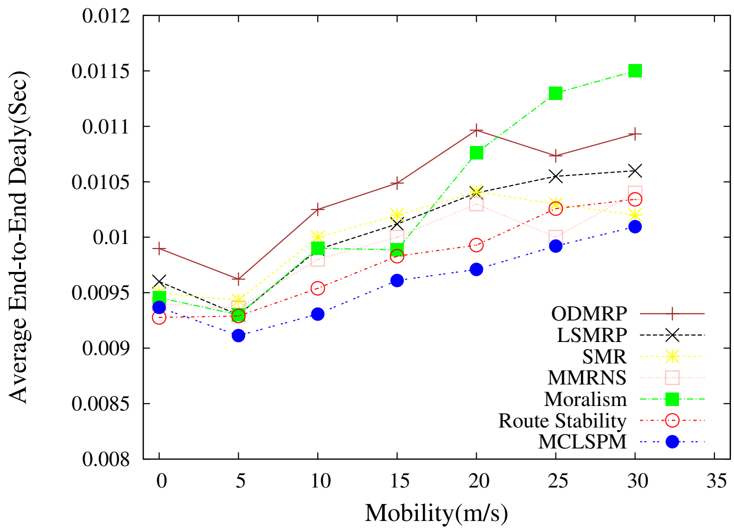

FIGURE 6.9: Average end-to-end Delay (sce) by increasing node mobility

nodes are placed in three dimensional scenario. The scenario configuration has been changed according to simulation parameters as shown in Table 6.2. Our proposed routing protocols have performed significant well with the consideration of FANETs parameters in the simulation environment.

6.6 Summary

FANETs is a type of adhoc networks and required a reliable QoS–aware multicast routing protocol for data communication from one node to other destinations. For reliable communication in FANETs, we have presented three approaches. The conclusion of this chapter is the analysis of FANETs performance on 2D and 3D scenarios with different performance metrics. A scenario has been shown for multiple inputs and multiple outputs system. Source nodes are surveillance the border areas and communicate the streaming data to all the destinations. The effect of PDR and End-to-End delay of our proposed protocols have been shown and compared with existing protocols on FANETs configurations. The results present that our proposed protocols are performing better than existing protocols.

Chapter 7

Conclusions and Future Work

In this thesis, the issues related to multicast routing protocols in MANETs (Mobile Adhoc Networks) have been addressed arising out of link failure. Link failures may be occur out of various situations such as low bandwidth, node mobility variation, low signal strength and multiple transmission. QoS–aware multicast routing protocol will allow us to overcome the challenges of link failure and node mobility. Stabilization of routes once abstracted can be used for achieving superior performance and link quality. we have explored this issue of selection of stable links to ensure a route that does not break too often. Towards this end, in this thesis, we propose three routing solutions.

In the first contribution, a stable link is identified on the basis of SINR metric. Indirectly SINR metric is an estimate of the distance between nodes as smaller (larger) the distance, higher (lower) is the value of SINR. For reliable path selection, the highest SINR link is added to the Forwarding Group. This technique may not work in cases, where node moves out of the communication range. So mobility prediction is applied to the node, that will help to identify the node traveling time in the communication range of estimating node. In a multicast network, a route is created for particular time limit i.e. RRI (Route Refresh Interval), Our algorithm tries to construct a reliable route that is likely to remain active till RRI. The main findings of this contribution are listed below:

1. Our Proposed approach outperforms the existing protocols (SMR and ODMRP) by exploitation of better prediction of the node active time. It helps to make a reliable route for communication.

2. Moralism has compared with existing protocols on different streaming data rate ($128kbps$, $512kbps$, $1024kbps$ and $4096kbps$) to validate the proposed routing technique.

3. In a high mobility scenario, Moralism surpasses its performance in terms of successful transmissions because of the feature of advanced range prediction. If the maximum transmission range is $500m$ and, the node is travelling with the speed $50m/sec$ with RWP mobility model, it can take maximum $10sec$ to travel their respective CR. In our case, RRI is assumed to be $20s$, that is twice of total travel time. So, the link shall not persist and link failure takes place. To overcome this, one needs a constraint on speed and/or RRI.

4. Moralism will not work with high mobility scenarios, because the node will move away from the communication range in the required RRI.

In the second contribution, the routes are created using the previous history of nodes in terms of packets received. Stable link and stable route are estimated on the basis of ETX matrix. Because a group of stable link does not guarantee a stable (reliable) route, we estimate the route reliability by multiplying link probability. The main inferences from this contribution are listed below:

1. Proposed technique is analyzed by comparing the obtain results with that of ODMRP, EODMRP, and MMRNS. The system parameters used for our comparative study are PDR, average end-to-end delay, average route lifetime, control overhead and memory overhead.

2. Route stability based protocol focused on stability of a complete route, while link stability protocol emphasized on the most stable link at each hop, MMRNS estimates a stable link based on received signal strength and energy of nodes and ODMRP and EODMRP, considered the minimum hop-count path.

3. As the route is stable, chances of route failure are least in case of route stability technique and are highest in the case of ODMRP and EODMRP. MMRNS considers link stability, but the process of route reconfiguration increases computational and control overhead. Thus, it can lead to packet drop and increase in end-to-end delay.

4. On comparing the obtained results, it is observed that route stability based protocol showed the better performance in terms of higher PDR, lower average end-to-end delay, longer route time and a little overheads, followed by better performance in the case of link stability based protocol, MMRNS, ODMRP and EODMRP lagged behind other protocols. In the case of rising node mobility, the performance of our protocols is lowered but still better than ODMRP, EODMRP and MMRNS.

5. It can be inferred from our experiments that a dynamically adapted route refresh interval does not guarantee a stable link. Emphasizing on a stable link can improve the throughput but selecting a stable route yields better performance as compared to stable link.

6. There may be a possibility of involvement of weak links (less stable than other links) in the route, while considering link stability. This possibility increases, because of rapid and unpredictable changes in network topology. The unstable link in a route increases the chances of a route failure. As a result, all efforts to discover a stable route would be futile. Hence, it is better to consider route stability issues and select a route that is more durable.

In our third proposal, a single metric embedding different objective cost functions is proposed and is applied to estimate the stable link for reliable communication in a QoS-aware multicast routing protocol. Link stability factor is calculated using contention count, hop count and RSSI metric. This is done as any one of these parameters is not able to handle all the conditions of the network. The effect of low and high contention count has analyze on network performance. The main findings from this proposal are listed below:

1. A median contention count has been selected such that connectivity remains well maintained in the network and also contention-free route can be made available.
2. Our proposed protocol and ODMRP have evaluated results on the basis of performance metrics such as PDR, EED and ARL. It has been observed from obtained experimental results that our protocol outperforms ODMRP in all cases.
3. In case of maximum and minimum contention count, EED is decreased as compared to ODMRP but is still much higher than our protocol. One more advantage of our protocol is that it discovers the path that are reliable as well as shortest too. As the shortest path guarantees lesser hop counts, it ensures reduced EED due to reduced number of retransmissions that are required for successful delivery of data packets to the destination. Hence, in our case, EED is minimum as compared to other cases.
4. It has been observed from the results that contention count impacts the efficiency of a routing protocol significantly. If a large number of nodes are there in transmission range of a node, it suffers competition for resources and would yield poor performance. Obviously, a least contention count would reward resources availability, but the connectivity in the network would be compromised. There are chances that an active node gets detached from the network.
5. Observation of results for PDR show that a stable and reliable path can be discovered based on appropriate contention count. Additionally, results for EED for all cases ensure that reduced hop count is an added advantage to the protocol.

In Chapter 6, a real world application scenario for our proposed works is shown. A swarm of UAVs is creates an adhoc network for communicating streaming data. It is expected that our proposed approaches will help to create improved reliable path for end-to-end communication. A number of simulations were performed for FANETs parameters. All proposed routing protocols have simulated over UAV configuration parameters to validate the outcomes and inferences.

On the basis of our understanding of multimedia data transfer over multicast MANETs, following may be taken up as an extension in future being research challenges:

1. We will work to consolidate a system using our approaches to establish uninterrupted communication in a real-time application.

2. Develop a robust QoS-aware multicast routing protocol that can reliably transmit video streaming data over flying adhoc networks. As discussed above, our protocol should be reliable with all the constraints in FANETs such as scalability and high bandwidth.

Appendices

Appendix A

Link Stability Based Multicast Routing Protocol (LSMRP)

In LSMRP [120], link stability is estimated for each link to construct a route between source and destination. For route establishment, select a reliable link that transmits data packets within the route expiration time. In the routing process, every node finds its next-hop to communicate data packet towards the destination. In ODMRP, selection of next hop node is based on "First Come First Served" concept with no consideration of link state. In LSMRP, we make use of SINR to estimate quality of link. It is hypothesized that a good signal strength at a node is indicative of that it is close to source/intermediate node and the link is not likely to break for some time. To select more reliable links as compared to other links, buffer the information(like SINR value, Source addr, Multicast Group addr, Previous hop addr) from all available links for similar multicast group receiver. After cessation of waiting time of buffered link, maximum SINR valued link is chosen as a stable link and the respective node is added to previous hop address of the current node.

A.1 An Example

The Figure 3.1 shows paths between source A and destinations L and M as $P1$ and $P2$, obtained from ODMRP protocol using minimum hop count while $P3$ and

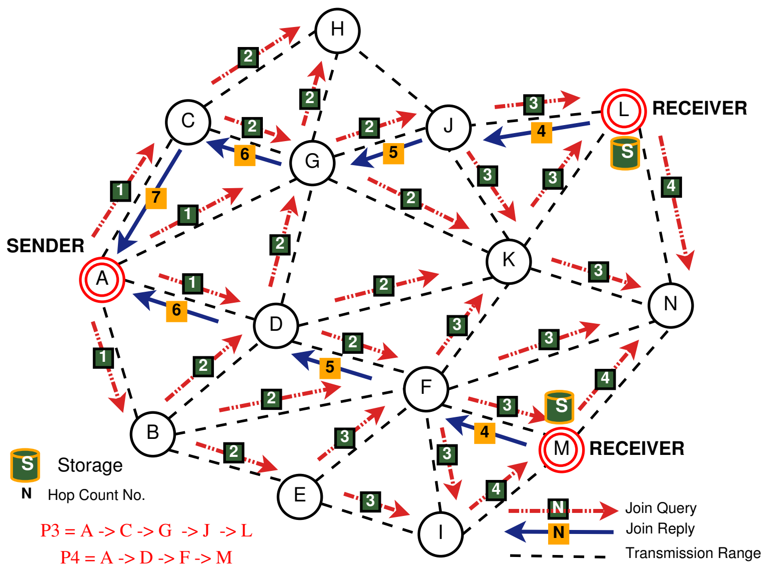

FIGURE A.1: LSMRP Work Flow

$P4$ are shown in Figure A.1 using signal strength of nodes. The path $P3$ has been selected over path $P1$ due to weak signal strength of node A as compared to C by estimating node G. However, the path $P4$ does not change to $P2$ because it is already getting best signal strength.

A.2 Algorithm

Steps for the Algorithm 8 for given proposal are as follows:

1. Sender node broadcasts a 'Join Query (JQ)' packet for multicast group address (MGA).
2. Intermediate nodes receive 'JQ' from others and discard duplicate packets for similar source and MGA.
3. A node starts a timer after receiving the first packet and waits until the 'waiting time' ends.
4. Every intermediate or receiver node estimates SINR ratio for different links, stores this information in a buffer till the expiry of 'waiting time'.
5. Receiving node selects the link with maximum SINR as a stable link and sets the corresponding node as a previous hop address.

6. Finally receiver can transmit 'Join Reply (JR)' to previous node address for confirmation of route to a source node.

Algorithm 8 Algorithm for Link Stability

Require: s {Source node}
  $D = \{d_1, d_2, \cdots, d_k\}$ {set of k destinations}
  $P_{s \rightsquigarrow D}$ {Stable route from source to destinations}
  ζ {SINR Value}
  φ {Forwarding Group}
Ensure: : Stable paths from $s \rightsquigarrow D$
$P_{s \rightsquigarrow D} = \emptyset$
$\varphi = \emptyset$
s broadcasts 'Join Query'
$u = s$
Repeat:
for $v \in$ neighbor(u) **do**
  $\zeta_{max} = 0$
  while 'Expiry Time' not finished **do**
    Receive packet from neighbour w
    if not duplicate **then**
      ζ = SINR of $\ell_{v \to w}$
      if $\zeta_{max} < \zeta$ **then**
        $\zeta_{max} = \zeta$
        $\ell^{v}_{stable} = \ell_{v \to w}$
        $f = w$
      end if
    end if
  end while
  $P_{s \rightsquigarrow D} = P_{s \rightsquigarrow D} \cup \{\ell^{v}_{stable}\}$
  $\varphi = \varphi \cup \{f\}$
end for
if $v \notin D$ **then**
  $u = v$
  Goto **Repeat**
end if

A.3 Results

Proposed LSMRP protocol is implemented in Exata/Cyber v2.0 [84]. MANET scenario with 100 nodes and parameters for experimental setup is shown in Table A.1 and is used for comparing our proposal with standard ODMRP. For fair comparison and evaluation of our proposal, 10 different simulations runs with different random seed values were performed.

TABLE A.1: Simulation Parameters for LSMRP Protocol

Simulation Parameter	**Value**
Simulator	Exata Cyber 2.0
Simulation Time	600 Sec.
Number of nodes	100
Area	1500 Square meter
Node Density	15 square meter
Radio Type	802.11a/g
Data Rate	24 Mbps
No. of Simulations/run	10
Mobility Model	Random Way Point Model
Mobility	5-25m/s or 18-90 km/h
Pause Time	10 Sec
Routing Protocol	ODMRP,LSMRP
Traffic Type	Multicast Constant Bit Ratio(MCBR)
Size of packet	512 Bytes
Total Sent Packet	19967

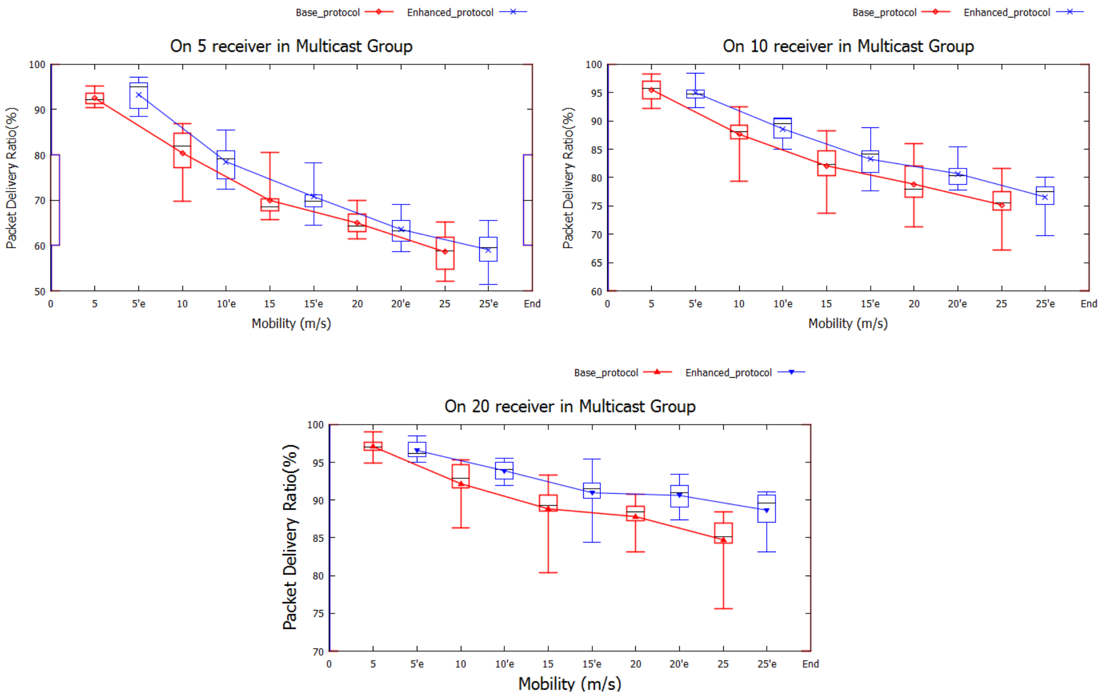

FIGURE A.2: Effect of network mobility on PDR

For better analysis of results, box plots [121] are used of every comparison. Each box-plot displays minimum, maximum, median, 25% and 75% quartiles. Average value over all simulations is also plotted. Red color has been used to depict performance of ODMRP whereas blue color reflects performance of LSMRP. Following paragraphs compare LSMRP with ODMRP on different performance metrics. In figures, base protocol refers to ODMRP and enhanced protocol refers to LSMRP.

1. Packet Delivery Ratio: In our experimental setup, effect on only multicast communication with one source and $n \in 5, 10, 20$ receivers with node mobility varying in the range of [0-25] m/s has been observed. Effect of mobility on Packet Delivery ratio is illustrated in Figure A.2. It can be observed that LSMRP outperforms ODMRP even when number of receivers are increased from five to twenty. As mobility increases, performance degrades in both protocols but LSMRP still performs better than ODMRP as in latter, in every refresh interval of route, more links fail due to mobility. In LSMRP routing protocol links persist in active mode due to the fact that high signal strength links are chosen at the time of route establishment. Another inference that can be drawn from the Figure is that PDR increases with increase in number of receivers. This is owing to the fact that routes to intermediate nodes can be utilized by more receivers. Overlap of routes to receivers improves PDR as only packets lost in initial part of a route shall not reach destination(s).

2. Average End-to-End delay: Figure A.3 represents effect of mobility on average End-to-End delay in both ODMRP and LSMRP protocols. Effect is observed for different numbers of receivers when mobility is varied. As can be inferred, delay is lesser for LSMRP. The delay is calculated on the basis of the number of retransmissions required to transmit the packet from source to destination and waiting time in the buffer queue. Our proposal LSMRP reduces the number of retransmissions by selecting a stable link from others.

A.4 Limitations

LSMRP is based on selection of stable link and not stable route. The nature

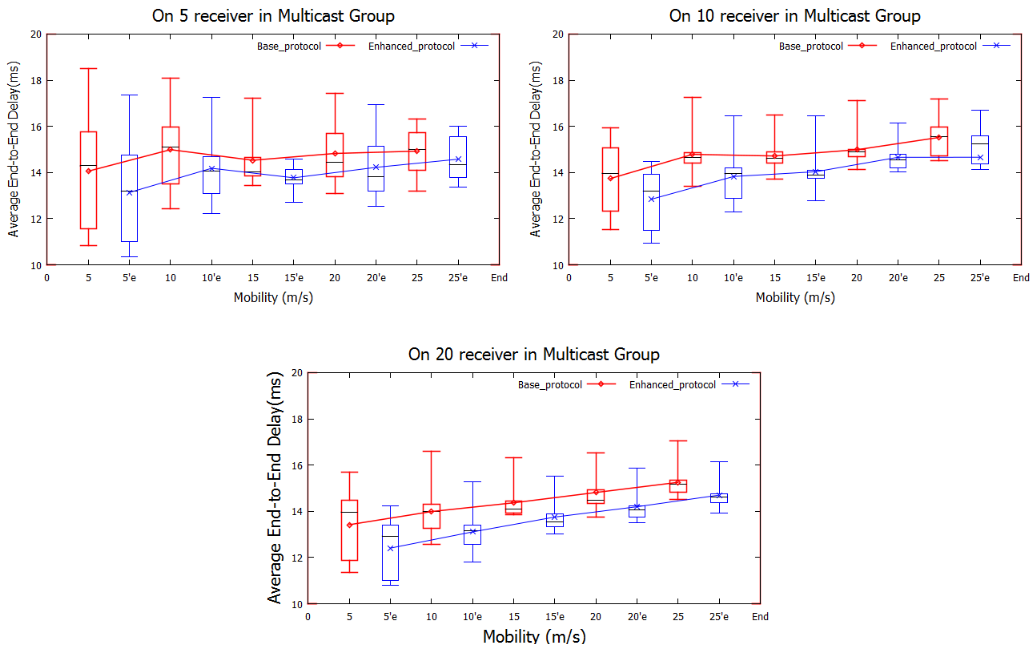

FIGURE A.3: Effect of network mobility on End-to-End Delay

of algorithm is local i.e. while selecting a link, it looks for most stable link in the neighborhood. If the neighborhood of the end node of this stable link is highly dynamic, the route may not be stable. Due to incremental nature (route is constructed by selection of stable links one-by-one), the algorithm fails to gather global view of the network and is not able to select a route that is stable in respect of all constituent links. While a group of stable links may lead to a stable route, it is not true for all cases. In high mobility scenarios, the node creating stable link may move out of communications range of transmitting node due to high mobility or displacement. Due to mobility of nodes, a link that is stable at time t may not remain stable at $t + \delta$.

Publications

A. Journal Publications

[J-1] Singal, G.; Laxmi, V.; Gaur, M.S., Rao, V., "MOraLISM: MObility prediction with LInk Stability based Multicast routing protocol in MANETs", Wireless Networks, Springer-Journal. doi:10.1007/s11276-015-1186-7.

[J-2] Singal, G.; T. Swati; Laxmi, V.; Gaur, M.S.; Rao, V., "Improved Multicast Routing in MANETs using Link and Route Stability", International Journal of Communication Systems, Wiley-Journal. doi:10.1002/dac.3243.

[J-3] Singal, G.; Laxmi, V.; Gaur, M.S.; Rao, V., "Multi-constraints link stable multicast routing protocol in MANETs", Ad Hoc Networks, Volume 63, August 2017, Pages 115-128, ISSN 1570-8705, doi:10.1016/j.adhoc.2017.05.007.

B. Conference Publications

[C-1] Singal, G.; Laxmi, V.; Gaur, M.S.; Lal, C., "LSMRP: Link stability based multicast routing protocol in MANETs," Seventh International Conference on Contemporary Computing (IC3), pp.254,259, 7-9 Aug. 2014.

[C-2] Singal, G.; Garg, H.; Laxmi, V.; Gaur, M.S.; Lal, C., "Impact analysis of attacks in multicast routing algorithms in MANETs," 9th International Conference on Industrial and Information Systems (ICIIS), 2014, pp.1,6, 15-17 Dec. 2014.

[C-3] G. Singal, V. Laxmi, M. S. Gaur, S. Todi, V. Rao and A. Zemmari, "MCLSPM: Multi-constraints link stable multicast routing protocol in adhoc networks," 2016 Wireless Days (WD), Toulouse, 2016, pp. 1-6. doi: 10.1109/WD.2016.7461508.

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QoS–aware Multicast Routing Protocols in MANETs

PhD Viva-voce Presentation

Gaurav Singal (2012RCP9509)

Supervised By
Manoj Singh Gaur, Vijay Laxmi, D Vijay Rao

July 24, 2017

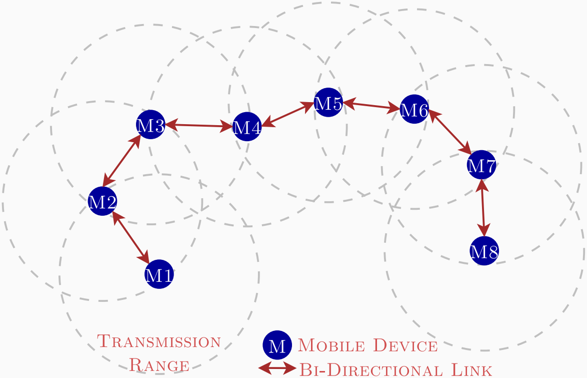
Malaviya National Institute of Technology, Jaipur

Table of contents

Mobile Adhoc Network

Introdction to MANETs

- Mobile Ad hoc NETwork(MANET) is a self configuring, fixed infrastructure less network of mobile devices.
- Every node in MANET acts as host and router.
- The nodes have limited resources, transmission power and battery life.
- Nodes communicate using multi-hop networks.



Applications

- Military Battlefield
- Disaster Relief Operation
  - Group-based Voice Communication
  - Map-based Tracking
- Real-time Video Streaming Applications.
  - Video Surveillance.
  - Video Lectures.
- VoIP

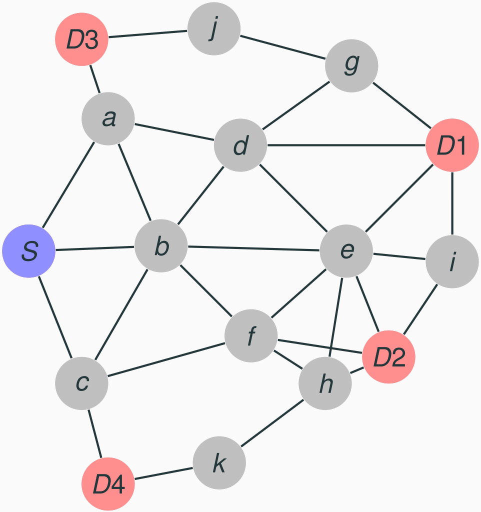
General Research Challenges in MANETs

- Bandwidth Utilization
- Connectivity Maintenance
- Energy Efficient
- Multimedia communication

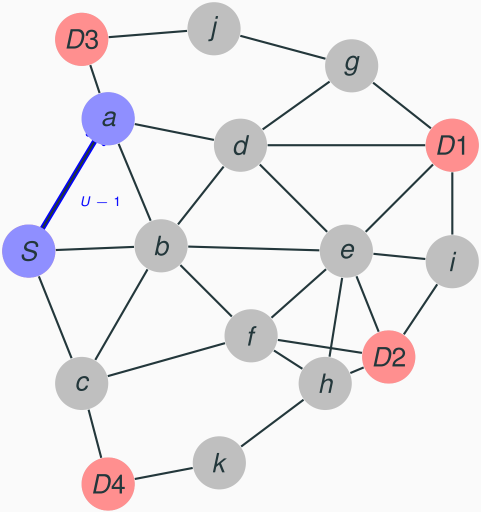
Unicast v/s Multicast Networks

- In Unicast, one source and one destination.
- Multi-casting is the transmission of packets to a group of host.
- Advantages of Multicast over multiple Unicast transmission:
  - Reduced Bandwidth consumption.
  - Improved transmission efficiency.
  - Reduced Energy consumption.
  - Decreases the cost such as delay and control overhead.

Unicast Process



Unicast Process



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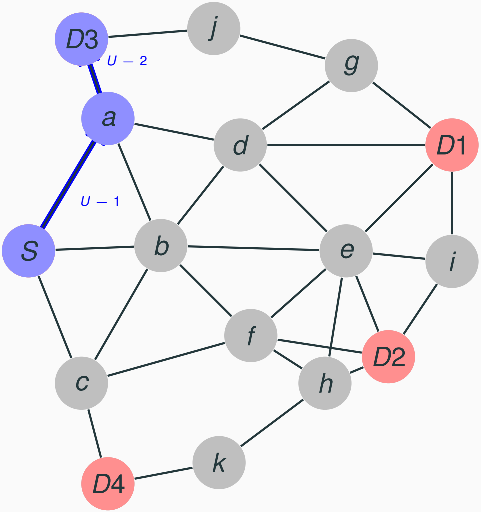

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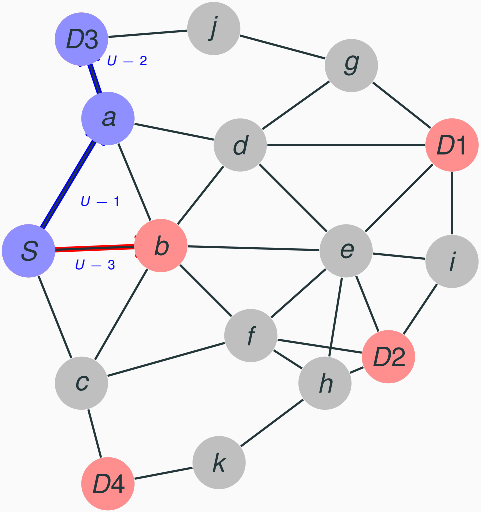

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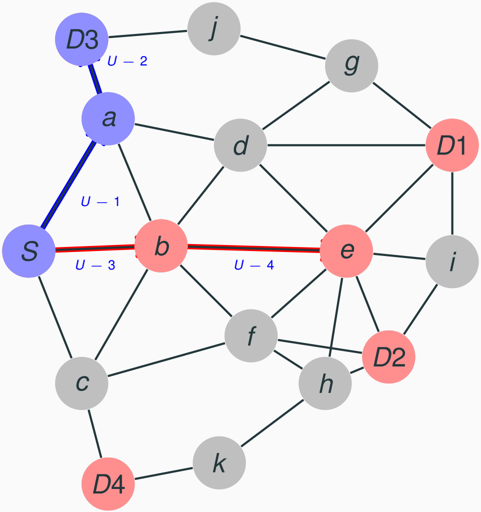

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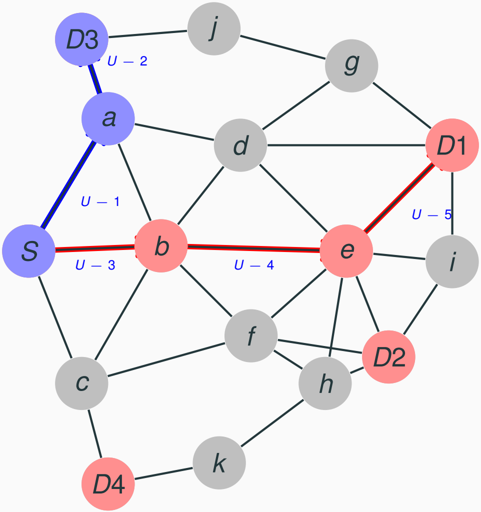

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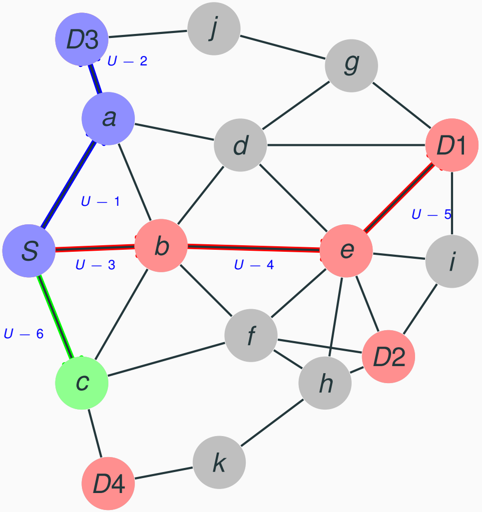

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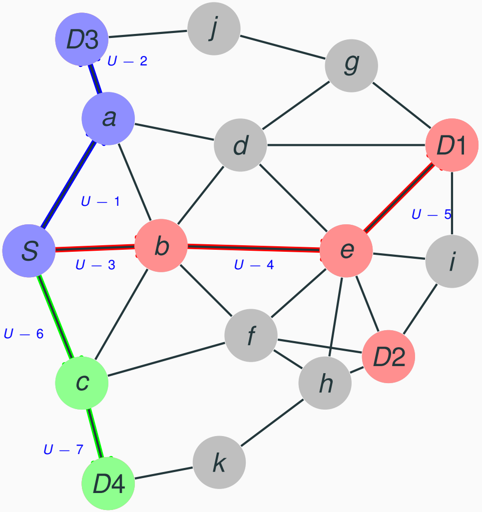

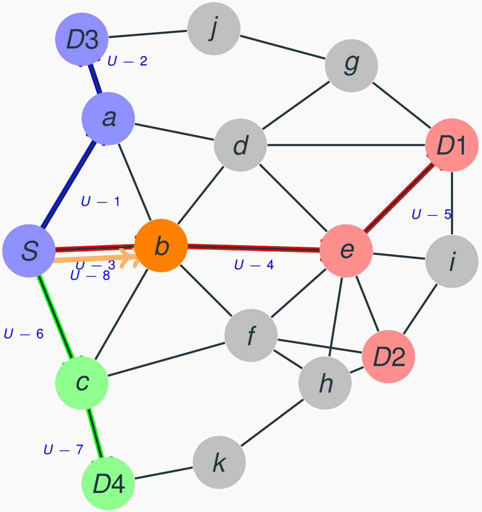
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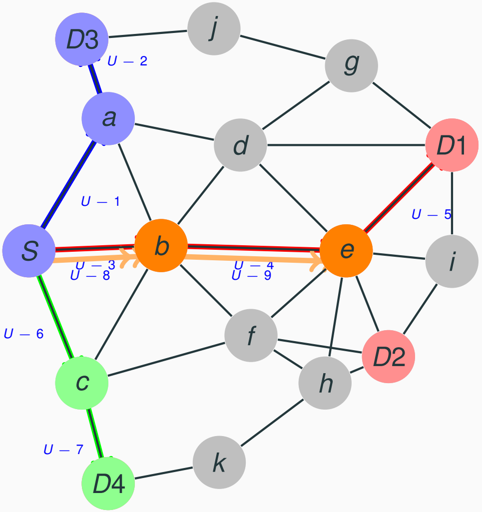
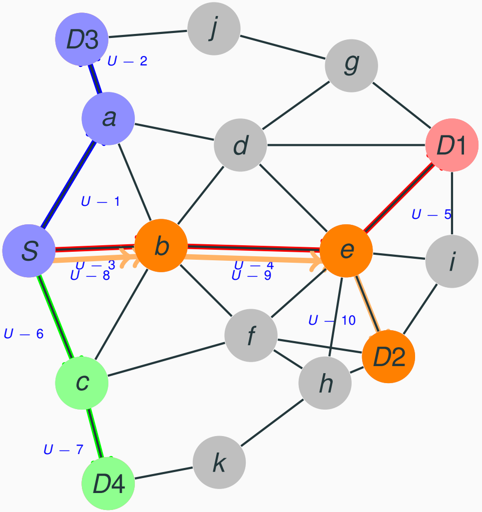
U − 8

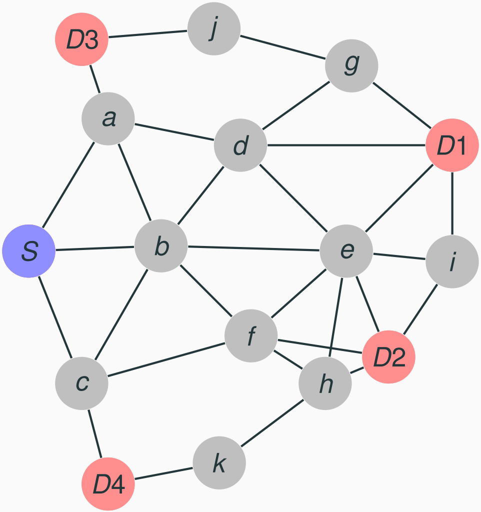
Unicast Process



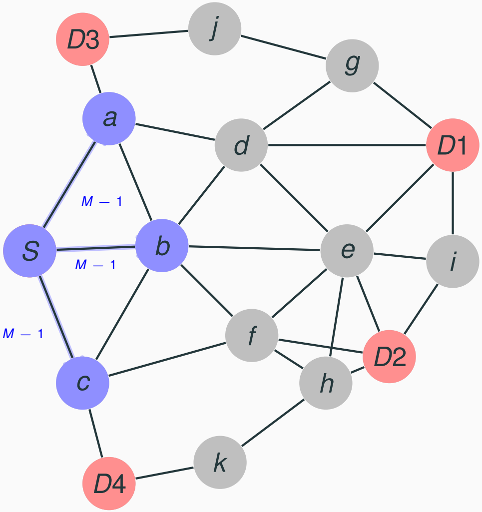
Unicast Process



Multicast Process



Multicast Process



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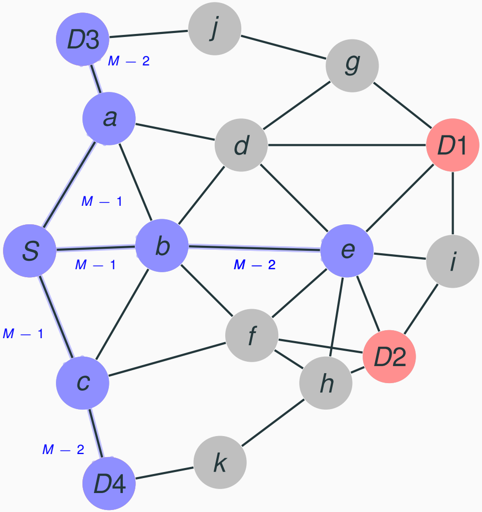

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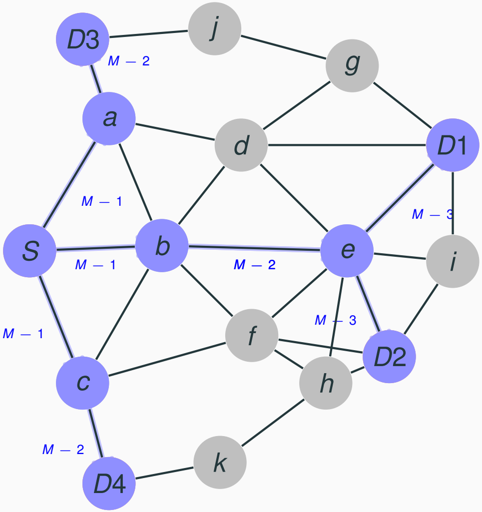

Multicast v/s Unicast

- In Unicast network, total number of links (L_U) are:

$$L_U = \sum_{i=1}^{k} (K_i)$$

Multicast v/s Unicast

- In Unicast network, total number of links (L_U) are:
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- In Multicast Network, total number of links (L_M) are:

$$L_M = \bigcup_{i=1}^{k} (K_i)$$

- Total Free links (L_F):

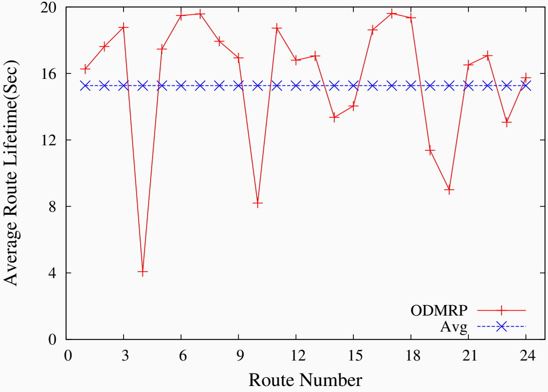
$$L_F = L_U - L_M$$

$$L_F = 10 - 8 = 2$$

K $\{K_1, K_2, K_3, \ldots, K_k\}$ represents the intermediate nodes from S to every destination.
k Total number of links

Prerequisites

- Bandwidth is fixed for our communication network.
- If enough bandwidth is not available for communication then packets drop ratio increases.
- We have to sustain the connected route till next refresh.



Motivations

- Link stability is getting tremendous attention in MANETs, as it is necessary for maintaining the connectivity in reliable and robust network.
- Link stability means that selected link for routing will be available till next refresh.
- Growing popularity of multimedia services there is a need to support Quality of Service (QoS) metrics.
- Available QoS–aware routing protocol not equipped to solve problems because of link and route failures.

* To overcome these challenges, there is a need of devising a reliable MRP (Multicast routing protocol) that is simple, scalable, robust and energy efficient.

QoS (Quality of Service)

- QoS is an idea that guarantees for uninterrupted transmission of multimedia data while maintaining certain quality parameters[1] required by applications.
- The idea of providing QoS in MANETs is not to extinct overhead but to keep it as low as possible.
- Maintaining a QoS in MANETs (without resource reservations).
  - Route should remain available.
  - Overhead should be lower.
  - Route break should be low.

[1] Packet Delivery Ratio, End-to-End delay, and Average Route Lifetime

Objectives

Devise QoS–aware MRP for streaming applications in wireless networks.

- Stabilize (longer time) route by maximizing the Multicast active route time (i.e. route remains connected).

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- To include QoS constraints in ODMRP (On-Demand Multicast Routing Protocol) to escalate their performance in terms of throughput, Delay and overhead.
- To improve performance metric (Available Route Lifetime) in MRP by resolving the issues of node mobility and link failure.

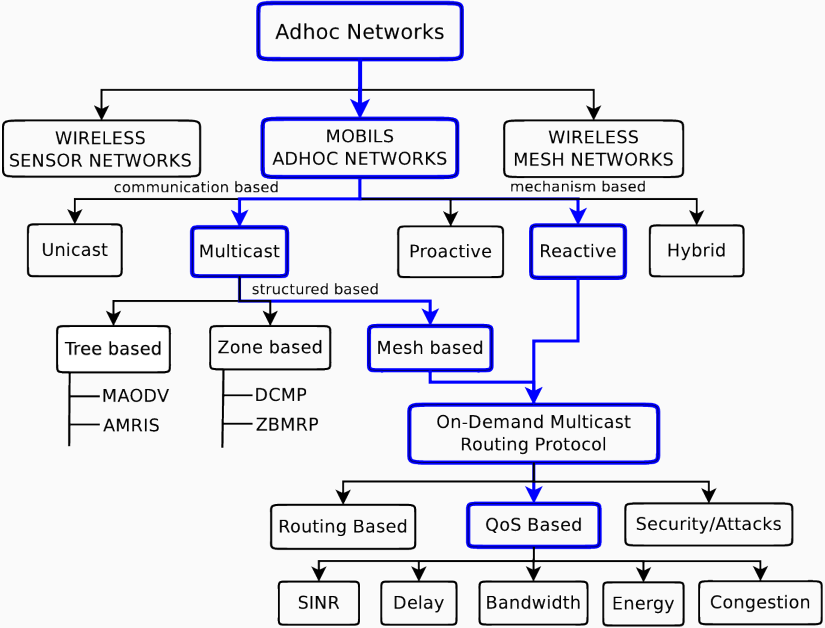

Figure 1: Taxonomy of Research Plan

ODMRP: On-Demand Mulicast Routing Protocol

- Sung *et al*[2,3] proposed ODMRP (On-Demand Multicast Routing Protocol) in 1999.
- On-Demand, Mesh based, Multicast scheme and uses a forwarding group concept.
- Supplies multiple routes for one particular destination.
- Avoids Channel overhead and improves scalability.

[2] Sung-Ju Lee and Gerla, M. and Ching-Chuan Chiang. On-demand multicast routing protocol. Wireless Communications and Networking Conference, 1999. WCNC. 1999 IEEE, 1298–1302 Cited by:243 vol.3

[3] Sung-Ju Lee, Su William and Mario Gerla.On-Demand Multicast Routing Protocol in Multihop Wireless Mobile Networks. Mobile Networks and Applications, 2002 SPRINGER, Vol. 7, no. 6,pages 441–453 Cited by:1567

ODMRP Process

Steps for ODMRP Process:

- Source sends 'JQ' and waits for 'JR' from destination(s).
- Intermediate node receives 'JQ' and rebroadcasts it.
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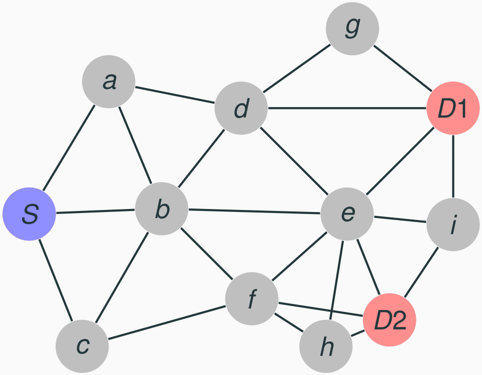

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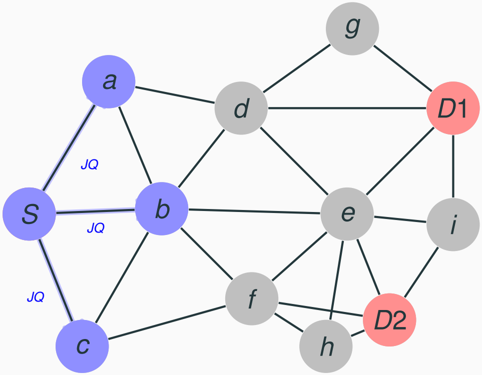

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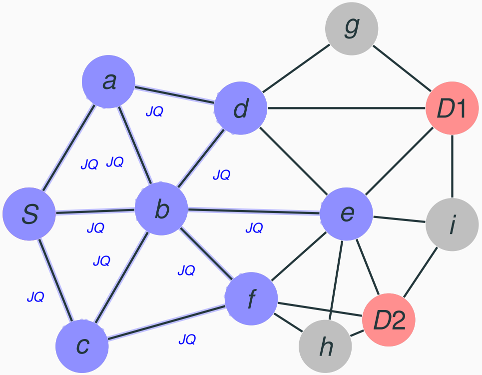

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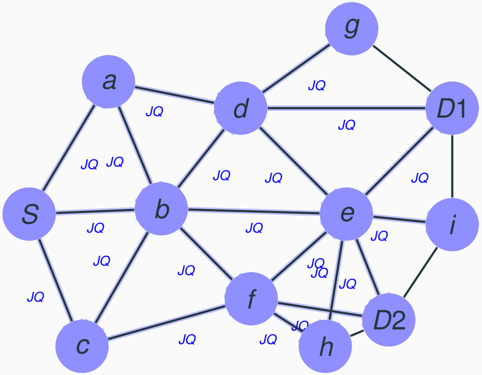

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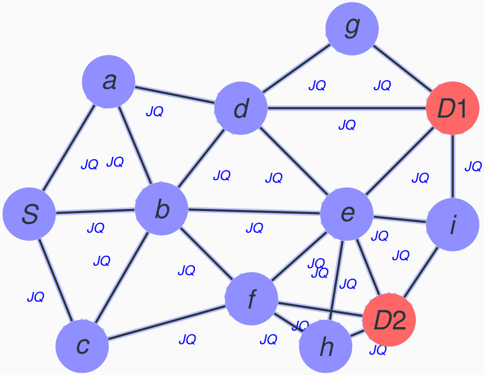

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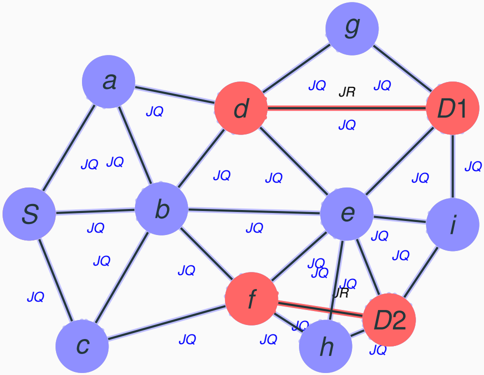

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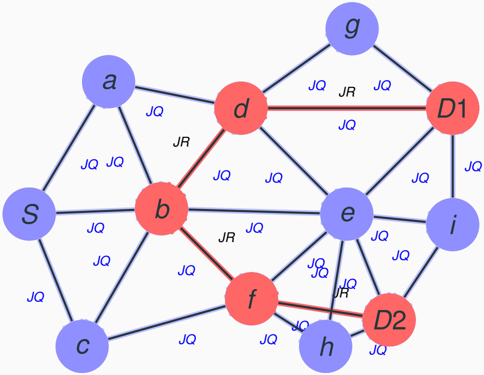

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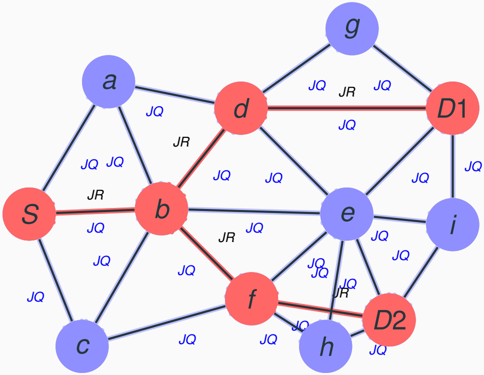

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Simulation Parameter

Simulation Parameter	Value
Simulator	EXata Cyber 2.0
Simulation Time	600 Sec.
Number of nodes	50-100
Area	1500 Square meter
Node Density	15 square meter
Radio Type	802.11a/g
Data Rate	24 Mbps
Mobility Model	Random Way Point Model
Mobility	5-25m/s or 18-90 km/h
Route Refresh Interval	20 Sec
Expiry Time	8 msec
Node Pause Time	10 Sec
Routing Protocol	ODMRP, LSMRP, MMRNS
Traffic Type	Multicast Constant Bit Ratio(MCBR)
Size of packet	512 Bytes
Total Sent Packets	19967
Simulation/Results	10

Table 1: Simulation Parameters

Performace Metrics[1]

- **Packet Delivery Ratio (PDR)**
  - Ratio of the total number of packets actually received by destinations to the number of packets supposed to be delivered to them.

$$PDR = \frac{\sum Number.of.data.packets.received}{\sum Number.of.data.packets.sent} \tag{1}$$

- **Average End-to-End Delay (AEED)**
  - Time difference between sending of packets at the source and receiver[4].

$$AEED = \frac{\sum (Receiving.time - Sending.time)}{\sum Total.Packets} \tag{2}$$

[4] Combination of deferring, transmission, propagation, re-transmission time

Performace Metrics[2]

+ **Control Overhead**
  - Total number of packet transmit in network for route configuration and maintenance.

$$Overhead = \frac{\sum(Number.of.control.packets)}{\sum Total.sent.packets} \tag{3}$$

+ **Average Route Time (ART)**
  - Calculated as the time spent after route discovery till the route expires.

$$ART = Route.expire.time - Route.discover.time \tag{4}$$

Link Stability based Multicast Routing Protocol

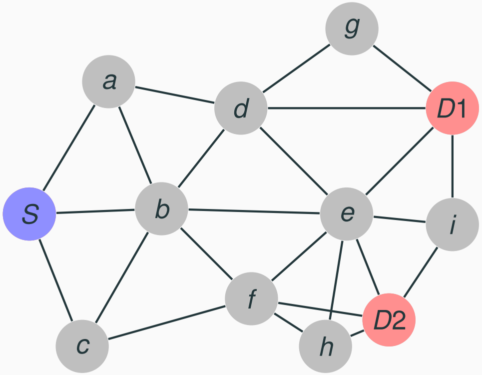
LSMRP: Link Stability based MRP

- Estimated link stability of every link en-route from source to set of destinations.
- Link stability is estimated by computing SINR value of requesting links.
- All incoming packets from neighbours during ‘expiry time’ interval are examined for SINR value.
- Select the link with highest SINR, Unlike others protocols which respond to first incoming packet (FCFS).
- Highest SINR link will sustain for longer duration.

LSMRP Process

Steps for LSMRP Process:

- Source generates a ‘JQ’ packet for multicast group address.
- Intermediates nodes receive ‘JQ’ and broadcast to others.
- Receiving nodes calculates SINR ratio from different senders.
- Node set a timer (‘Expiry Time’) that is initiated after receiving first packet.
- After ‘Expiry Time’, a node extract SINR of all links and select the maximum one.



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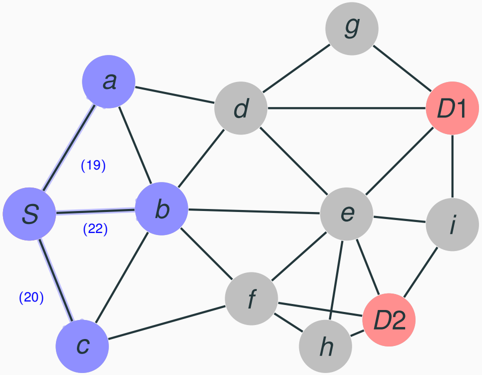

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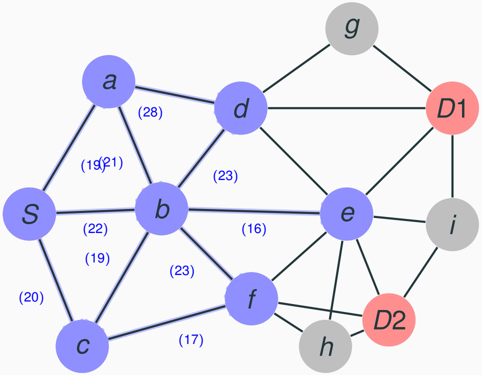

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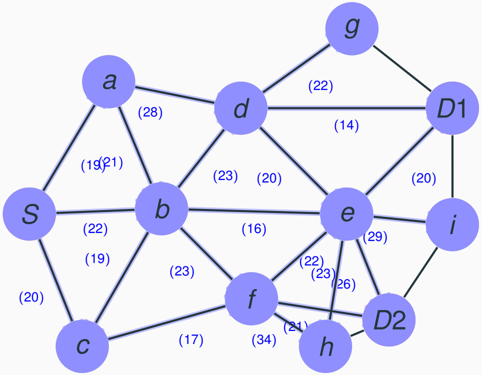

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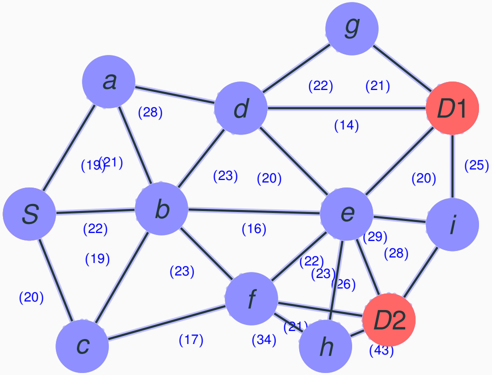

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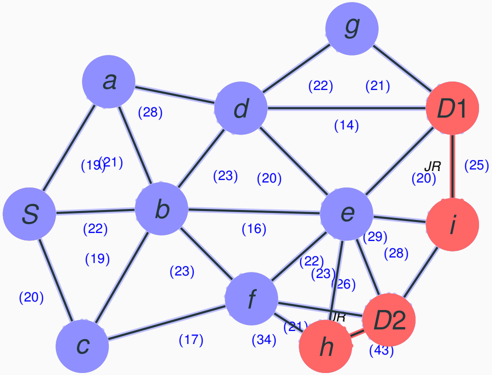

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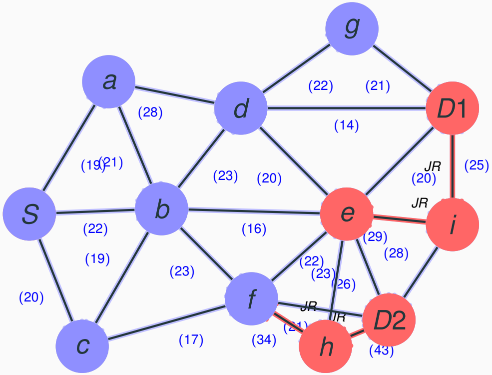

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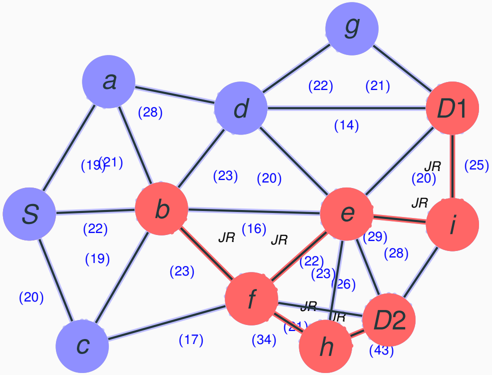

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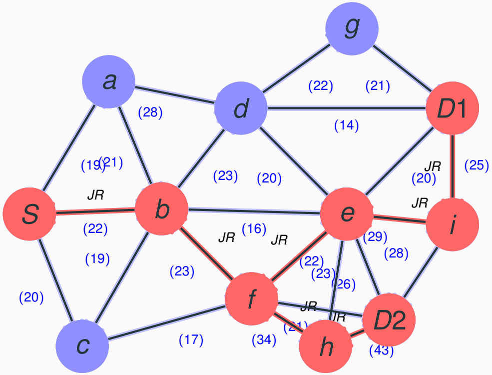

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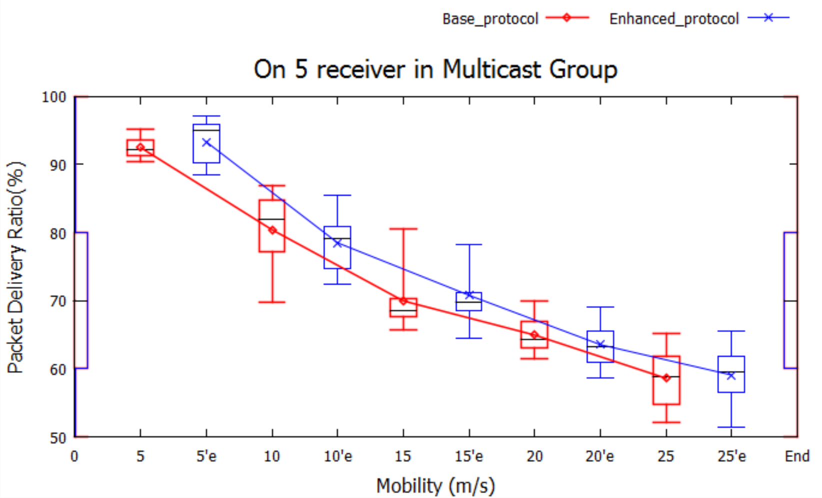
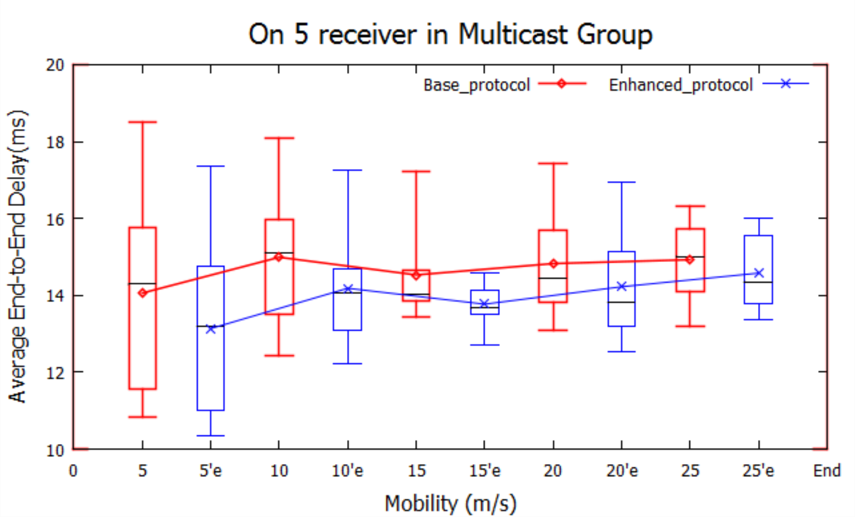
Results: Packet Delivery Raio



Results: Aerage End-to-End Delay



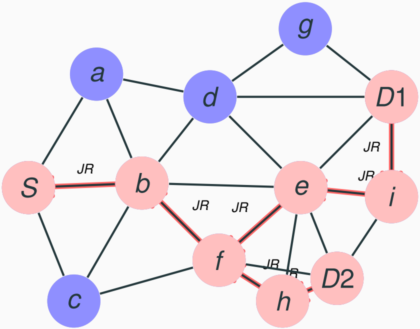
Link Stability based Multicast Routing Protocol

+ Limitations

* High signal strength node may be disconnected after a time interval as it has moved out from node's communication range.
* Choosing a link greedily with max-SINR easily causes unbalanced link usage.
* Set of stable links may lead to an unreliable route.
* Nearby node may have high RSSI, but not guarantee good bandwidth or data transfer rate.

Mobility Prediction with Link Stability in Multicast Routing

Issues in LSMRP



- After time t, node f will move to f' and node i will move to i'.
- This time node e will get disconnected from the $Route_{D1 \to S}$.

- So, we have to apply mobility prediction method to estimate the nodes' movement.

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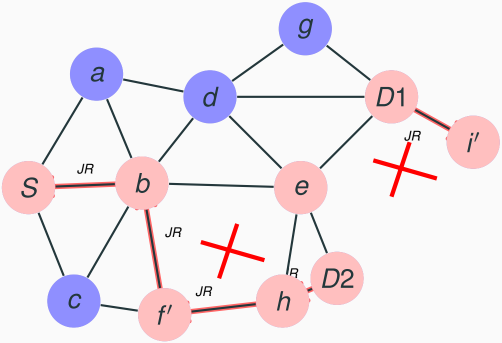

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MOraLISM: MObility prediction with LInk Stability based Multicast protocol in MANETs

- It is an extension of LSMRP approach.
- Mobility prediction is important for link stability.
- We are predicting node mobility for estimation of stable node.
- On the basis of variations in RSSI, examine node informs whether requesting node is coming towards or moving away.
- We will estimate 'Total Travel Time (TTT)' of a node in the communication range.

* Assumption: Nodes are moving with homogenous speed using RWP mobility model.

Types of Node Movement

- Node $N1$ can moves to the communication range (CR) of Node N in three ways.

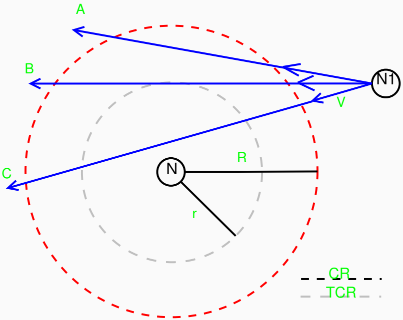


Figure 2: Possible combinations of node movement

- Three categories: A(outside TCR), B(on TCR) and C(inside TCR).
- Discard all the links which belongs to class A.
- Always consider category C links for reliable communication.
- Select category B if C is not. available.

Total Travel Time Estimation

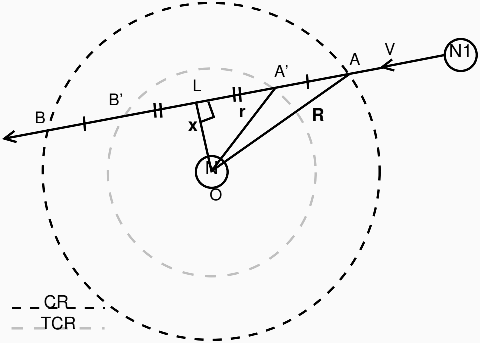


Figure 3: Node coming inside CR of estimating node

- Estimate total travel time (TTT) of node $N1$ in CR of node N.

$$TTT = TTD/V$$
$$TTD = 2(AA' + A'L) \quad (5)$$

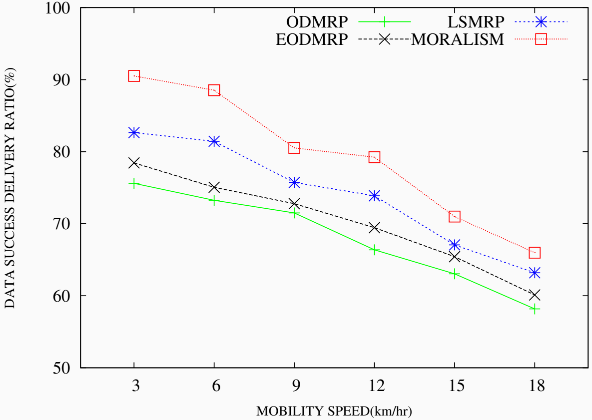
- After applying pythogoras theorm:

$$A'L = \frac{R^2 - r^2 - (AA')^2}{2 * (AA')} \quad (6)$$

- AA' have to be estimated locally by applying timer.

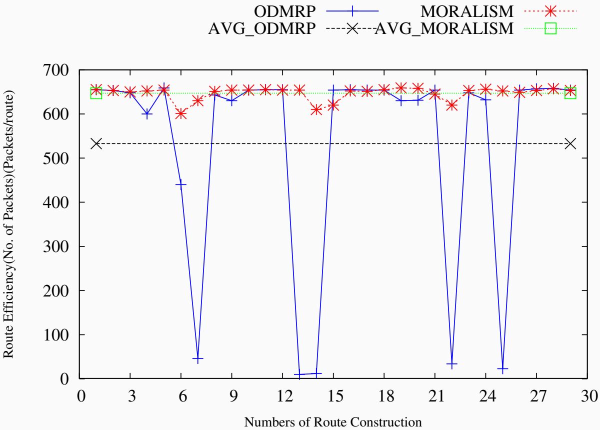
TTD: Total Travel Distance, V: Velocity, R: Radius of CR and r: Radius of *Threshold_CR*

Results: Data Successful Delivery Ratio



- MORALISM outperforms all protocol around 11% to 19%.
- It sustains till RRI by prior prediction of node movement.

Results: Available Route Lifetime



- In MORALISM protocol, route never fails during RRI.
- Approximate 100 more packets received than ODMRP.

Mobility Prediction Model and Link Stability based Multicast routing protocol

+ Limitations

* This approach will only work for low mobility scenario and RWP mobility model (i.e. for a specific direction).
* Selection of one un-reliable link from the set of stable links may cause unreliable route.
* Average Prediction overhead is increases in the network.

Improved Multicast Routing using Link Stability and Route Stability

Multicast Routing: Link and Route Stability

- Link stability, is calculated by probability of successful transmission of HELLO packets.

$$P_{ij} = \frac{N_{recv}}{N_{exp}} \tag{7}$$

- The maximum value of P_{ij} indicates most stable link.
- Selection of a stable link escalates route stability, but the route may contain some less stable links also which will decrease the throughput.
- One possible solution is to compute the probability of stable route.

$$P_{route} = \prod_{i=1}^{I} P_i \tag{8}$$

- The maximum value of P_{route} indicates most stable link.

I Total number of intermediate node for particular route.

Link and Route Stability

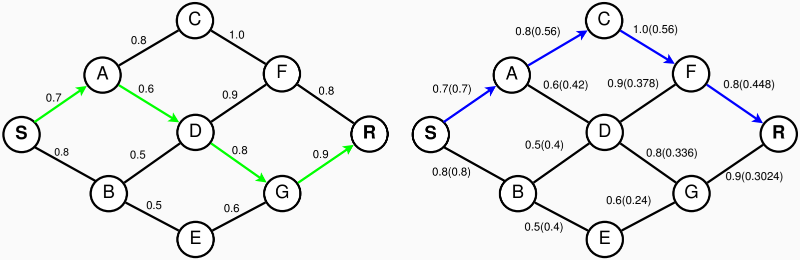
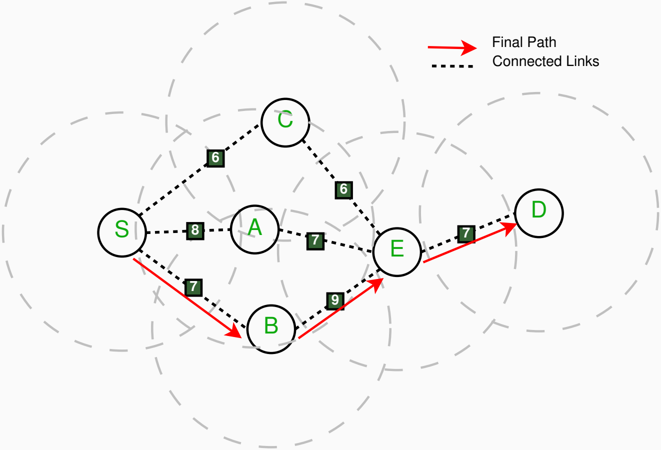


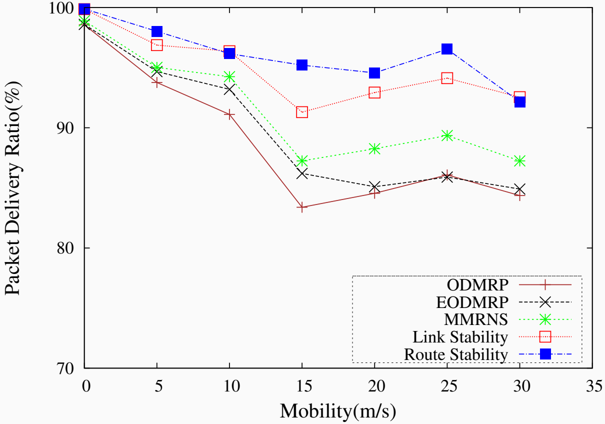
Figure 4: Differentiate between link and route stability

Probabilistic Approach Process

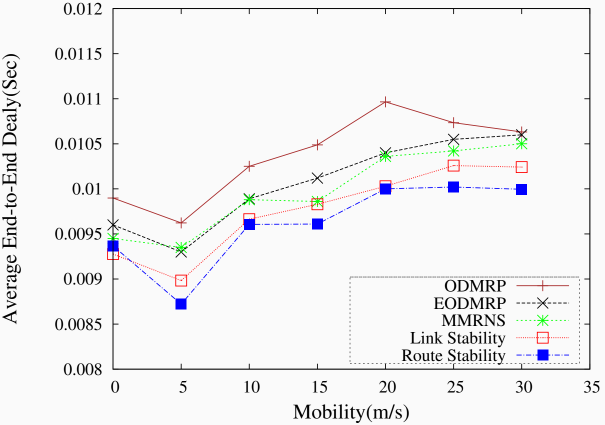


- Calculate 'Packet Success Ratio' at each link by transmitting Periodic hello packets.
- Route S-B-E-D have higher probability 0.441.

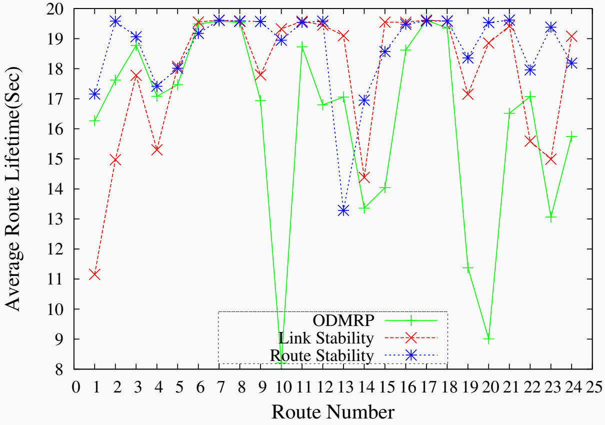
Results:Packet Delivery Ratio



Results: Average End-to-End Delay



Results: Average Route Lifetime



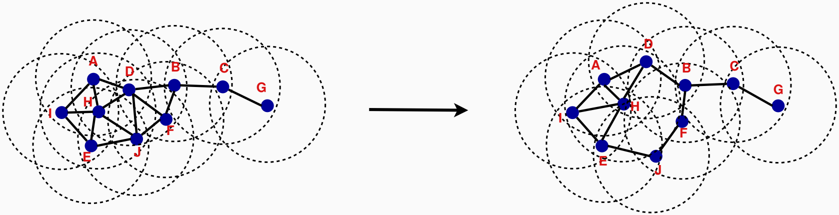
Improved multicast routing using link stability and route stability

+ Limitations

* Packet overhead is increased as compared to other routing protocol.
* Single QoS metric unable to meet all network requirements.

Multi-constraints Link Stable Multicast Routing Protocol

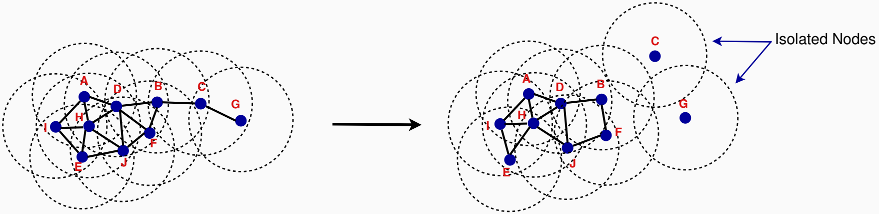
Effect of node density: Connectivty among Nodes



(a) At time t

(b) At time $t' = t+i_2$

Effect of node density: Isolation of Nodes



(a) At time t

(b) At time t' = t+i $_1$

Process of Multi-objective Base Function Multicast Routing

- Calculate the Link Stability Factor on the basis of:
  - Contention Count
  - Hop Count
  - Signal Strength
- Determine maximum *LSF* value (*max_LSF*) at each hop.
- Prune all the adjacent nodes that has less *LSF*.
- Create a mesh consisting of stable forwarding nodes for reliable end-to-end data transmission.
- Create a route which doesn't contain isolated nodes and also has lesser contention.

LSF

- **Contention Count** The contention set is maintained by each node in the network and it stores the address of all adjacent nodes. The neighbor nodes for node F can be given by the contention set C_F:

  $$C_F = \{A, B, C, D\}$$

  Then contention count (ρ) of a node F can be represented as:

  $$\rho_F = |S|$$

  where $|S|$ signifies the cardinality of contention set C_F and ρ_F represents the contention count of node F. As example, contention count for node F is 4.

LSF

- Signal strength is directly proportional to link stability factor.

$$LSF_i \propto SS_i^*$$

- An efficient protocol must select a stable route while minimizing the hop count. Therefore, hop count is inversely proportional to LSF.

$$LSF_i \propto \frac{1}{HC_i^\#}$$

- From Equations, LSF_i can be written as:

$$LSF_i \propto \frac{SS_i^*}{HC_i^\#}$$

* Upper-Lower Bound Normalization
\# Upper Bound Normalization
i particular link

LSF[2]

- Contention count should be a median which will provide better connectivity and contention-free route.

$$CC_{med} = \frac{CC^*_{max} + CC^*_{min}}{2}$$

$$CC_{diff_i} = |CC^*_i - CC_{med}|$$

- Hence, LSF_i can be calculated as:

$$LSF_i = \frac{SS^*_i}{HC^{\#}_i} - |CC^*_i - CC_{med}|$$

$$Stable\_Link = \max_{i=1}^{rl} LSF_i$$

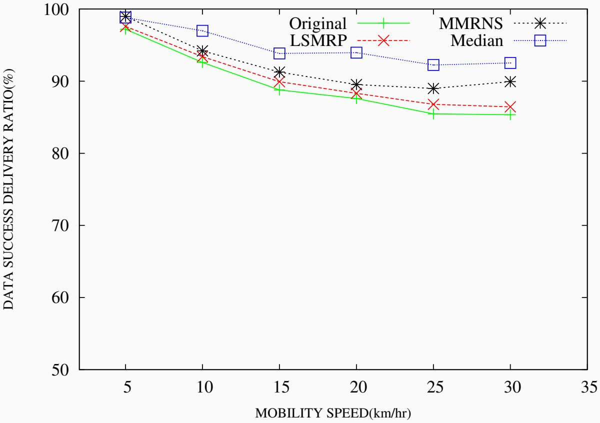
---

* Upper-Lower Bound Normalization # Upper Bound Normalization
i particular link, rl total number of requested links
CC_{med} Median Contention Count
$0 < CC_{diff_i} < 0.5$ i.e. 0 = Highly recommended & 0.5 = Not recommended
$-0.5 < LSF_i < 1$ i.e. 1 = Highly recommended & -0.5 = Not recommended

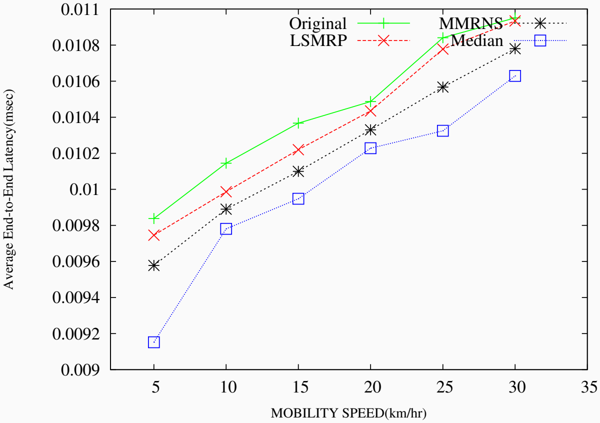
Example

Contention Count	RSSI	Hop Count	$N_{ContentionCount}$	N_{RSSI}	$N_{HopCount}$	LSF
23	10.363956	1	0.6	0.012132	0.5	-0.075736
24	16.055869	2	0.7	0.201862	1	0.001862
27	10.143511	2	1	0.004784	1	-0.495216
22	16.472802	2	0.5	0.21576	1	0.21576
19	14.421476	2	0.2	0.147383	1	-0.152617
20	28.329875	2	0.3	0.610996	1	0.410996
17	18.335973	2	0	0.277866	1	-0.222134

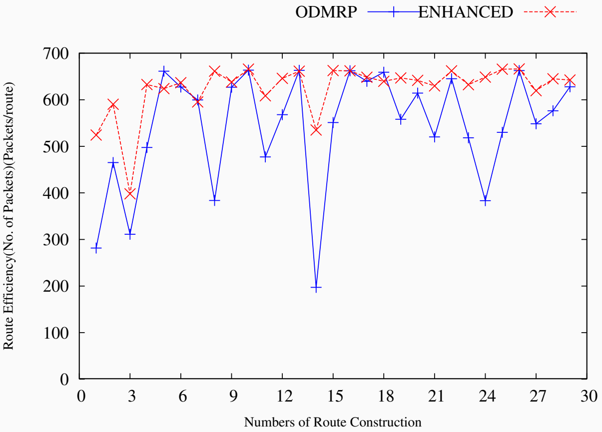
Results: Data Successful Delivery Ratio



Results: Average End-to-End Delay



Results: Average Route Lifetime



Flying Adhoc Networks: An Introduction

Flying Adhoc Networks

- Flying Adhoc Networks (FANETs[5]) is a combination of MANET and UAV (Unmanned Aerial Vehicles).
- UAVs are
    - Remotely Piloted aircraft
        - Controlled from a Remote Location.
        - Fly automatically based on pre-program plans.
    - High Mobility Devices.

---

5 lker Bekmezci, Ozgur Koray Sahingoz, amil Temel. Flying Ad-Hoc Networks (FANETs): A survey. Ad Hoc Networks, Volume 11, Issue 3, May 2013, Pages 1254-1270, ISSN 1570-8705

Applications

- Real-time Surveillance’s Missions
- Border control and battlefield
- Homeland Defense and Security
- Natural disaster Recovery

Use Case Scenario

Conclusions

Conclusions

- QoS–aware MRP will allow us to overcome the challenges of link failure and node mobility.
- Stabilization is required for achieving superior performance and link quality.
- Enhances Quality of service(QoS) by computing various link stability parameter.

Future Work

- Apply all implemented techniques in emulation environment (video data) for the validation of simulation results.
- Develop a new routing algorithm and networking model to construct a reliable integrated model for FANETs.

Publications

- Journals
  - Singal, G.; Laxmi, V.; Rao, V.; T. Swati; Gaur, M.S., "Improved Multicast Routing in MANETs using Link and Route Stability", volume 30, number 11, year 2017, International Journal of Communication Systems, Wiley-Journal.
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  - Singal, G.; Laxmi, V.; Gaur, M.S.; Rao, V., "Multi-constraints Link Stable Multicast Routing Protocol in Adhoc Networks", vol 63, pages 115–128, year 2017, AD HOC NETWORKS, ELSEVIER-Journal.

- Conferences
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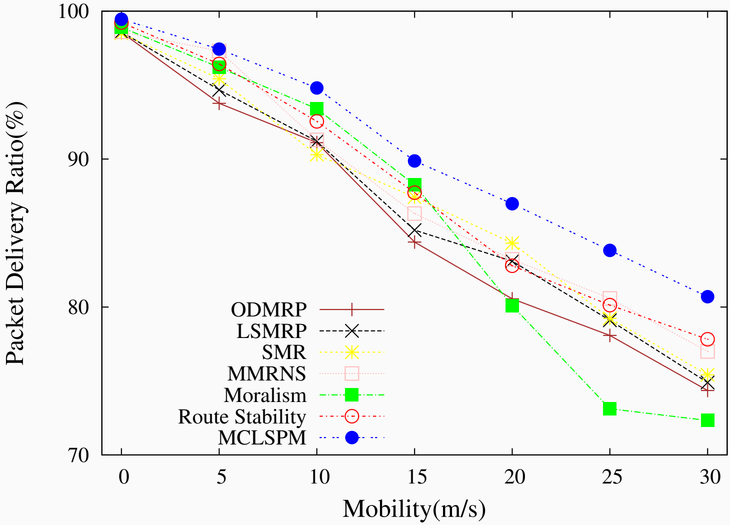
Thank You

FANETs: Simulation Parameters

Simulation Parameter	Values
Simulator	EXata/Cyber v2.0
Simulation Time	500 Seconds
Scenario Dimension	(1-10) Sq.km.
Height of Node	0-500m
Transmission Range	500m
Mobility Model	Random mobility model
Mobility	10-30 m/s
Routing Protocol	ODMRP, LSMRP
Traffic Type	Multiple MCBR
Size of Packet	512 bytes
Maximum Data Rate	2-54 Mbps
Multicast Group Size	2-5
Number of nodes	(10-50)

RESULTS: PACKET DELIVERY RATIO



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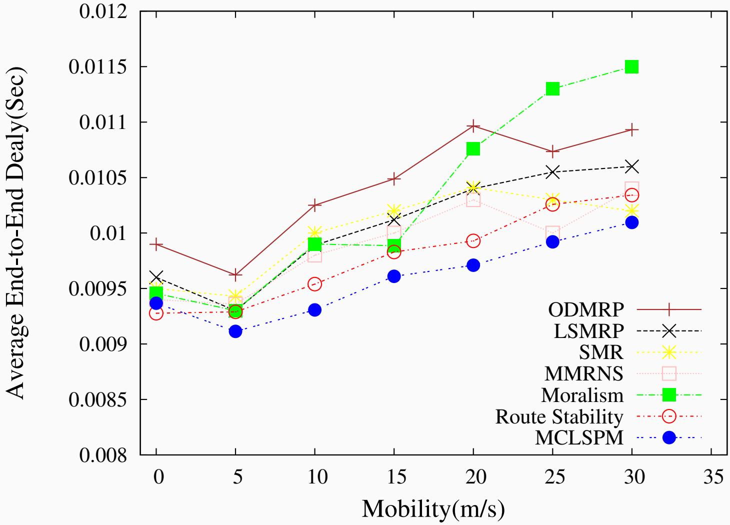
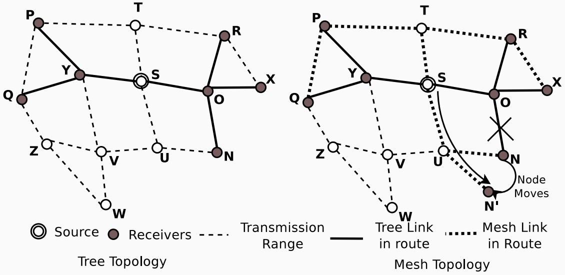
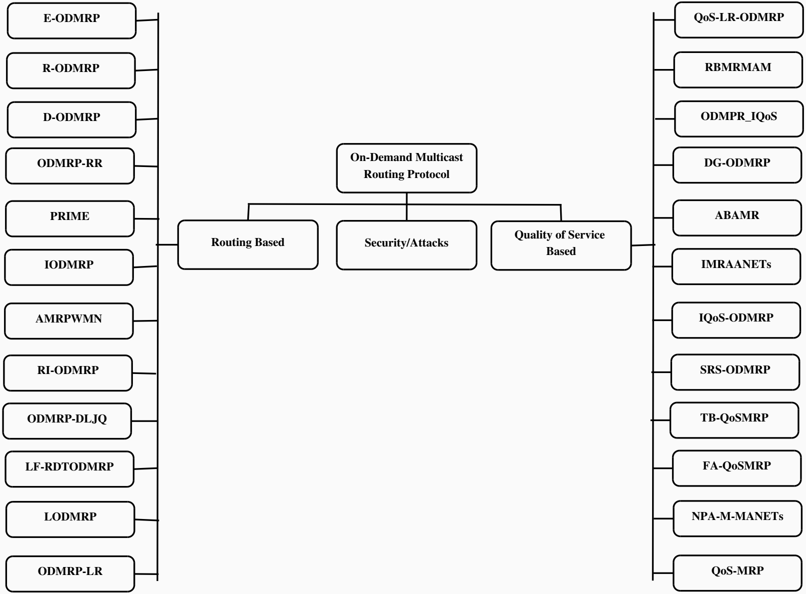


Mesh over Tree based MRP

+ Tree based MRP is very efficient in network routing and better packet delivery ratio as compared to other topology.
- Excessive reconfiguration overhead in case of rerouting.
+ Mesh based MRP have limited reconfiguration by redundancy of packets.
+ In mesh based MRP their exist more than one active route in between single pair of source and destination.



ODMRP Extensions



LSMRP: Comparison

Protocol	QoS Metric	U/M	Year	Technique	Simulator	Type
DG-ODMRP [5]	Delay	M	2009	Routing Selection	1	C
RB-MRMAM [15]	SS	M	2009	Forwarding Group	1	C
SRS-ODMRP [2]	Energy and Delay	M	2010	Mobility Handling	4	C
QoS-MRPM [12]	Entropy	M	2012	Route Discovery Suppression	1	C
MMRNS [3]	Power and Distance	M	2012	Mobility Handling	1	J
FGMOM	SS	M	2013	Link state prediction	2	J
NPA-MAM [14]	Energy	M	2013	Routing Selection	1	C
MPMEL [6]		U	2013	Mobility Prediction	1	C
LSMRP [**?**]	RSSI	M	2014	Routing Selection	3	C
MORALSIM	RSSI	M	2016	Mobility Prediction	3	J

Table 2: Comparison with other Protocol, U: Unicast, M: Multicast, 1: NS2, 2: Glomosim, 3: Qualnet, 4: Opnet

Link and Route Stability Comparison

Protocol	QoS Metric	U/M	Year	Technique	Simulator	Type
PPMA [9]	Energy, node mobility and availability	M	2006	Tree Based	1	J
IQoS-ODMRP [7]	Delay and Bandwidth	M	2010	Routing Selection	2	C
TB-QoSMRP [10]	Energy	M	2011	Routing Selection	2	C
FA-QoSMRP [4]	Delay and Energy	M	2012	Routing Selection	1	C
CLS-AODV [16]	SS	U	2010	link and Route Selection	1	J
IMRPLR	ETX without Ack	M	2016	Link and Route Selection	3	J

Table 3: Comparison with other Protocol, U: Unicast, M: Multicast, 1: NS2, 2: Glomosim, 3: Qualnet, 4: Opnet

MCLSPM: Comparison

Protocol	QoS Metric	U/M	Year	Technique	Simulator	Type
AAM-QoS [11]	Bandwidth and Delay	M	2010	Routing Selection	1	C
IMRAANETs [8]	Energy	M	2010	Routing Selection	1	C
RadiaLE [1]	LQE	U	2011	Routing Selection	1	J
NEBM [13]	PER	U	2014	Mobility Handling	1	J
ITCD [17]	Interference, delay	U	2015	Topology control	1	J
MCLSPM	Node Density, RSSI, Hop Count	M	2016 -	Routing Selection	3	J

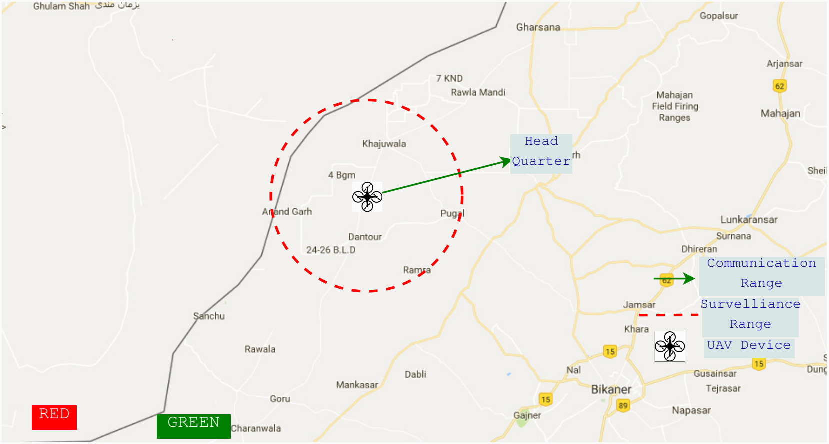
Table 4: Comparison with other Protocol, U: Unicast, M: Multicast, 1: NS2, 2: Glomosim, 3: Qualnet, 4: Opnet

Effect of multiple communication on PDR

- Area: 1000 sq. m
- Number of nodes: 60
- Data rate: 6 mb/s

Configuration	1	13	37	11	17	43	9	11
One Source and Four Destinations	97.0%	98%	97.3%	97.9%	-	-	-	-
Two Source and Seven Destinations	97.1%	97.9%	97.4%	97.8%	96.4%	97.7%	97.3%	-
Two Source and Eight Destinations with common destination	97.1%	97.9%	97.4%	97.2%	96.4%	97.7%	97.3%	96.3%
Two Source and Eight Destinations with mobility $5m/s$	94.3%	93.5%	94.1%	92.9%	93.8%	93.7%	95.9%	93.2%

UAV Scenario



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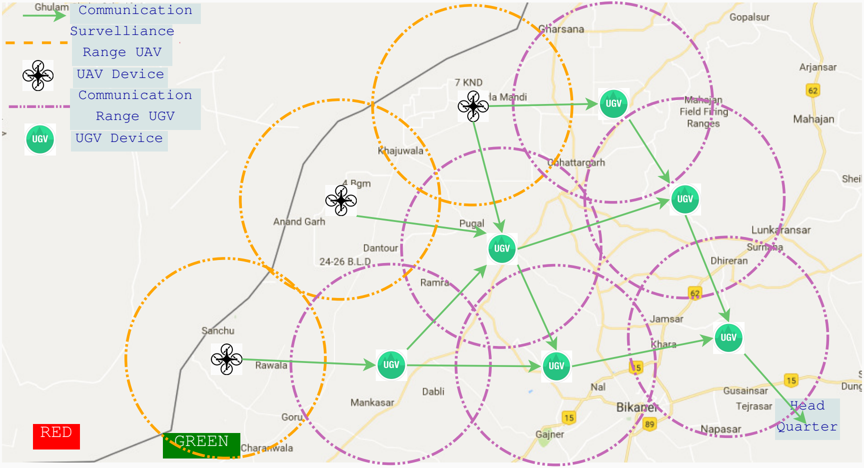
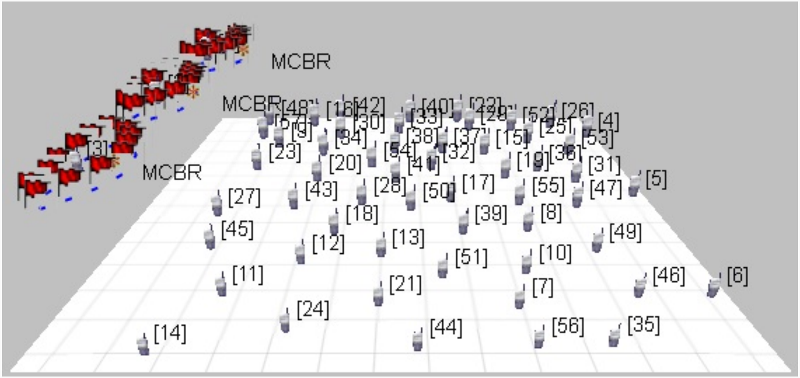


UAV Topology



Network Representation

A MANET network can be described by triplet $(G(V, E), P_e, \theta(R))$, where

- The graph $G(V, E)$ represents the topology of network.

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- $\{P_e(l, i, j) | l, i, j \in V, P_e \leftarrow \{\varphi(e), \eta(v), \rho\}\}$ shows the Probability of link(P_e) at route R, for any source i to destiantion j that depends on signal stregth, contention set and hop count.

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- $\{\theta(R)(r,S,D_i) | r,S,D_i \in V\}$ shows the route cost factor at route R, for any source device S to destination D_i, while considering a multicast routing protocol.

Network Representation[2]

- A stable link has maximum link quality from a set of requested links for a particular node.

$$L = \max_{i=1}^{rl}\left(P_{e_i}\right)$$

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$$R = \varnothing$$
$$R = R \bigcup_{i=1}^{l} (L_i)$$

* In wireless network, the probability of route failure (RF) dependes on the weakest link in the route.

$$P_{RF} = 1 - \min_{i=1}^{l} (P_{e_i})$$

---

rl Total number of requested links
l Total number of links in a stable route

Probability Model

- Link quality (l_q) values vary in the range of X to Y, i.e. $X < Y$.

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- Probability of a link (P_e) is calculated by normalized l_q in between 0 to 1.
- $\theta(R)$ (Route cost factor) of a path is:

$$\theta(R) = \sum_{i=1}^{l} - \log\{P_{e_i}\}$$

Probability Model

- Link quality (l_q) values vary in the range of X to Y, i.e. $X < Y$.
- Probability of a link (P_e) is calculated by normalized l_q in between 0 to 1.
- $\theta(R)$ (Route cost factor) of a path is:

$$\theta(R) = \sum_{i=1}^{l} - \log\{P_{e_i}\}$$

- The stable route (S_R) is minimum of all routes cost factor for particular source and destination.

$$S_R = \min_{i=1}^{p} \theta(R)_i$$

---

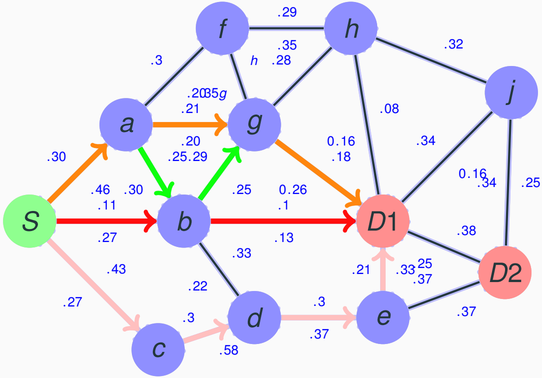
p Total number of path for single source and destination

Probability Distribution

X	S	A	B	C	D	E	F	G	H	D_1	J	D_2
S	*	0.30	0.11	0.43	-	-	-	-	-	-	-	-
A	0.45	*	0.27	-	-	-	0.46	0.21	-	-	-	-
B	0.27	0.30	*	-	0.33	-	-	0.29	-	0.10	-	-
C	0.27	-	-	*	0.30	-	-	-	-	-	-	-
D	-	-	0.24	0.58	*	0.30	-	-	-	-	-	-
E	-	-	-	-	0.37	*	-	-	-	0.21	-	0.37
F	-	0.20	-	-	-	-	*	-	0.29	-	-	-
G	-	0.20	0.25	-	-	-	-	*	0.28	0.18	-	-
H	-	-	-	-	-	-	0.54	0.24	*	0.08	0.32	
D_1	-	-	0.13	-	-	0.33	-	0.26	0.16	*	0.34	0.38
J	-	-	-	-	-	-	-	-	0.27	0.16	*	0.25
D_2	-	-	-	-	-	0.37	-	-	-	0.25	0.34	*

Table 5: Probability Distribution

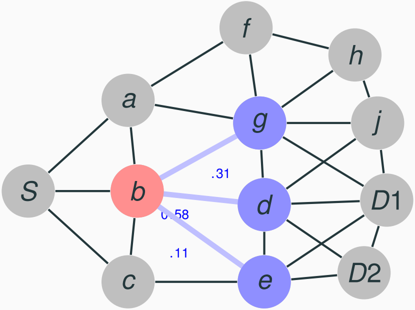
EXAMPLE



Routes	Routes Cost
$S \rightarrow A \rightarrow G \rightarrow D_1$	1.93
$S \rightarrow B \rightarrow D_1$	1.95
$S \rightarrow A \rightarrow B \rightarrow D_1$	2.12
$S \rightarrow B \rightarrow G \rightarrow D_1$	2.09
$S \rightarrow C \rightarrow D \rightarrow E \rightarrow D_1$	2.07
$S \rightarrow A \rightarrow B \rightarrow G \rightarrow D_1$	2.39

Table 6: Routes for $S \rightsquigarrow D_1$

EXAMPLE



Node	CC	RSSI	HC	N_{CC}	N_{RSSI}	N_{HC}	LSF	P
g	7	28	2	1	0.61	1	0.11	0.31
d	6	29	2	0.50	0.64	1	0.64	0.58
e	5	17	2	0	0.22	1	-0.28	0.11

Table 7: Probability Estimation