Reliable On-Demand Routing Protocols For Mobile Ad-Hoc Networks

A Thesis submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy (Ph.D.)

By

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Abstract

Mobile Ad-Hoc Network (MANET) facilitates the creation of dynamic reconfigurable networks, without centralized infrastructure. MANET routing protocols have to face high challenges like link instability, node mobility, frequently changing topologies and energy consumption of node, due to these challenges routing becomes one of the core issues in MANETs. This Thesis mainly focuses on the reactive routing protocol such as Ad-Hoc On-Demand Distance Vector (AODV) routing protocol.

Reliable and Efficient Reactive Routing Protocol (RERRP) for MANET has been proposed to reduce the link breakages between the moving nodes. This scheme selects a reliable route using Reliability Factor (RF); the RF considers Route Expiration Time and Hop Count to select a routing path with high reliability and have less number of hops. The simulation result shows that RERRP outperforms AODV and enhance the packet delivery fraction (PDF) by around 6% and reduces the network routing load (NRL) by around 30%.

Broadcasting in MANET could cause serious redundancy, contention, and collision of the packets. A scheme, Effective Broadcast Control Routing Protocol (EBCRP) has been proposed for the controlling of broadcast storm problem in a MANET. The EBCRP is mainly selects the reliable node while controlling the redundant re-broadcast of the route request packet. The proposed algorithm EBCRP is an on-demand routing protocol, therefore AODV route discovery mechanism was selected as the base of this scheme. The analysis of the performance of EBCRP has revealed that the EBCRP have controlled the routing overhead significantly, reduces it around 70% and enhance the packet delivery by 13% as compared to AODV.

An Energy Sensible and Route Stability Based Routing Protocol (ESRSBR) have also been proposed that mainly focuses on increasing the network lifetime with better packet delivery. The ESRSBR supports those nodes to participate in the data transfer that have more residual energy related to their neighbour nodes. The proposed protocol also keeps track of the stability of the links between the nodes. Finally, the ESRSBR selects those routes which consist of nodes that have more residual energy and have stable links. The comparative analysis of ESRSBR with AODV and recently proposed routing protocol called Link Stability and Energy Aware (LSEA) routing protocol revealed that the proposed protocol ESRSBR has a significantly affect the network lifetime, increases it around 10% and 13% as compared to LSEA and AODV protocols respectively. The ESRSBR also decreases the routing overhead by 22% over LSEA and by 38% over AODV.

To My Family

Acknowledgements

My humble gratitude to the Creator of our universe, profound thanks to my Lord without His blessing and mercy this thesis would not have final shape.

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List of Abbreviations

AODV	Ad-Hoc On-Demand Distance Vector Protocol
BID	Broadcast ID
CBR	Continuous Bit Rate
CMMBCR	Conditional Max-Min Battery Capacity Routing
DARPA	Defence Advanced Research Projects Agency
DCE	Data Communication Equipment
DIP	Destination IP Address
DREAM	Distance Routing Effect Algorithm for Mobility
DSDV	Destination-Sequenced Distance-Vector Routing
DSN	Destination Sequence Number
DSR	Dynamic Source Routing
DTE	Data Terminal Equipment
EAODV	Energy Aware AODV
EBCRP	Effective Broadcast Control Routing Protocol
EB-RREP	Effective Broadcast Route Reply
EB-RREQ	Effective Broadcast Route Request
ES-RREP	Energy Sensible Route Reply
ES-RREQ	Energy Sensible Route Request
ESRSBR	Energy Sensible and Route Stability Based Routing
FORP	Flow Oriented Routing Protocol
GPS	Global Positioning System
HC	Hop Count
HT	Holding Time
IARP	Intra-Zone Routing Protocol
IERP	Inter-Zone Routing Protocol
LAR	Location Aided Routing
LET	Link Expiration Time
LSEA	Link Stability and Energy Aware
MANET	Mobile Ad-Hoc Network
MBCR	Minimum Battery Cost Routing
MMBCR	Min-Max Battery Cost Routing

MPR	Multipoint Relay
MTPR	Minimum Total Transmission Power Routing
NRL	Network Routing Load
OLSR	Optimized Link State Routing
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistant
PDF	Packet Delivery Fraction
RABR	Route Lifetime Assessment Based Routing
RE	Residual Energy
RERR	Route Error
RE-RREP	Reliable and Efficient Route Reply
RE-RREQ	Reliable and Efficient Route Request
RERRP	Reliable and Efficient Reactive Routing Protocol
RET	Route Expiration Time
RF	Reliability Factor
RN	Reliable Node
RR	Reliable Route
RREP	Route Reply
RREQ	Route Request
RSS	Received Signal Strength
RT-Table	Routing Table
RWP	Random Waypoint Mobility
SIP	Source IP Address
SSA	Signal Stability based Adaptive
SSN	Source Sequence Number
TRG	Two Ray Ground
Wi-Fi	Wireless Fidelity
WMN	Wireless Mesh Network
WSN	Wireless Sensor Network
ZLERP	Zone and Link Expiry based Routing Protocol
ZRP	Zone Routing Protocol

List of Publications

Published Journal Papers

- S. M. Khan, R. Nilavalan and A. F. Sallama, "A Novel Approach for Reliable Route Discovery in Mobile Ad-Hoc Network," *Wireless Personal Communications,* vol. 83, pp. 1519-1529, July 2015.

- Sallama, M. Abbod and S. M. Khan, "Applying Sequential Particle Swarm Optimization Algorithm to Improve Power Generation Quality," International Journal of Engineering and Technology, vol. 4, pp. 223-233, 2014.

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Poster Presentation

- S. M. Khan, Q. Ni "Delay-Constraint Routing Simulation For Vehicular Ad Hoc Network", Presented Poster on IEEE-SED-ResCon, June 2011, Brunel University, UK.

Submitted Journal Paper

- S. M. Khan, R. Nilavalan, "Energy Sensible and Route Stability Based Routing Protocol for Mobile Ad-Hoc Network," Wireless Personal Communications, August 2015.

Statement of originality

While registering as a candidate for the above degree, I have not been registered for any other research award. I certify that the results and conclusions presented in this thesis are my own work. This thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree. Due acknowledgement has been made in the text to all other material used.

Chapter 1

Introduction

1.1 Introduction

In recent years, an incredible development has been observed in the arena of wireless networks. This remarkable growth in wireless network is because of its easiness to keep people connected. The people's lifestyle has also improved by wireless networks, because of the fact that it keeps the people connected, entertained and have impacted positively on their productivity.

Mobile Ad-Hoc Network (MANET) is an infrastructure-less wireless network [1]. In MANET every node can communicate with each other as well as they can move randomly in any direction in the network [2]. These characteristics of mobility and infrastructure less nature of MANET are very beneficial for military and natural disaster applications [3].

Following sections of this chapter present motivation of this work, and the scope of this research. Further, the research methodology and the major contributions to knowledge have been described. In the last section of this chapter, thesis organogram and brief outlines of thesis chapters are presented.

1.2 Motivation

This thesis is the end result of research efforts put into addressing the following issues by designing, analysing and evaluating techniques to overcome these issues.

Mobility is an important feature of the MANET. Due to the mobility of node the network topology becomes very dynamic that causes the path disconnection between the data sending and receiving nodes. AODV [4] and DSR [5] are considered as standard in on demand routing protocols - both of them selects the shortest path between the source node and the destination node for data transfer. The shortest path may not always be the most reliable or a long live path for data transfer. The frequent breakage of the established path degrades the network performance. When an active or established route between source and destination is broken, the routing protocol executes route maintenance procedure that consumes many network resources that eventually influence negatively on the performance of the network. It is very important to find the longest life route between source and destination [6, 7]. The issue of finding a long life route between the source and destination nodes – becomes the source of motivation for research and development of a routing algorithm that can select a longer life route, reduce the number of route re-discovery and maintenance procedure and eventually enhance the performance of the network.

Broadcasting is basic communication operation used in the route discovery process of many on-demand routing protocols in Mobile Ad-hoc Network (MANET) such as AODV [4] and DSR [5]. When a source node wants to send a data packet, it initiates the route discovery process by broadcasting RREQ packet. After receiving this RREQ packet by neighbouring or intermediate node, if this RREQ packet already been processed by this node, it discards this RREQ packet. Otherwise – it checks for the route to the destination if this node did not find the valid route to the destination; the RREQ packet will be rebroadcast by the node to its neighbours. This process of broadcasting and rebroadcasting of the RREQ packet continues until the required destination discovered. The process of rebroadcasting is also referred as flooding, and it is the main source for the potential increase in retransmission of the RREQ packet in the network; as a result, it leads to high network congestion and significant network performance degradation. This phenomenon is basically referred as broadcast storm problem [8]. Rebroadcasting enhances the overhead of the network and also consumed bandwidth available in the network [8, 9]. Therefore, controlling the redundant rebroadcast in the network for getting better network performance is a challenging task.

In designing of routing protocol for Mobile Ad-Hoc Networks (MANETs) energy consumption is also one of the most complicated and challenging issue, because mobile nodes are powered by batteries. Moreover, restoring or recharging batteries is generally unimaginable in critical situations like in military or relief missions. Battery decaying of a node does not affect itself only, but the overall lifespan of a system is affected. Link failure in the network will lead to re-routing and establishing a fresh route from source to destination. Frequent route discoveries are required, to re-establish the broken path which can cause additional power utilization of nodes. Thus, to extend the lifetime of the network considering the node energy in the routing process is an important solution. This became a reason of motivation to build a routing scheme that can reduce the node energy usage, extend the lifetime of the network, reduce the packet loss and make intelligent routing decision by considering battery levels of nodes.

1.3 Scope of the thesis

Since the research presented in this thesis tackles multiple issues, the aims are multi-fold:

a. Designing and development of an on demand routing protocol for Mobile Ad-Hoc Network (MANET), with the aim of reducing the frequent link breakage and enhancing the packet delivery by incorporating the mobility parameters like node speed and node direction. The protocol should also be expected to reduce the routing overhead of the network while enhancing the data delivery.

b. The research aims at a design of a MANET routing protocol that reduce the retransmission of the RREQ packet by selecting the specific nodes to rebroadcast the RREQ packet. Furthermore, the designed protocol should discover a reliable route between the source node and the destination node which offer minimum network overhead while maintaining high data delivery and high throughput.

c. The research also aims to address the important energy constraint of the mobile node and develop a routing protocol that enhances the network life and reduce the energy consumption of the node.

1.4 Research Methodology

Following five stage strategy were followed in succeeding the desired goals and objectives.

- Literature Review
- Comprehensive analysis of various published works
- Identification of issues and problem
- Suggested solutions to overcoming the problem
- Network Simulator used for verification of results

Related research articles, research papers that include journal papers and conference proceedings were reviewed in the initial phase of this research. In the literature review process, reactive routing protocols in MANETs were deeply studied.

Secondly, the routing process of On-Demand routing protocols has been studied thoroughly that involved various published articles on this topic. During the literature review and analysis of the published work, some issues related to route discovery were identified. A new route discovery processes were proposed to overcome these issues. The proposed algorithms were implemented and tested in Network Simulator (NS-2). The functions of the proposed algorithm were also tested using Simulator, individually.

Moreover, the performance of the proposed algorithms was compared with the other existing protocols. Finally, the obtained results were deeply analysed and explained.

1.5 Contribution to Knowledge

This thesis contributes to knowledge by designing and developing of reliable route discovery schemes for MANETs. During the attempt to design the proposed schemes, following contributions to knowledge emerged.

a. A new Reliability-Based routing protocol called Reliable and Efficient Reactive Routing Protocol (RERRP) has been proposed that specifically designed to minimize the frequent link breakage and enhances the packet delivery ratio in MANETs. This scheme selects a reliable route using Reliability Factor (RF); the RF considers Route Expiration Time and Hop Count to select a routing path with high reliability and have less number of hops.

b. An Effective Broadcast Control Routing Protocol (EBCRP) [10] has been proposed for controlling the "Broadcast Storm" problem in a MANET. The EBCRP is mainly considered the mobility parameters of a node while controlling the redundant re-broadcast of the route request packet. The selective forwarding concept has been introduced in this scheme to control the "Broadcast Storm" issue related to reactive routing protocols. The proposed EBCRP control the redundant re-broadcasting of the RREQ packet by allowing only the reliable nodes (RN) to rebroadcast the RREQ packet. The selection of RN basically depends upon the position, direction and speed of the node. The comparative analysis revealed that by controlling the flooding of RREQ packet, the proposed protocol EBCRP have significantly reduces the network routing load and enhances the packet delivery ratio.

c. An Energy Sensible and Route Stability Based Routing Protocol (ESRSBR) have also been proposed that mainly focuses on increasing the network lifetime with better packet delivery. The ESRSBR supports those nodes to participate in the data transfer that have more residual energy related to their neighbour nodes. The proposed protocol also keeps track of the stability of the links between the nodes. Finally, the ESRSBR selects those routes which consist of nodes that have more residual energy and have stable links.

1.6 Thesis Organisation

This thesis consists of six chapters cf. Figure 1-1. After an introductory chapter-1, the chapter-2 introduces the MANETs and presented its advantages and characteristics. Furthermore, chapter-2 also elaborated the taxonomy of the MANET routing protocols. At the end of this chapter various routing protocols were explained with the help of examples.

Chapter-3 provides a detailed description of the different components of Reliable and Efficient Reactive Routing Protocol (RERRP). Afterwards, a deep comparative analysis of RERRP with existing on demand routing protocol in several scenarios are also presented at the end of this chapter.

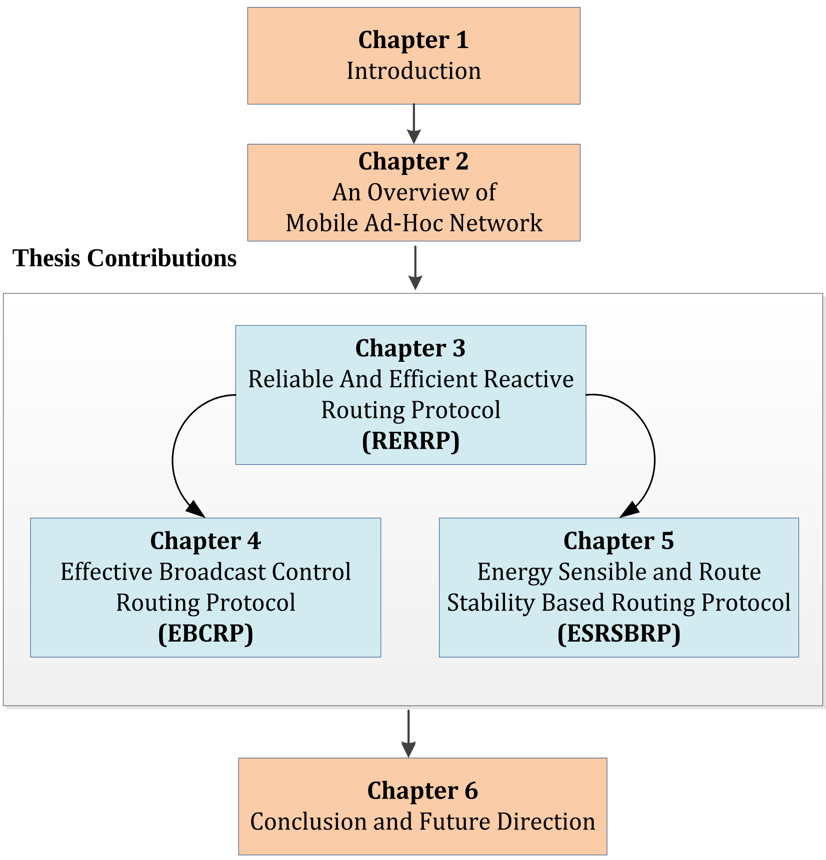

Figure 1-1: Thesis Organisation

Chapter-4 introduces the flooding issue in on-demand routing protocol, followed by the detail description of the existing broadcast control routing techniques. Further, the proposed routing scheme "Effective Broadcast Control Routing Protocol" (EBCRP) has been explained in detail. At the end, the simulation model and the comparative study of EBCRP with other reactive routing protocol has also been presented in detail.

Moreover, chapter-5 focuses on our proposed scheme, i.e. Energy Sensible and Route Stability Based Routing Protocol (ESRSBR). It contains the brief overview of the existing schemes that concentrate on the reduction of the consumed nodes energy. Later the complete description of the proposed scheme is given. Performance comparison of the ESRSBR with other routing schemes has also been presented at the end of this chapter.

Eventually, the research findings of the thesis along with the future work are presented in Chapter 6.

1.7 References

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Chapter 2

An Overview of Mobile Ad-Hoc Network

2.1 Introduction

In the past few decades mobile computing and wireless communication have experienced tremendous growth due to the rise of inexpensive and widely available devices. Communication devices such as cell phone, laptop, smart phone and Personal Digital Assistant (PDA) wirelessly connect to the internet to communicate and share data. The aim of wireless technology is to remove the tradition of being attached to wire as they allow anywhere and anytime connectivity. Additionally, the establishment of a wired infrastructure network is added a big ticket than the wireless network, making it a feasible choice. There are many kinds of wireless networks available like Wireless Mesh Network (WMN), Wireless Sensor Network (WSN) and Mobile Ad-hoc Network (MANET). An overview of MANETs, its characteristics, applications and different types of routing protocols will be discussed in the following sections.

2.2 Mobile Ad-Hoc Networks (MANETs)

Mobile Ad-Hoc network or 'temporary' network work without fixed infrastructure [1, 2]. It offers speedy and simple network formation in cases where it is unrealistic like in battlefield and natural disaster applications. MANET is a self-governing system of independent mobile nodes randomly connected with each other and forming arbitrary topology [3]. An Ad-Hoc network works without any centralized administration, every node makes its own decision independently.

In Mobile Ad-Hoc Networks due to the mobility of nodes network topology changes rapidly and unpredictably over time, making message routing is a very big challenge in MANETs. Figure 2-1 shows the random and unpredictable movement of nodes in different directions. Despite the challenge of message routing, MANETs are very easy to establish quickly with low cost as compared to traditional network.

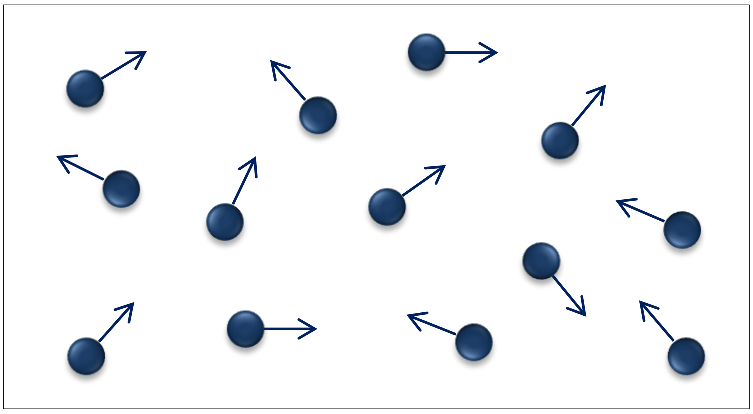


Figure 2-1: Random Movement of nodes in MANET

Figure 2-2 illustrates an example of a MANET scenario. Suppose node 'A' is source node and node 'D' is a destination node and both are not within the transmission range of each other. Therefore, node 'A' can not send data directly to node 'D'. Hence, routing between node 'A' and node 'D' is taking place through the intermediate nodes, i.e. node 'B' and node 'C'.

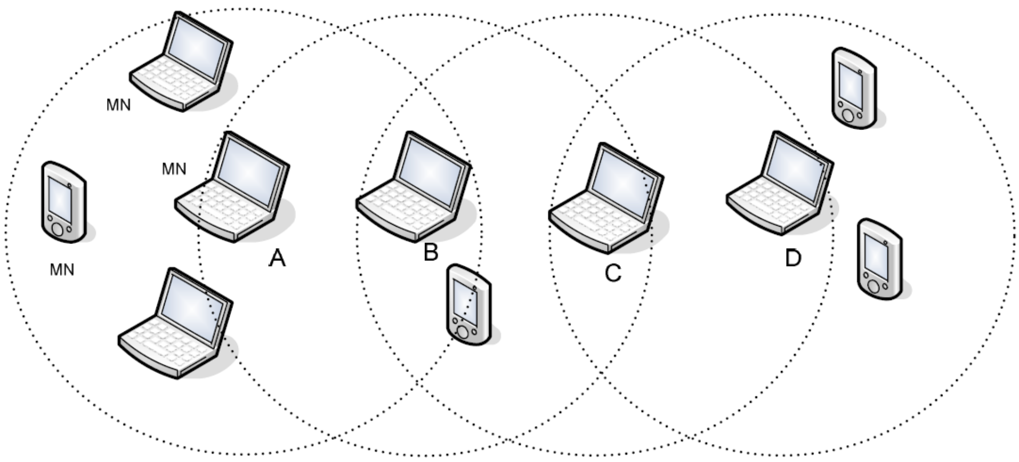


Figure 2-2 : A scenario for a Mobile Wireless Ad Hoc Network (MANET)

2.3 Characteristics of MANETs

A Mobile Ad-Hoc Network is a special type of wireless network, which shares common characteristics of wireless networks [4]. Apart from sharing of the common characteristics of wireless networks, it also has the following distinguish characteristics [5]:

2.3.1 Dynamic Network Topology

The mobility is a very important feature of MANETs which allows nodes to move arbitrarily with different speed without interrupting active communications while the nodes are within the communication range. However, due to mobility of node network topology becomes very dynamic that causes the path disconnection between the data sending and data receiving nodes [6, 7].

2.3.2 Decentralised Operations

A MANET node cannot depend on centralised support functions for security and routing. However, all the support functions must be designed independently in MANET node so that they can operate efficiently without any centralised support. This distributed nature of MANET offers a further robustness against a single point of failure in centralised approaches.

2.3.3 Limited Energy

The nodes in Mobile Ad-Hoc Networks are battery powered and their power supplies are not permanent [8, 9]. Thus the protocol design of the network should optimize for minimum power consumption.

2.3.4 Multi Hop Communication

If a node in Mobile Ad-Hoc Network wants to send data to another node which is not present in its transmission range, then the data are travelling through the different intermediated node, this process is referred as multi hop communication. As we know the fact that every node in MANET can also perform the function of router to direct the data packet which helps to achieve multi-hop communication.

2.3.5 Autonomous Terminal

In MANET each node works as a Data Terminal Equipment (DTE) and Data Communication Equipment (DCE). In other words beside the basic processing capability as a host, the mobile node can also participate in switching capabilities as a router.

2.4 Applications of MANETs

Initially MANET applications and deployments have been military oriented. But after the rapid advancement in the mobile ad-hoc networking research, non-military applications have also been grown substantially. Due to the flexible nature of MANETs this technology is applicable for different scenarios for example, educational, commercial, rescue and search operations [9-11]. In Personal Area Networking (PAN) and home networking, MANET also has many applications. For more applications and additional details of MANETs, interested users can refer [9] and [12]. However, a summary of the major applications in MANETs is presented below:

2.4.1 Military Battlefield

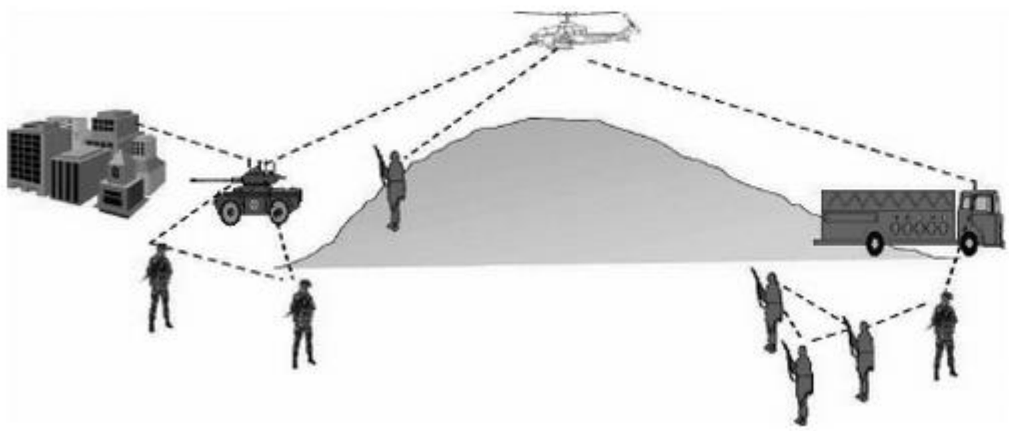


Figure 2-3: Military Application of MANETs [13]

Military tools are equipped with wireless connectivity card. MANETs technology helps the military in information sharing between soldiers in the field, military tanks and the headquarter [13]. Initially MANET applications and deployments have been military oriented. One of the examples of such application includes reconnaissance of enemy positions in the battlefield [11] cf. Figure 2-3. But after the rapid advancement in the mobile ad-hoc networking research, non-military applications are increased exponentially.

2.4.2 Commercial Application

The motivating factor for the commercial applications was the infrastructure less nature of MANET, because it reduces the infrastructure cost and availability of inexpensive wireless devices. Following are the some examples of commercial applications of MANET.

- **Collaborative Networks**
  A conference room with participants wants to share some files between themselves without the involvement of internet is a typical example of collaborative Networks. In such networks, devices like palmtops, laptops, PDAs and other communicating devices involve for the exchange of the data.

- **Home Networks**
  Home networks involve communication between smart appliances, cordless phones, Personal Computers (PCs), PDAs, entertainment systems and laptops. MANET reduces the overhead of going through centralised nodes, which makes this technology a good choice for the implementation of home networking applications.

2.4.3 Emergency Services

In emergency search and rescue operations, deployment of MANETs may be a very convenient choice. Scenarios where other communication facilities are destroyed because of the natural disaster like flood and earthquake; instant deployment of mobile ad-hoc network in these scenarios can activate the communication rapidly. For instance, fire brigades, ambulance and police vehicles can remain connected and share information between them if they form MANET.

2.5 Routing in MANETs

Discovering a route between the source node and the destination node in a data communication network is called “Routing”. The unique characteristics of MANETs, such as those discussed in Section 2.3, make routing in MANETs a challenging task. The task of finding the best route between the source node and the destination node has always been considered by the researchers [14-16]. The routing protocols for MANETs can be mainly classified into three main categories [17-19], i.e. Reactive Routing, Proactive Routing and Hybrid Routing, as shown in Figure 2.4. A more detailed descriptions of routing protocols for Ad-Hoc wireless networks and MANET are presented in [20], [21], and [22].

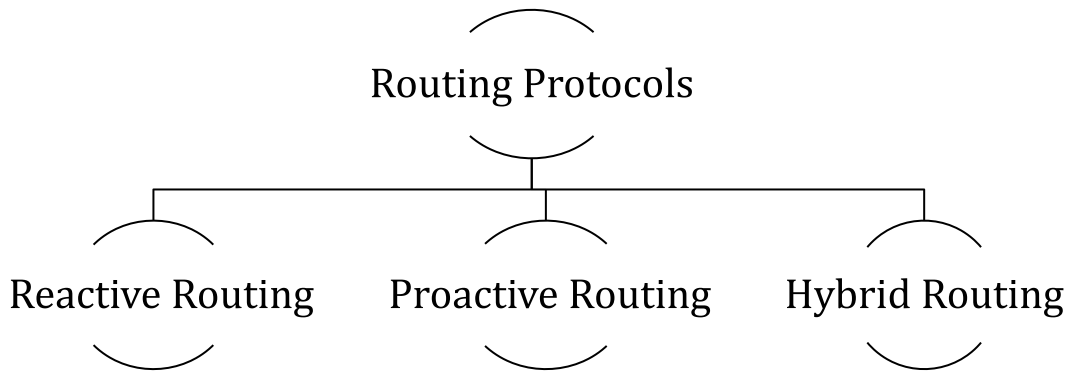


Figure 2-4: MANET Routing Protocols Classification

2.5.1 Reactive Routing Protocols

Due to the unique characteristics of MANETs, its routing protocol design needs to deal with different distinctive challenges. On demand route discovery mechanism is utilized in reactive routing protocol, i.e. a route is formed only when it is needed by the source node [23, 24]. Unlike the proactive routing protocol, each node does not initiate the route discovery process until a route is required. Every node only keeps information about the active path to the destination. AODV [14] and DSR [15] are the traditional reactive routing protocol which have been extensively analysed and investigated in the literature. The main functionalities of these routing protocols have been described in the following section.

2.5.1.1 Ad-Hoc On-Demand Distance Vector Protocol (AODV)

AODV [14] is an efficient routing protocol for Mobile Ad-Hoc Network. AODV is an on-demand routing protocol that determines a route only when it is needed. This algorithm basically combines the advantageous concept from Destination-Sequenced Distance-Vector Routing (DSDV) [16] and Dynamic Source Routing Protocol (DSR) [15]. The concept of hop-by-hop routing and the mechanism of sequence numbers were borrowed from DSDV. The route maintenance and on-demand route discovery process of AODV was borrowed from DSR. AODV avails sequence number information in a manner like DSDV to bypass routing loops and to indicate a freshness of a route. The asset of AODV is that it tries to reduce the routing overhead by initiating a route on an on-demand bases rather than keep up a complete list of each destination. Therefore, authors of AODV classify it as a pure on-demand routing system [14]. Establishing a route only when it is needed makes AODV a very important and beneficial scheme for MANETs. Route discovery and route maintenance are the two processes of AODV routing mechanism.

- **Route Discovery Process of AODV**

At time, when a node in the network attempt to send a packet to another node in the network, it first checks that whether it has a route to the desired destination node in its routing table. If an active route towards the destination is available, it simply forwards the data packet to the next hop towards the destination. Otherwise, it initiates a route discovery process. In the route discovery process, a route request (RREQ) packet is initiated, if a valid route is not available for a desired destination. The RREQ packet contains the following information;

- Source IP address (SIP),
- Source Sequence Number (SSN),
- Destination IP address (DIP),
- Last known Destination Sequence Number (DSN) and
- Broadcast ID (BID).

The combination of BID and the SIP address is used to uniquely identify the particular RREQ packet. Every time when a source node initiates a RREQ packet, BID of this particular node is also incremented.

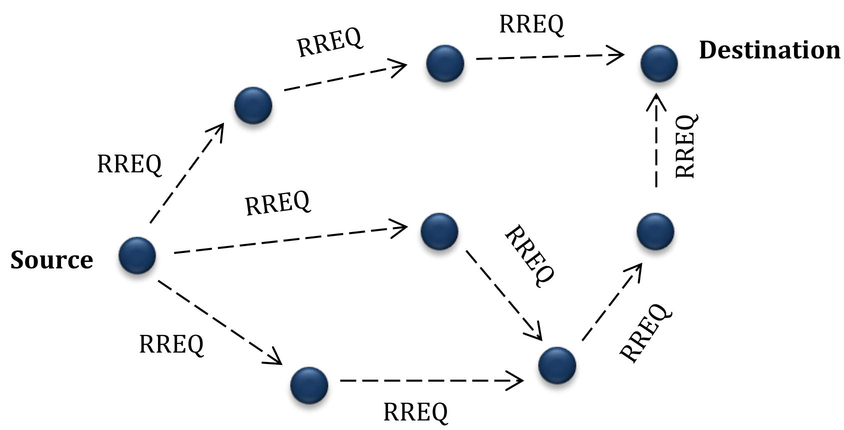


Figure 2-5 : Propagation of RREQ Packet in AODV

Once the RREQ packet is generated, the source node broadcast this RREQ packet to its all neighbours node and start a timer to wait for a reply, as shown in Figure 2-5. Two sequence numbers are present in RREQ packet, i.e. destination sequence number and source sequence number. The freshness of the reverse path is identified by the source sequence number while the destination sequence number indicates that whether this route is fresh enough to use as a reply for the corresponding route request.

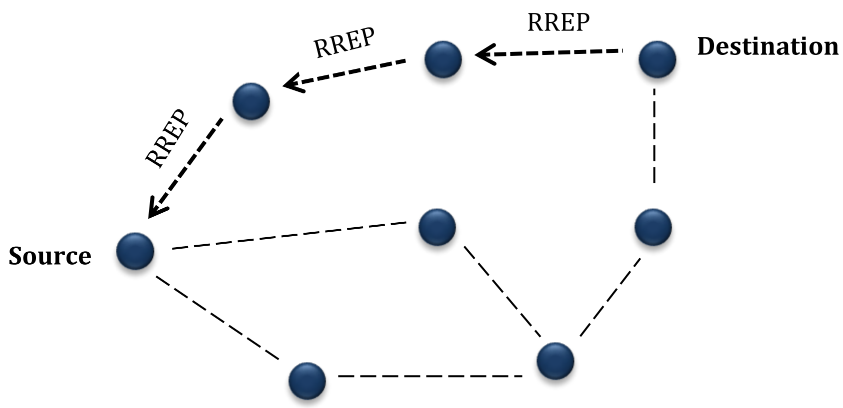


Figure 2-6 : Path of RREP to the Source in AODV

A RREP is generated when the receiving node is destination node or has a fresh enough route to the destination, as shown in Figure 2-6. A route is viewed as a "fresh enough", if the destination sequence number present in the routing table of this node is greater than or equal to the destination sequence number present in the RREQ packet. As RREP is propagating towards the source node, each intermediate node follows this way and adds a forward route entry to its routing table towards the destination node. If the node is not the destination node and don't have a valid route to the destination, it increments the RREQ's hop count by one and re-broadcasts this packet to its neighbours.

- **Route Maintenance Process of AODV**

The discovered route between source and destination has been maintained as long as it is required by the source node. A source node can re-initiate the route discovery process if it moves and causes the link breakage. If the link breaks due to the movement of intermediate node a Route Error (RERR) message is generated and sent back to the concerned source node. RERR message also contains a list of all the other destinations that cannot be reached because of the link breakage. When a neighbour node receives the RERR message, it checks its routing table for the destinations that are listed in RERR message. If any such destinations are presented in its routing table than it simply mark this particular route entry as an invalid and set distance to destination equal to infinity. Later, the RERR message propagates towards the source node. "Hello" message is also used to maintain the local connectivity between the neighbour nodes. This "hello" message broadcast periodically that ensure the next hop is still within reach. If several "HELLO" messages are not received by a particular node, a link break is detected and RERR message is propagated.

2.5.1.2 Dynamic Source Routing (DSR)

The DSR protocol is introduced in [15] is an on-demand routing protocol that is based on an idea of source routing. In source routing, every data packet header carries the whole list of intermediate nodes between the source and the destination by which this packet needs to pass. Each node is expected to maintain a route cache that contains the originator route learned by the node. This protocol dynamically helps to find a source to destination route across multiple network hops. Route discovery and route maintenance are two important phases of DSR to find and maintain a route.

- **Route Discovery of DSR**

A route discovery process was initiated by the source node if it wants to send data to other node for which there is no route available in its route cache. If it has a valid route to the destination, it simply starts sending the data by utilizing this route. A route request packet was broadcasted by the source node to initiate the route discovery process. Each route request packet contains a unique request ID, destination address and source address. Every node which receives the request whether it has a route to the destination or otherwise it append its own address to the route record in the route request message and forward the packet, as shown in Figure 2-7. If a node receives multiple route request bearing the same request ID or it find its own address already listed in the route record, it discards the request.

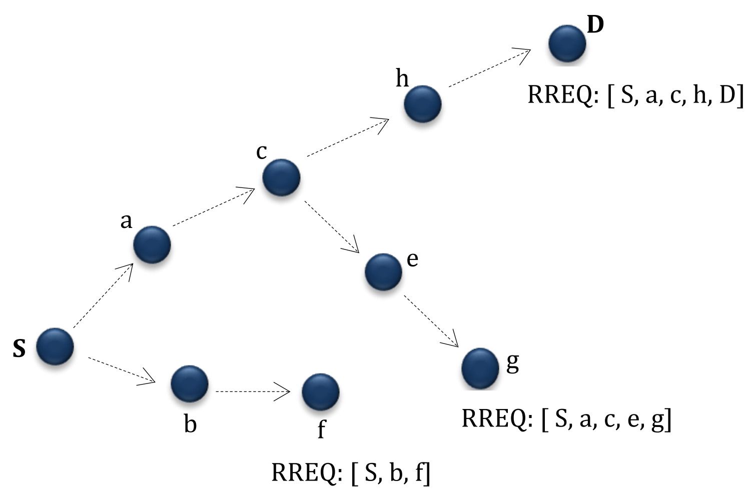


Figure 2-7 : Route Request Dissemination in DSR

A route reply is generated, if the node has a valid route to the destination or itself a destination, then it simply generates and sends back the RREP packet towards the source node [25], as shown in Figure 2-8.

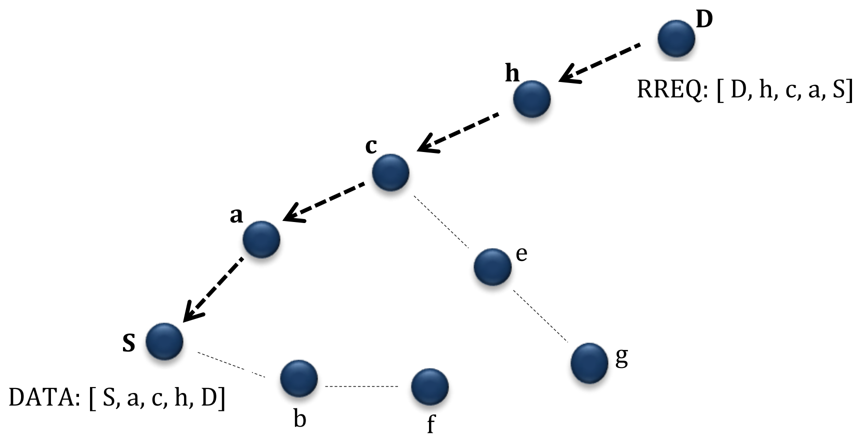


Figure 2-8 : Route Reply in DSR

A route reply packet in DSR consists of the addresses of all the nodes between the destination node to the source node. When the source node receives this RREP packet, it records the information available in RREP packet in its cache. After recording the information the source node starts sending the packets towards the destination, utilising this fresh route.

If the intermediate node has a path to the destination, it will append its cache route to the route record and return with route reply.

- **Route Maintenance of DSR**

Detection of the changes in the network topology is a responsibility of route maintenance mechanism. Whenever, an intermediate node detects a link failure while it is trying to send data over this link a RERR message is generated and transmitted towards the source node. This RERR message deletes all the entries of the broken link from the route caches of the nodes along the path. When a source node receives this RERR message and still has data to send for this particular destination. The source node needs to re-initiate the route discovery process.

2.5.2 Table-Driven Routing Protocols

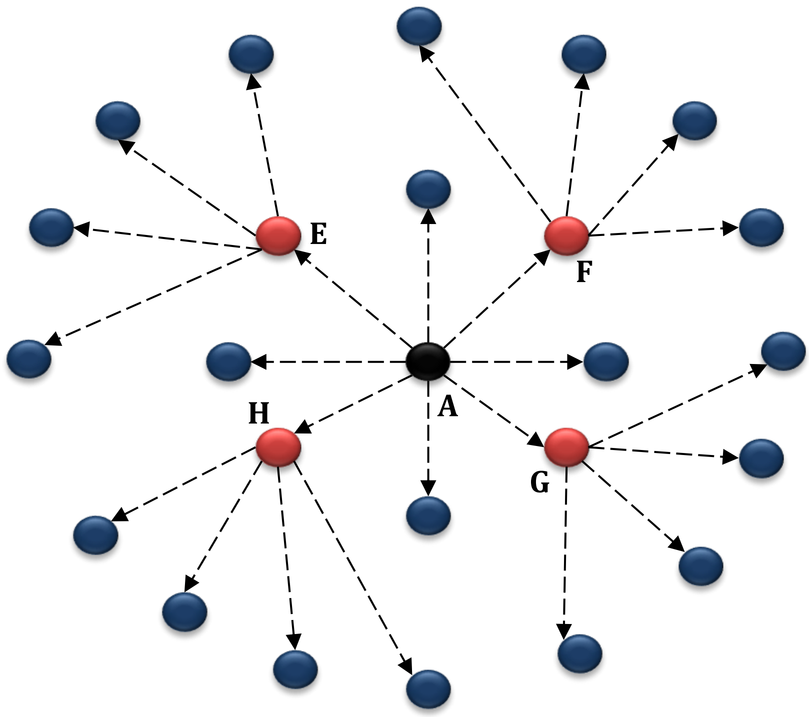
Each node in Table-Driven routing protocol maintains consistent and up-to-date routing information for every other node in the entire network. In order to maintain a consistent view of the network every node in the network also have to maintain one or more table to store routing information and these tables are updated regularly in order to maintain up-to-date routing information. If the network topology changes frequently then updated information propagate to every node even no traffic is affected. This frequently propagation of routing information leads to high overhead on the network. The benefit of this approach is that it minimizes the initial delay and the path will always be available on request. The following sections discuss the different table-driven routing protocols.

2.5.2.1 Destination Sequenced Distance Vector Protocol (DSDV)

DSDV [16] routing protocol is basically a modified version of Bellman-Ford routing mechanism. DSDV addressed the problem of routing loops by incorporating the concept of sequence numbers. The routing table of each node consists of available destination, number of hops and the sequence number. These sequence numbers are used to distinguish between the stale routes from the new ones and thus avoid routing loops. To maintain the consistency of the routing table in the network, routing tables are periodically transmitted through the network. This exchange of complete routing table puts a huge amount of overhead on the network. To reduce this overhead, these updates are divided in two types of information, i.e. Full dump and smaller incremental. The full dump will carry all the available routing information, but on the other hand the smaller increment only carries the information that has changed since the last full dump.

2.5.2.2 Optimized Link State Routing Protocol (OLSR)

The Optimized Link State Routing (OLSR) protocol [26, 27] is a proactive routing protocol for MANETs. The important feature of OLSR is that it reduces the routing overhead. To support this feature, OLSR introduces the concept of multipoint relay (MPRs) [26, 28]. The selected nodes that can only forward the packets are referred to as MPR. Figure 2-9 shows the section of MPR nodes of node 'A' [22]. The node 'A' broadcast the HELLO packets to all of its neighbours to exchange the neighbours list. This list helps the node 'A' to calculate the set of MPR nodes. From the neighbours list node 'A' only select the one hop relay points that can forward the packets to two hop neighbours. For example, in Figure 2-9 nodes 'E', 'F', 'G' and 'H' are selected as MPR nodes by node 'A'. Since, the selected MPR nodes cover the entire two hops away node from node 'A'.



Nodes E, F, G and H are the MPR nodes of node A

Figure 2-9 : MPR nodes illustration in OLSR routing [7]

Instead of pure flooding, the packets can only forwarded by the node's MPRs. In dense and large networks OLSR performed well [26]. In the route discovery procedures MPRs act as an intermediate router. Hence, OLSR may not select the shortest path; this is identified as a disadvantage of OLSR.

2.5.3 Hybrid Routing Protocols

Hybrid routing algorithms [29, 30] combine the proactive and the reactive approaches in an attempt to bring together the advantages of the two approaches. Hybrid Protocols divides the network into different zones. Within the zone it uses a proactive routing protocol for establishing the routes between source and destination. On the other hand, outside the zone routing is a responsibility of reactive routing protocols. For an example of hybrid routing, the Zone Routing Protocol (ZRP) is presented in the following section.

2.5.3.1 Zone Routing Protocol (ZRP)

The Zone Routing Protocol (ZRP) [20, 29] is widely known hybrid routing protocol that is generally suitable for large-scale network. ZRP divides the entire network into zones.

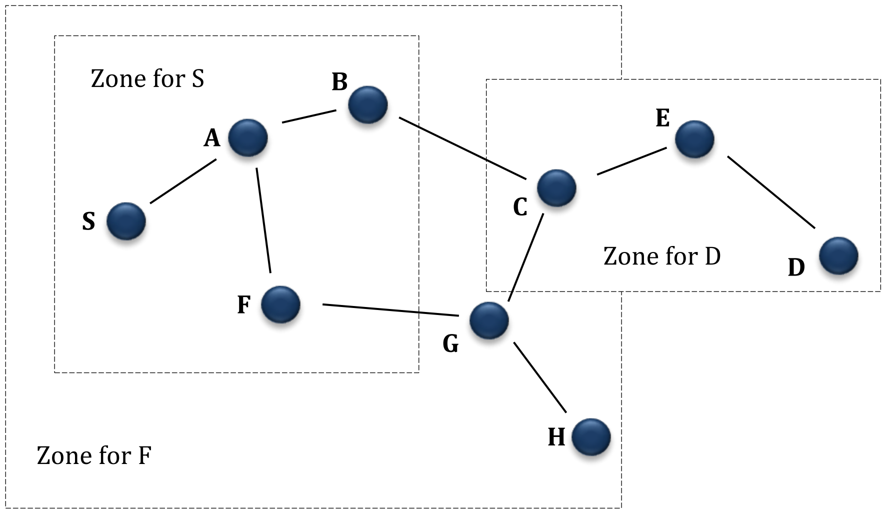


Figure 2-10 : Network using ZRP. The dashed squares show the routing zones for node S, F and D

ZRP was intended to accelerate the data delivery and minimise the processing overhead by choosing an appropriate routing technique between the proactive and reactive routing protocols. In ZRP the whole network is divided into zones, inside the zone a proactive routing approach or Intra-Zone Routing Protocol (IARP) was considered to find the route between the source node and the destination node. The routing between two different zones was done by utilizing the reactive routing protocol or Inter-Zone Routing Protocol (IERP). Thus, if the source node and the destination node are in the same zone, the data packet can be delivered immediately because of the proactive process every node kept routing information for all the nodes of the same zone. If the destination is not present within the originator zone, a reactive process is called out to find a suitable route. The originating node sends a route request to its border node (of its zone), comprising of its own address, sequence number and destination address. The border node when receives the request checks its local routing zone for the destination node, if it finds the destination node in its routing zone it generates a route reply packet and send back to the source using reverse path. Then source node used this saved path in route reply to send packet to destination. However, if the destination node is not a member of this local zone, the node transmits the packet to its border node by appending its own address to the route request packet.

Figure 2-10, shows an example of route discovery in ZRP. The dotted lines in this figure shows the transmission range of node S, F and D. Suppose node 'S' wants to send data to node 'D'. We can see in the Figure 2-10 that node 'D' does not reside within the transmission range of node 'S'. Then node 'S' sent the route request message to its border nodes, i.e. nodes 'B' and 'F'. After the border nodes receive the route request for node 'D', they check the existence of node 'D' in their respective routing zone. Both the border node didn't find the node 'D' in their routing zone; thus the request of node 'D' is forwarded to the respective border nodes. The border nodes of node 'F' are node S, B, C and H while the border nodes of node 'B' are S, F, E and G. Here in the Figure 2-10 we can see that the requested node 'D' is found within the routing zone of node 'C' and node 'E'. Finally, the border node that has the node 'D' in its routing zone generates the route reply and sent back to the source node.

2.6 Chapter Summary

This chapter has presented an overview of different aspect of MANET, such as definition, characteristics and the applications of MANET. The characteristic features of MANET are briefly described like dynamic network topology, decentralised operations, limited energy, multi hop communication and the autonomous terminal. The MANET applications are also pointed out with example and how those applications work with different scenarios. This chapter also presented a thorough study of different types of MANET routing protocols.

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Reliable and Efficient Reactive Routing Protocol for Mobile Ad-Hoc Network

3.1 Introduction

Mobile Ad-Hoc Networks (MANET) are infrastructure less wireless network [1, 2]. In MANET every node can communicate with each other as well as they can move randomly in any direction in the network [3, 4]. These characteristics of mobility and infrastructure less nature of MANET are very beneficial for military and natural disaster applications [5, 6].

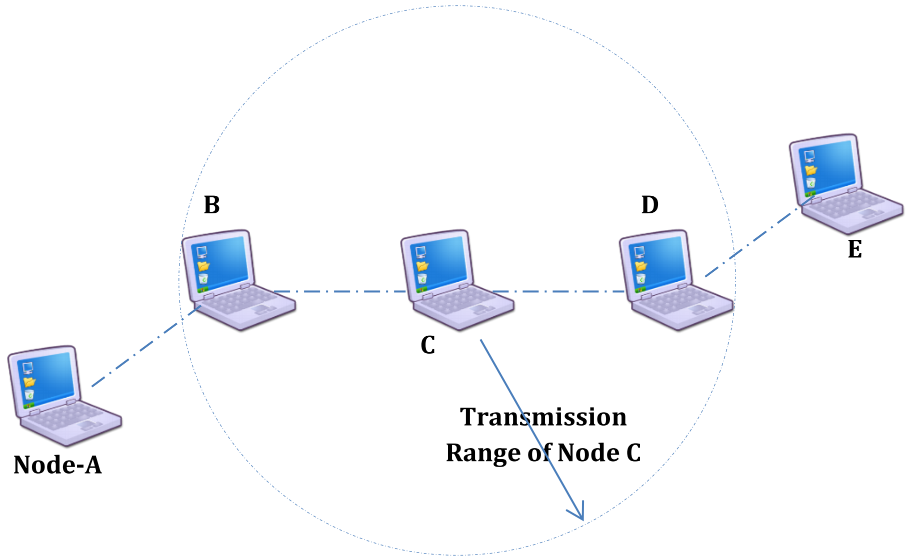

Figure 3-1 : Established Route between Node 'A' to Node 'E'

However, due to mobility of nodes, network topology becomes very dynamic that causes the path disconnection between the data sending and data receiving nodes. Figure 3-1 illustrates an active and established route between node ‘A’ and node ‘E’ at time ‘t’. Suppose at time ‘t+1’ node ‘D’ reaches to a new position. This new position of node ‘D’ is out of the transmission range of the node ‘C’ cf. Figure 3-2. Due to the mobility of node ‘D’, the active link between node ‘C’ and node 'D' breaks. The breakage of this link causes path disconnection between node 'A' and node 'E'. That means the stability or reliability of a path between source and destination is based on every individual link between the active paths.

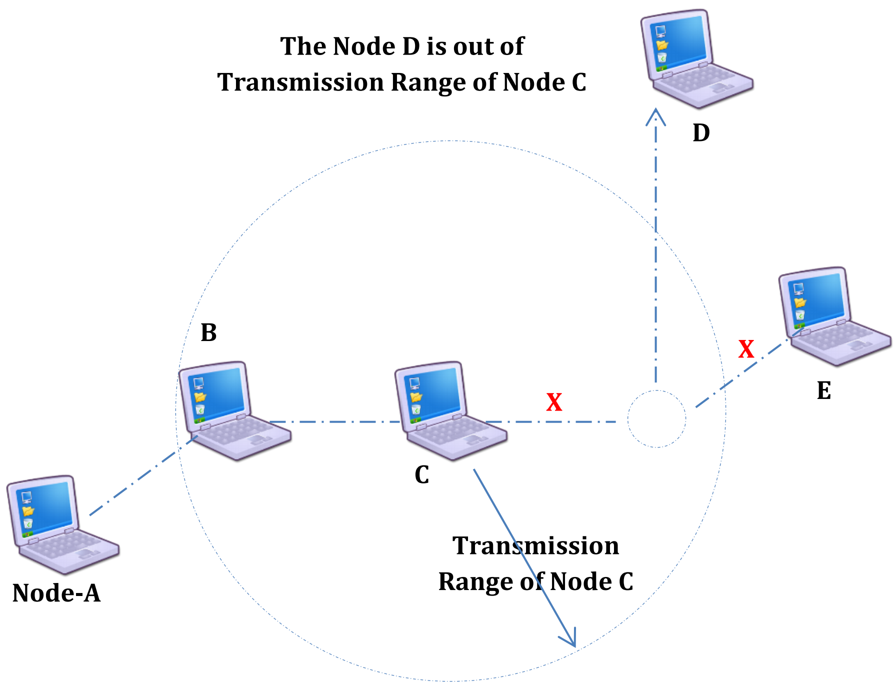

Figure 3-2 : Effect of Node Mobility on Established Path

Ad-Hoc On-Demand Distance Vector (AODV) routing [7] and Dynamic Source Routing (DSR) [8] are considered as standard for on demand routing protocols where both of them select the shortest path between source and destination for data transfer. The shortest path may not always be the reliable path for data transfer because of the frequent changes of the network topology due to the mobility of the nodes. The frequent breakage of established path degrades the network performance [9]. When an active or established route between the source node and the destination node breaks, the routing protocol executes route maintenance procedure which consumes network resources and eventually influence negatively on the performance of the network [10]. It is very important to find a longer life route between source node and destination node [11, 12]. Selection of longer life route reduces the number of route rediscovery and maintenance procedures that eventually enhance the network performance [13]. Therefore, to reduce the path disconnection due to mobility in the network, the routing protocol also needs to consider node mobility and select the reliable route between the source node and the destination node [14].

This chapter mainly focuses new protocol called Reliable and Efficient Reactive Routing Protocol (RERRP) for Mobile Ad-Hoc Network. RERRP selects the reliable route among all the feasible routes between the source node and the destination node. The selection of reliable route is based on our proposed function called Reliability Factor (RF) which considers node mobility and hop count to locate the reliable route.

3.2 Related Work

As mentioned above, link stability is very important to consider in the design of MANETs routing protocol. There exist several methods that use Global Positioning System (GPS) and Route Expiration Time (RET) [15, 16] while developing the routing algorithms. Some researchers also consider the Received Signal Strength (RSS) while calculating the stability of the route. Following section highlights the existing routing protocols that uses RET or RSS in their routing algorithms.

Link life time prediction method was proposed in [17]. In this paper, the authors considered the mobility and location information for predicting link lifetime. The authors of [17] also presumed that all node clocks were synchronized with the clock of Global Positioning System. Therefore the link life between the two neighbour nodes can be estimated if the speed, direction and the position of the mobile nodes are known. The routing concept introduced in [17] estimates LET at each hop, which helps in the estimation RET. Route Expiration Time is described as a minimum LET of all the links between the whole route from source node to destination node. The maximum RET path considered as the best path.

The Flow Oriented Routing Protocol (FORP) [18] is another protocol in which authors develop a new technique called “Multi hop hand off” which determine an alternative route much faster. The FORP protocol calculates RET only for active source and destination pair with the help of the LET. On the path detection phase, the source broadcast a Flow-REQ message, including source ID, destination ID and sequence number. When a node sends a message to its next node, it attaches its own ID and the LET of the last link in which the message was received. When the message arrives at the destination it has a list of all the intermediate nodes with their respective LETs. The destination node utilizes these LET values and calculates RET by selecting the minimum LET. As the route is chosen, the Flow SETUP message flies out to the selected paths. Though the connection is established the intermediate node continues adding the LETs to the forwarded data packet to enable the destination to keep track of RET prediction. However, if the destination node determines that the chosen path is about to expire and a "critical time" is reached a special Flow-HAND-OFF message triggers and spread throughout the network until it finds the source node. The source node then determines the new substitute route based on their LET and RET. "critical time" is basically obtained by subtracting the delay experienced by the previous data packet arrived at the destination node on the established route from the route expiration of that route.

The research work in [19] proposed a unicast routing protocol called the Signal Stability–based Adaptive (SSA) routing that determines the durability of a connection with the help of periodically exchange (beacons) message in the region. The authors put link into two categories, i.e. weak and strong links. This routing protocol work with two thresholds for signal strength: threshold for strong link ${P_{th}}^{strong}$ and threshold for signal reception ${P_{th}}^{rec}$ in which ${P_{th}}^{strong}$ should be greater than ${P_{th}}^{rec}$ i.e. (${P_{th}}^{strong} > {P_{th}}^{rec}$). A link with a connected node is said to be strong if the strength of the periodically exchange message received from a connected node greater than ${P_{th}}^{strong}$. If the periodically exchange messages are less than ${P_{th}}^{strong}$ but greater than ${P_{th}}^{rec}$ the link is named as the weak link. Using strong link mechanism the source node tries to find a durable path to the destination in the route discovery process. An additional broadcast route discovery process is initiated if the original route discovery process was unable to find the route containing all strong links. The new discovery process will consider both strong and weak links while determining a route. This will eventually enhance the routing load in the network.

The Associativity Based Routing (ABR) [20] use "Associativity Ticks (AS)" to find the stability of the link. AS are calculated by counting the number of beacons received from neighbour node. Stability of link considered as high, if the nodes have high AS with its neighbour node. More stable link route will be selected by the destination node. However, ABR does not consider node direction and speed while estimating the stability of the link.

In [21], a Route Lifetime Assessment Based Routing (RABR) protocol was suggested by the authors, which works by computing a metric called "Link affinity". The average change in the signal strength of a link is referred as affinity of this link. The signal strength of a link is estimated by periodically received messages called "Beacons". This change in the strength of the signal can be characterized as positive and negative. When the change in average strength of the signal is greater than zero, then they assume that nodes are approaching each other and high affinity value is assigned to that link otherwise low affinity value will be assigned. The destination node will select that path among all feasible paths that have the largest affinity value. The minimum affinity value of all links between the source and destination is referred as the affinity value of the path. A Zone based routing scheme called "Zone and Link Expiry based Routing Protocol" (ZLERP) [22] has been recently proposed which adopt the concept of RARB.

An algorithm based on the signal strength was proposed in [23] , which select the stability of the path considering the strength of the signal. The forwarding node in this protocol adds the estimated signal strength in the RREQ packets. The whole path signal strength is calculated as the minimum of all the signal strength of the links that creates that path. Finally the destination node selects the largest estimated signal strength path and sends the reply back to that selected path.

In [24] a routing protocol has been proposed that can find the reliable path between the source node and the destination node. The selection of reliable path is based on the quality of the intermediate links. The link quality has been obtained by the Path-Link quality estimator. A prediction based routing protocol has been proposed in [25] that predicts link breaks in MANET. The prediction is based on the strength of the single and the threshold of the signal strength. By the help of this prediction mechanism the proposed protocol can proactively initiate the repair procedure earlier than the failure of a link.

3.3 Reliability Factor (RF)

Before presenting the proposed protocol, Reliability Factor (RF) is explained in this section which is used in the proposed protocol. RF basically selects the route with large route expiration time and has less number of Hops; that mean this is the reliable route for data transfer between source and destination [10]. RF is basically a difference of normalized values of Route Expiration Time (RET) and Hop Count (HC), which is calculated using equation (3-1).

$$RF = \frac{RET}{MaxRET} - \frac{HC}{MaxHC} \tag{3-1}$$

The estimations of the parameters necessary for the calculation of RF are Route Expiration Time (RET), Hop Count (HC), MaxRET and MaxHC; in the following section we define these parameters and give methods to estimate their value, required for the calculation of RF.

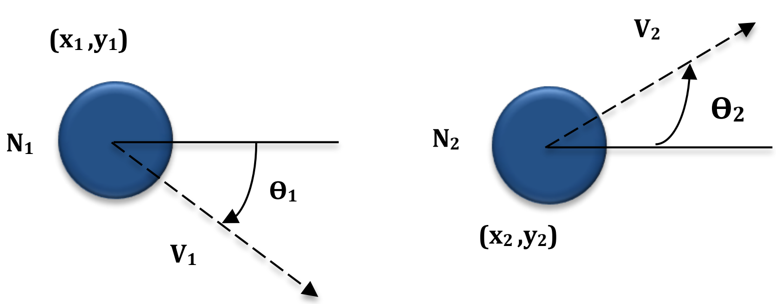

Figure 3-3 : Link Expiration Time

3.3.1 Route Expiration Time (RET)

The minimum expiration time of all the links between the source node and the destination node is referred as Route Expiration Time (RET). Whereas Link Expiration Time (LET) represents the estimated time span in which the connection between the two mobile nodes remain active or the two nodes remain connected [18]. Larger RET of the feasible route means the more strong link or reliable link.

The LET expresses the length of time for which two neighbours node in motion will remain connected; the calculation of LET can be illustrated as; suppose there are two nodes N_1 and N_2 having equal transmission ranges “r”. Let (x_1, y_1) and (x_2, y_2) be the x–y coordinates for nodes N_1 and N_2 respectively cf. Figure 3-3. As explained in [17] nodes N_1 and N_2 move at speeds of v_1 and v_2 at angles θ_1 and θ_2 respectively. Then the LET between nodes N_1 and N_2 is calculated using equation (3-2).

$$\mathrm{LET} = \frac{-(\mathrm{ab} + \mathrm{cd}) + \sqrt{(\mathrm{a}^2 + \mathrm{c}^2)\mathrm{r}^2 - (\mathrm{ad} - \mathrm{bc})^2}}{\mathrm{a}^2 + \mathrm{c}^2} \tag{3-2}$$

Where

$$a = v_1 \cos\theta_1 - v_2 \cos\theta_2$$

$$b = x_1 - x_2$$

$$c = v_1 \sin\theta_1 - v_2 \sin\theta_2$$

$$d = y_1 - y_2$$

Thus, the RET is the minimum LET of all the feasible routes of the network, calculated using equation (3-3). It is expressed as

$$RET = Min\ (LET_1, LET_2, LET_3, \dots, LET_n) \tag{3-3}$$

Table 3-1: Tabular Explanation of Figure 3-4

Link	Link Expiration Time (LET)	Route Expiration Time (RET)	Hop Count (HC)
Feasible Route 1 = S → A → B → C → E → D			
S → A	60	$RET_1 = 35$	$HC_1 = 5$
A → B	65		
B → C	50		
C → E	35		
E → D	40		
Feasible Route 2 = S → F → G → H → D			
Link	**Link Expiration Time (LET)**	**Route Expiration Time (RET)**	**Hop Count (HC)**
S → F	50	$RET_2 = 20$	$HC_2 = 4$
F → G	20		
G → H	60		
H → D	30		
Feasible Route 3 = S → I → J → K → L → M → D			
Link	**Link Expiration Time (LET)**	**Route Expiration Time (RET)**	**Hop Count (HC)**
S → I	40	$RET_3 = 30$	$HC_3 = 6$
I → J	70		
J → K	60		
K → L	30		
L → M	65		
M → D	45		
		MaxRET = 35	**MaxHC = 6**

3.3.2 Hop Count (HC)

It represents the number of hops involved in the feasible path between source and destination.

3.3.3 MaxRET

The MaxRET is defined as the maximum RET of all feasible routes available at the destination node. The LET between two mobile nodes is calculated using equation (3-2). Then the RET of the feasible route is the minimum of all the LETs in the feasible route. According to Figure 3-4 suppose node 'S' wants to send data to node 'D' there are three feasible routes available between node 'S' and node 'D'. The edges between nodes represent LET of those nodes like LET between node 'S' and node 'A' equal to 60. Table 3-1 summarize Figure 3-4 for better understanding of MaxRET.

$$MaxRET = Max\ (RET_1, RET_2, RET_3, \dots, RET_n) \tag{3-4}$$

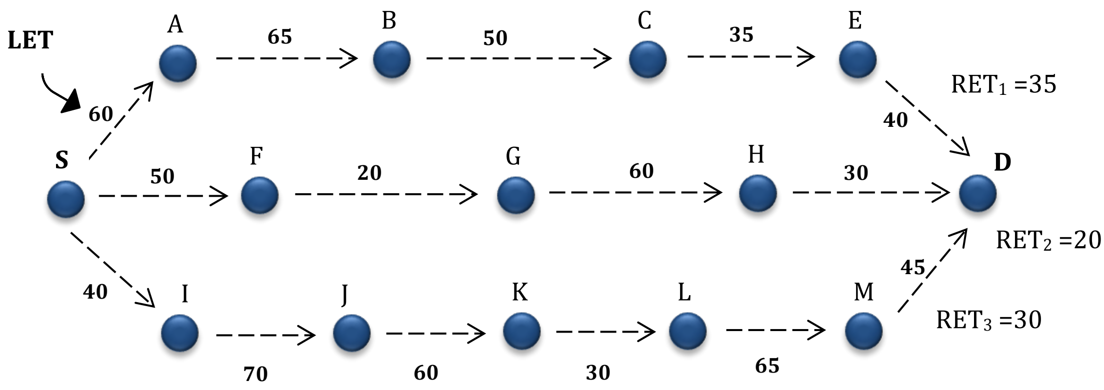

Figure 3-4 : Route Expiration Time for all the feasible routes

Since $RET_1 = 35$, $RET_2 = 20$ and $RET_3 = 30$

Therefore,

$$MaxRET = Max\ (RET_1, RET_2, RET_3)$$

$$MaxRET = Max\ (35, 20, 30)$$

$$MaxRET = 35$$

3.3.4 MaxHC

The MaxHC is defined as the maximum Hop Count of all feasible routes between the source node and the destination node cf. Figure 3-5.

$$MaxHC = Max\ (HC_1, HC_2, HC_3, \dots, HC_n) \tag{3-5}$$

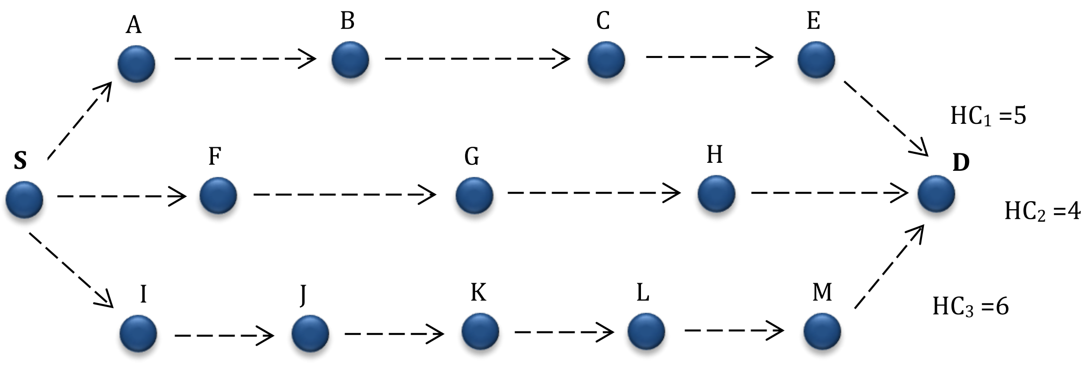

Figure 3-5 : Hop Count of all the feasible routes

Since $\mathrm{HC}_1 = 5$, $\mathrm{HC}_2 = 4$ and $\mathrm{HC}_3 = 6$

Therefore,

$$MaxHC = Max\ (HC_1, HC_2, HC_3)$$

$$MaxHC = Max\ (5, 4,6)$$

$$MaxRET = 6$$

3.4 Reliable and Efficient Reactive Routing Protocol (RERRP)

This scheme selects the reliable route based on the Reliability Factor (RF). RF considers Route Expiration Time and Hop Count to select a routing path with high reliability and have less number of hops. Reliable route selection is based on the value of RF, in a feasible path; a higher value of RF means a highly reliable route that can use for data transfer. RERRP always selects the most reliable path for routing in MANETs.

Ad-Hoc On Demand Distance Vector (AODV) [7] routing protocol is selected to implement the proposed algorithm. An AODV, a reactive routing protocol, build a route between the data packet generating node to the destination nodes, only when it is needed. Source node broadcast a route request (RREQ) packet to all its neighbouring nodes when it requires sending data. The propagation of RREQ packet is illustrated in Figure 3-6.

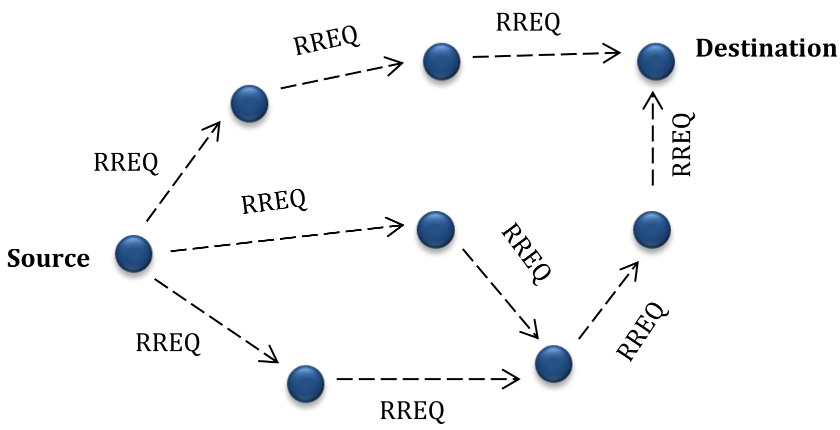

Figure 3-6: Propagation of RREQ Packet in AODV

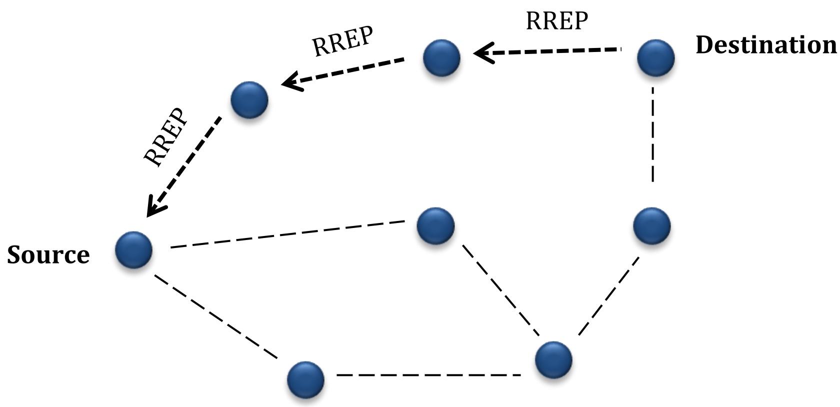

Figure 3-7 : Path of RREP to the Source in AODV

All the nodes that receive this RREQ packet will record the information of the node from where that RREQ packet was received. Recording the previous hop information is called backward learning. If an intermediate node has a valid route to the destination or itself a destination node, then it generates the route reply (RREP) packet and send back to the source node cf. Figure 3-7. When a source node receives the RREP message it starts sending the data packet.

- **Reliable and Efficient Route Request (RE-RREQ) packet:**

  In order to fulfil the requirements of the proposed algorithm, AODV routing request packet (RREQ) entries need to be extended by adding 5 new fields to its structure and named as RE-RREQ cf. Figure 3-8. The hop count information is already present in default AODV route request packet and this number of hops information accessed by the proposed protocol.

  - ***XPos, Ypos***: Contain the (X, Y) coordinates of the mobile node.
  - ***Speed:*** Contains the current speed of the mobile node.
  - ***Direction:*** Contain the direction or angle of the mobile node.
  - ***LET:*** Contain the link Expiration Time between the sender and receiver of this RE-RREQ.

…	Xpos	Ypos	Speed	Direction	LET

Figure 3-8: RE-RREQ Message Format

3.4.1 Route Discovery Process of RERRP

The proposed RERRP is an On-Demand Routing Protocol. When the source node ‘S’ want to transmit data to destination node ‘D’ and it has no routing entry for the particular destination than the route discovery process of the proposed protocol is initiated. The initiation of a route discovery process is done by broadcasting the route request (RE-RREQ) packet to all neighbour nodes. The RE-RREQ packet is an extension of the AODV RREQ packet, which is shown in Figure 3-8.

When a RE-RREQ packet received by a node, it searches for the reverse route towards the source node in its routing table. If there is already a route present in the table, then it updates the existing route otherwise create a reverse route towards the source node. If the receiving node is not the destination node and there is no valid route exist towards the destination in its routing table, then it calculates LET between the RE-RREQ sending node and the current node it also selects minimum LET between the current node and the source node. Finally, it increment the hop count and broadcast the RE-RREQ packet to the neighbour nodes refer to flow chart of route discovery process in Figure 3-9.

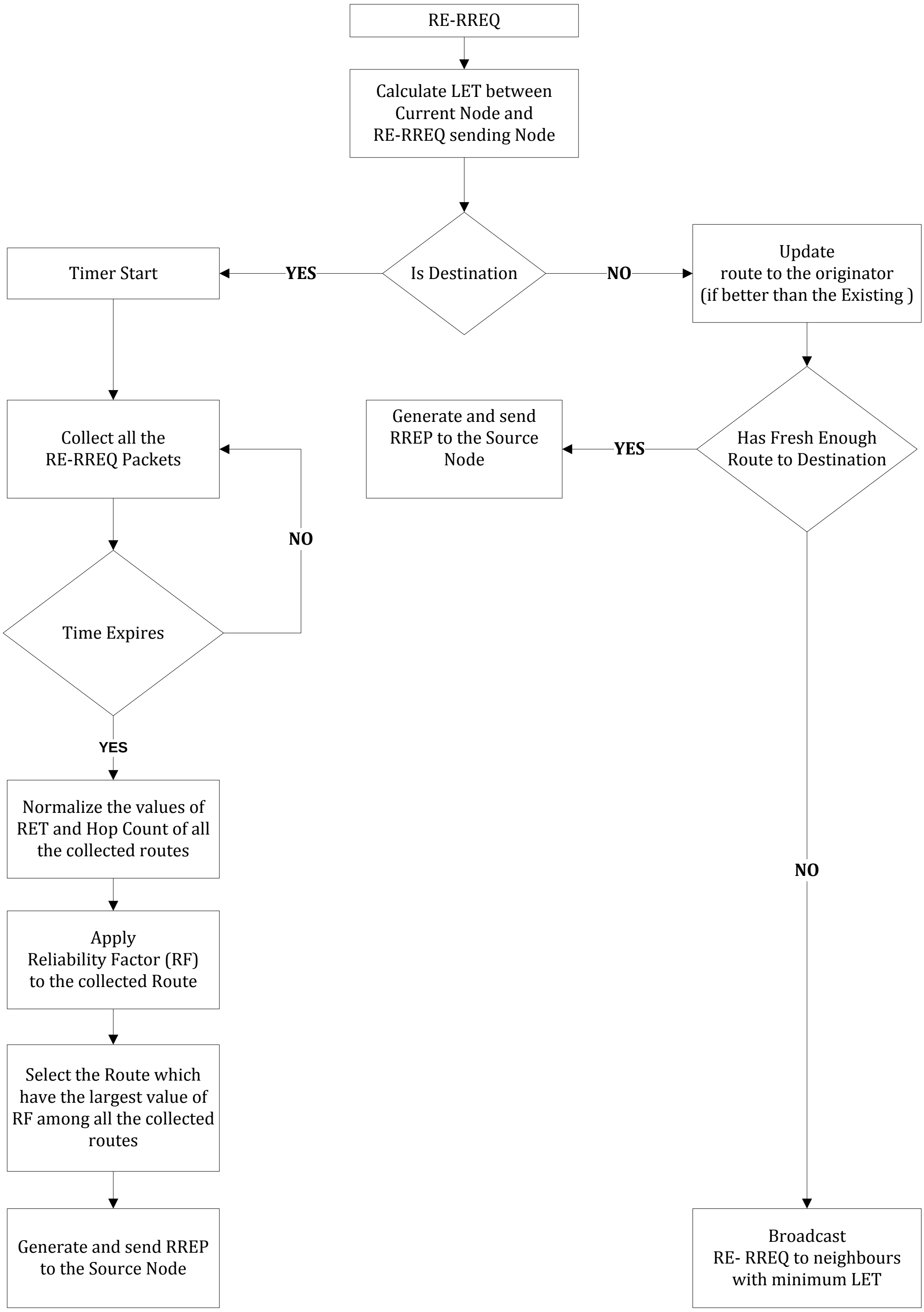

Figure 3-9 : Flow Chart of Route Discovery Process

The intermediate node may receive more than one copy of same RE-RREQ packet from various neighbouring nodes, it discards same RE-RREQ packet received later. An intermediate node generates RE-RREP message if it has an active route to the destination and if the intermediate node is a destination node, then it select the reliable route. The procedure of selection of reliable route is explained in section 3.4.2.

3.4.2 Route Selection of RERRP at Destination Node

When first RE-RREQ packet reaches to destination node 'D', a timer starts and waits for a certain time period. In between this time period the destination node start gathering other RE-RREQ packets which reaches for it. When the timer expires, the destination node calculates RF for each gathered route from source to destination and selects the route which has the higher RF value, for the route selection pseudocode refers Figure 3-10.

Algorithm 1: Route Selection

Suppose Source Node is "SN", Destination Node is "DN" and Current Node is "CN"

1: **IF** CN is DN **then**

2: Calculate the RET and the HC of all feasible routes.

3: Computes the RF of each feasible route

4: Selects one with the largest RF value.

5: Sends a RREP packet to that selected route.

6: **End IF**

7: SN receives the RREP packet from DN.

8: SN starts sending data to DN

Figure 3-10: Route Selection at Destination Node

Below an example is given that illustrates the route selection process of RERRP. Consider the network diagram cf. Figure 3-4 and Table 3-1 in which there are three feasible routes from source to destination.

MaxRET =35 **MaxHC = 6**

Feasible Route 1 = S → A → B → C → E → D

$RET_1 = 35$ $HC_1 = 5$

$RF_1 = (RET_1 / MaxRET) – (HC_1 / MaxHC)$

$RF_1 = (35/35) – (5/6) = 0.167$

$RF_1 = 0.167$

Feasible Route 2 = S → F → G → H → D

$RET_2 = 20$ $HC_2 = 4$

$RF_2 = (RET_2 / MaxRET) – (HC_2 / MaxHC)$

$RF_2 = (20/35) – (4/6) = 0.571 – 0.667 = -0.096$

$RF_2 = -0.096$

Feasible Route 3 = S → I → J → K → L → M → D

$RET_3 = 30$ $HC_2 = 6$

$RF_3 = (RET_3 / MaxRET) – (HC_3 / MaxHC)$

$RF_3 = (30/35) – (6/6) = 0.857 – 1 = -0.143$

$RF_3 = -0.143$

Since RF_1 is the highest value among the three feasible routes. Therefore, it selects route 1 to transfer the data.

3.5 Performance Evaluation

In order to evaluate the performance of RERRP, simulations were carried out using Network Simulator (NS2.35) software [26]. In the simulation, the Random Waypoint Mobility (RWM) model [27, 28] was employed. In RWM model every node individually picks a random initial point and waits for a period called pause time. It then moves with a velocity chosen normally between minimum and maximum velocities to a randomly chosen destination. After reaching the destination, it waits again for the pause time and then moves to a new randomly chosen destination with a new chosen velocity. Each node repeats independently the above mentioned movement until the simulation stops. The randomized speed values are taken from a truncated normal distribution with mean " $\bar{s}$ "and standard deviation σ_s [29], where

$$\bar{s} = \frac{Max_{Speed} + Min_{Speed}}{2} \qquad \sigma_s = \frac{Max_{Speed} - Min_{Speed}}{4}$$

Table 3-2: Simulation Parameters

Parameters	Value
Protocols	RERRP, AODV
No of Nodes	50
Simulation Area	1000m X 1000m
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground
Simulation Time	300 s
Data Rate	4 Packets/Sec
Experiment 1: Effect of Nodes Speed	
Min Speed	1 ms^{-1}
Max Speed	5, 10, 15, 20, 30, 40, 50 ms^{-1}
No of Nodes	50
Experiment 2: Effect of Node Density	
Number of Nodes	40, 60, 80, 100, 120, 140
Min Speed	1 ms^{-1}
Max Speed	20ms^{-1}

The key simulation parameters employed in simulating the effect of varying the node speed and varying node densities are shown in Table 3-2. Simulation of the proposed scheme is performed with 50 nodes in the area of 1000m X 1000m. This setting provides enough space for the mobility of nodes and to check the discovery of new routes. Traffic sources are set to continuous bit rate (CBR). The simulation is set to maximum 25 connections. 512-Byte data packets are used with a rate of 4 packets per second. A shared-media radio was selected with a nominal radio range of 250 m. The source-destination pairs are selected randomly over the network a zero pause time was used to simulate a mobility level with nodes that are continuously moving in the simulation area. Each data point represents an average of multiple runs with different seed values used for the traffic models and randomly generated mobility scenarios.

Following two simulation experiments are presented to check the performance of RERRP.

3.5.1 Experiment – 1: Effect of Nodes Speed on RERRP

In the network of 50 nodes the speed of the mobile node was changed from $5ms^{-1}$ to $50ms^{-1}$ to check the effect of different speeds on the proposed routing scheme.

3.5.2 Experiment – 2: Effect of Node Density on RERRP

The number of nodes was changed in the network from 40 nodes to 140 nodes to check the effect of node density on the proposed scheme. Here, the maximum speed of the mobile node is $20ms^{-1}$.

3.6 Performance Metrics

Following metrics are used in varying scenarios to evaluate the proposed protocols [30].

Packet Delivery Fraction: This is defined as the ratio of the number of data packets received by the destinations to those sent by the sources.

Normalized Routing Load: This is defined as the number of routing packets transmitted per data packet delivered at the destination.

Average End-to-End Delay: It is defined as the delay between the time at which the data packet was originated at the source node and the time it reaches the destination node. Data packets that get lost in route are not considered.

Throughput: The amount of data received by the destinations per unit time is referred as throughput of the network. Normally, it is measured in bits/sec.

Received Packets: Received packets represent the total number of data packets received at the destination.

Routing Packets: The Total number of routing packets involved in the network.

3.7 Simulation Results and Discussion of Experiment – 1

The performance of RERRP is compared with traditional AODV in terms of packet delivery fraction, normalized routing load, average End-to-End delay, throughput, Number of received packets and number of routing packets.

3.7.1 Number of Link Breaks vs. Max Speed

Figure 3-11 represents the number of link beaks on different node speed. The simulation result shows that more route begins to break as the speed of node increases. When the node starts moving faster that makes the routing path unreliable. Figure 3-11 also shows that the proposed protocol RERRP has less number of link breaks than AODV. This reduction in link breakage of the RERRP is because of its route selection mechanism in which it uses the concept of Reliability Factor (RF) to selects the most reliable route with higher expiration time. This selection of reliable route eventually reduces the route breakage. On the other hand, AODV only selects the shortest path between the source node and destination node. AODV also did not consider the expiration time of the route while discovering the route hence it faces the more route breakage.

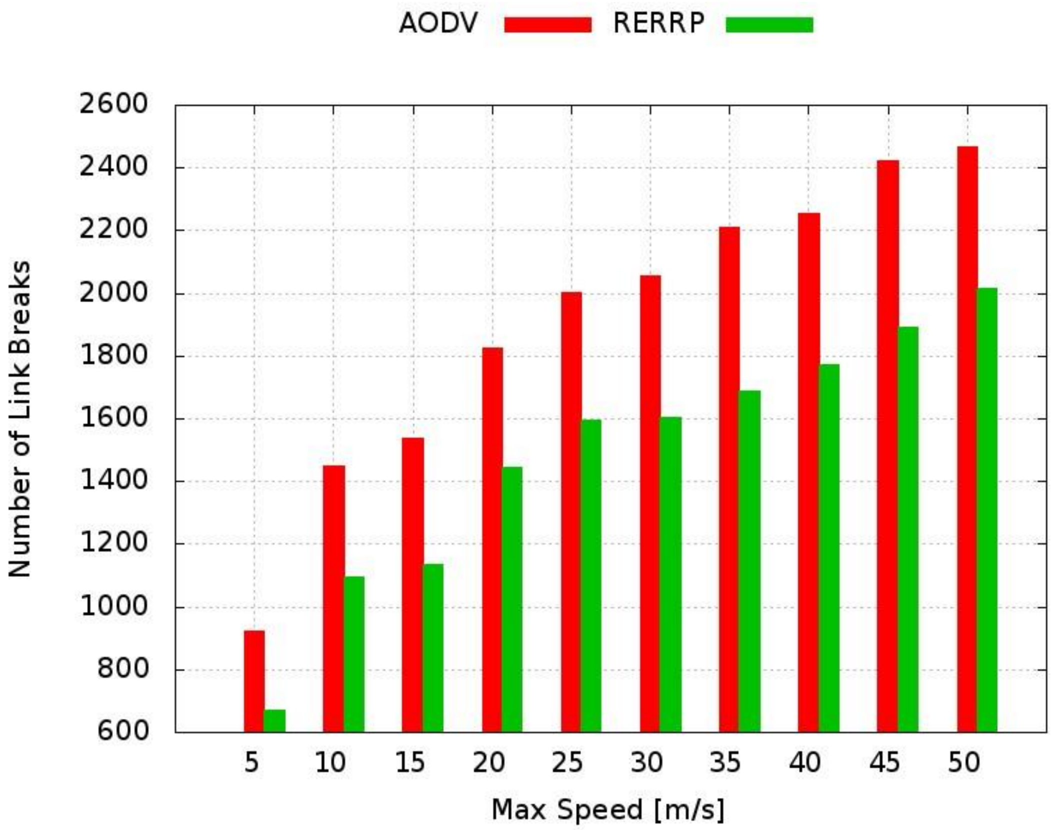

Figure 3-11: Number of Link Breaks vs. Max Speed

3.7.2 Packet Delivery Fraction vs. Max Speed

The ratio of the number of data packets received by the destinations to those sent by the source nodes is referred and Packet Delivery Fraction (PDF). Figure 3-12 represent the number of send packets of different node in the network and Figure 3-13 shows the number of received packets by the destination node.PDF is obtained by dividing the total number of received packets by the total number of send packets. Simulation is done seven times at every node speed with different seed values and Figure 3-14 represent the average result of all the simulations. Figure 3-14 show that as soon as the node speed increases the PDF of both protocol decreases. This is because of more route begins to break easily as the speed of node increases. Figure 3-14 also shows that the proposed protocol RERRP has more packet delivery than AODV. This enhancement in the delivery ratio of the RERRP is because of its route selection mechanism in which the destination node selects the most reliable route with higher expiration time. This selection of reliable route eventually reduces the route breakage cf. Figure 3-11 and hence the packet delivery increased. On the other hand, AODV only selects the shortest path between the source node and destination node. AODV also did not consider the expiration time of the route while discovering the route hence it faces the more route breakage and more data drops. It is also observed that at lower speed RERRP enhances around 2% to 3 % PDF as compare to AODV because at lower speeds less number of route breaks, but when the node speed increased the PDF of the proposed protocol RERRP enhances around 5% to 8% as compared to AODV.

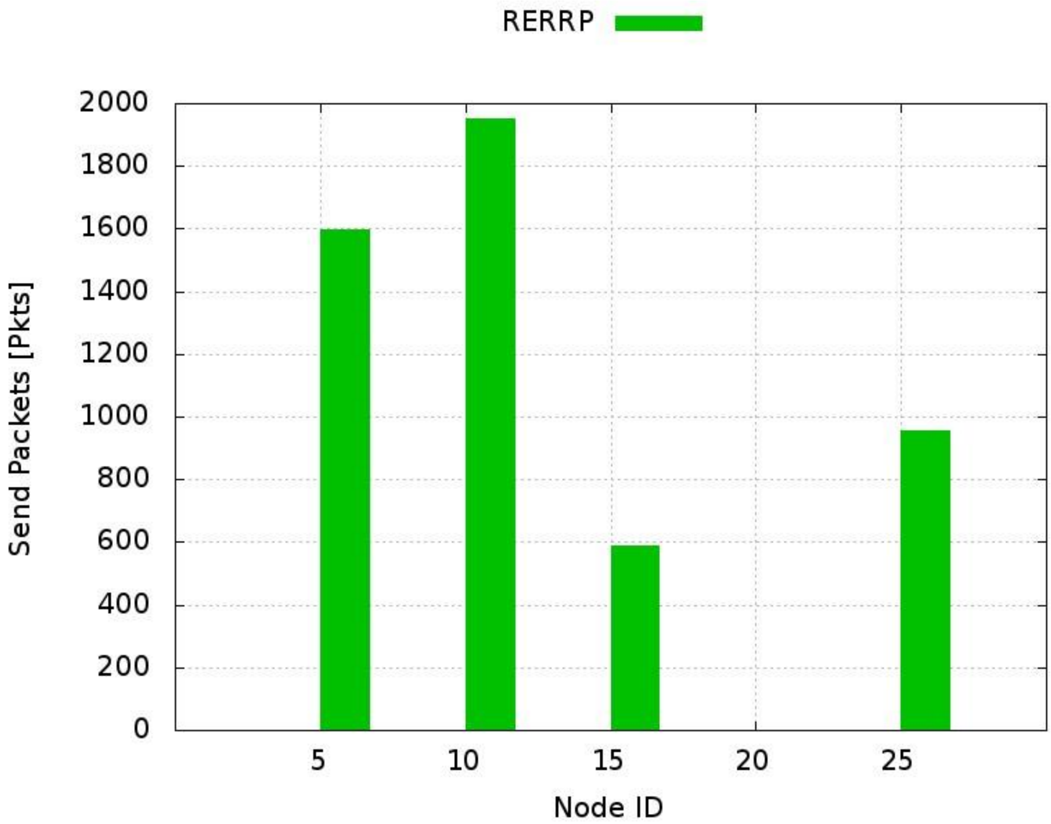

Figure 3-12: Send Packets vs. Node ID

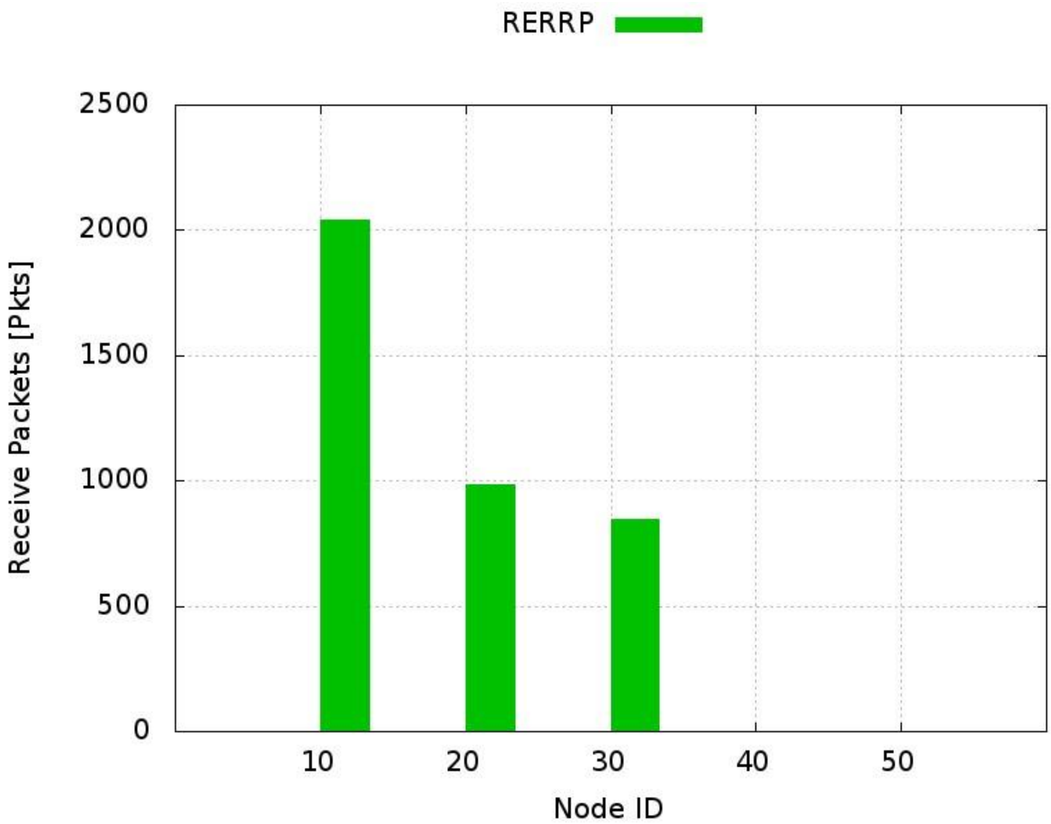

Figure 3-13: Receive Packet vs. Node ID

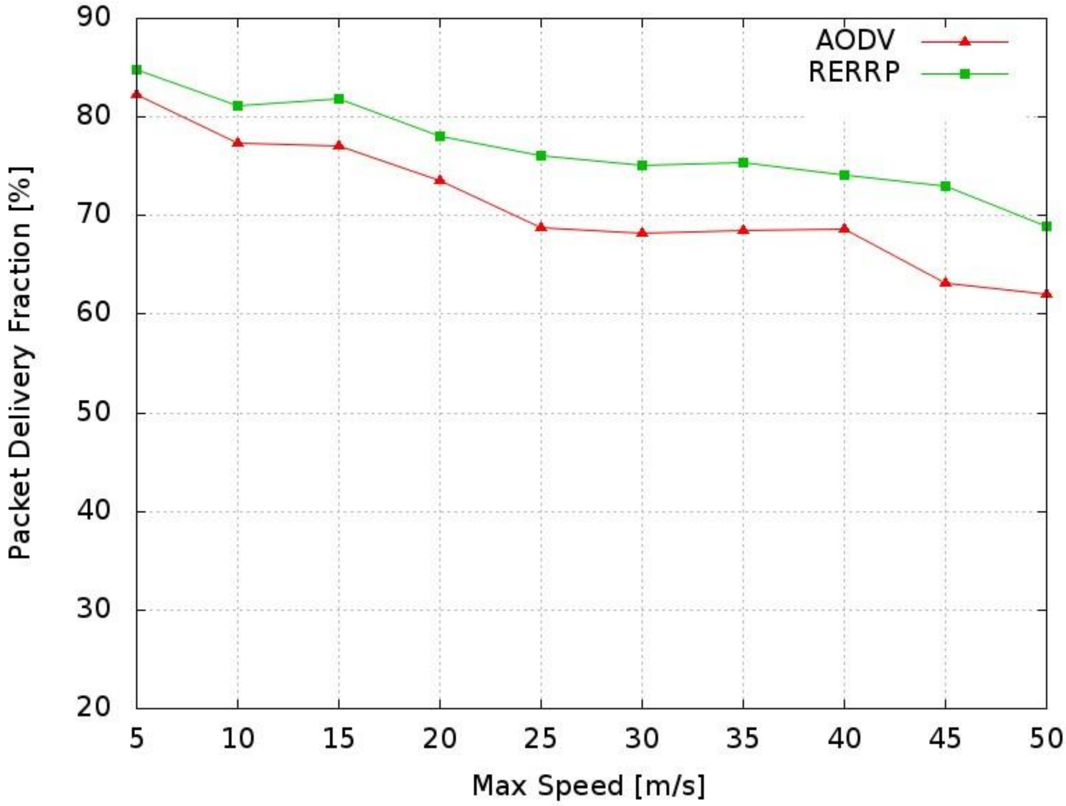

Figure 3-14: Packet Delivery Fraction vs. Max Speed

3.7.3 Network Routing Load vs. Max Speed

The number of routing packets required per delivered data packet represents the routing load of the network. Figure 3-13 shows the number of received packet on different nodes at the maximum node speed of $25ms^{-1}$ for a single simulation. Similarly, Figure 3-15 shows the number of routing packets on different nodes. The network routing load is obtained by dividing the total number of routing packets by the total number of received packets. Simulation is done seven times at every node speed with different seed values and Figure 3-16 represent the average result of all the simulations.

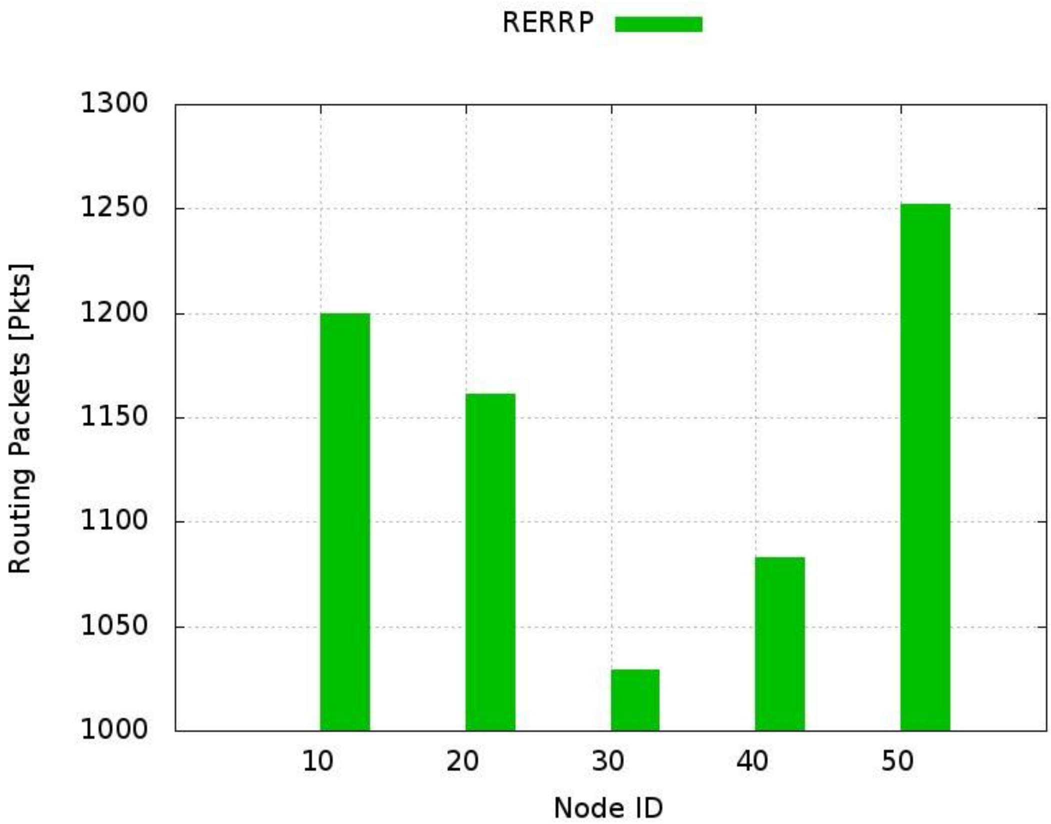

Figure 3-15: Routing Packets vs. Node ID

In Figure 3-16 simulation result shows that the network routing load of the RERRP is less than the AODV. The lower routing load of the proposed protocol RERRP is because of the selection of reliable and long life route between the source node and the destination node. Due to the selection of reliable route failures of the route was reduced cf. Figure 3-11. This reduction in the route failures eventually reduces the initiation of route rediscovery and maintenance procedure and hence the network routing load of RERRP is less than AODV. The comparison result between AODV and RERRP also showed that, RERRP has achieved superior performance in term of routing load. On average, RERRP reduces overhead by 30% as compared to AODV.

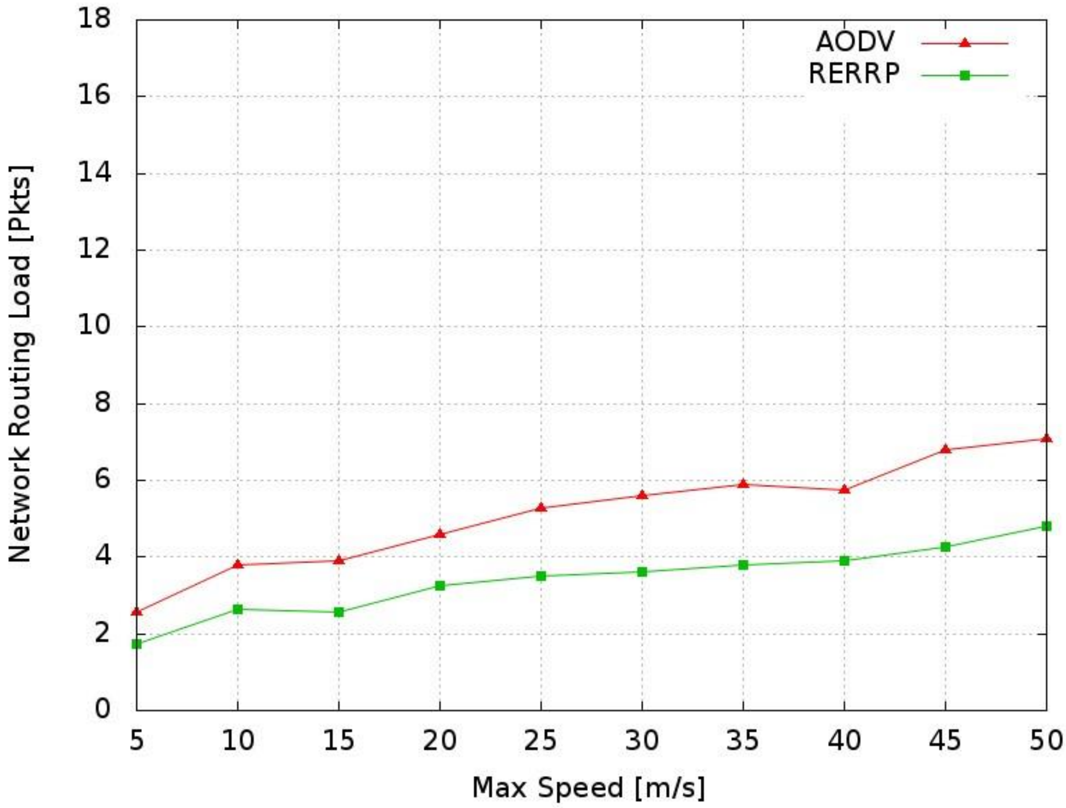

Figure 3-16: Network Routing Load vs. Max Speed

3.7.4 End-to-End Delay vs. Max Speed

Figure 3-17 represents the send time of the data packets and Figure 3-18 shows the receive time of the data packets. End-to-End delay of a packet is calculated by subtracting the send time from the received time of the packet cf. Figure 3-19. Average end-to-end delay of single simulation is obtained by adding all the delay of packets divided by all the total number of received packets. Simulation is done seven times at every node speed with different seed values and Figure 3-20 represent the average result of all the simulations. The average End-to-End delay comparison is represented in Figure 3-20, shows that the average end-to-end delay of both the protocol have similar patterns and have an approximately faces same delay.

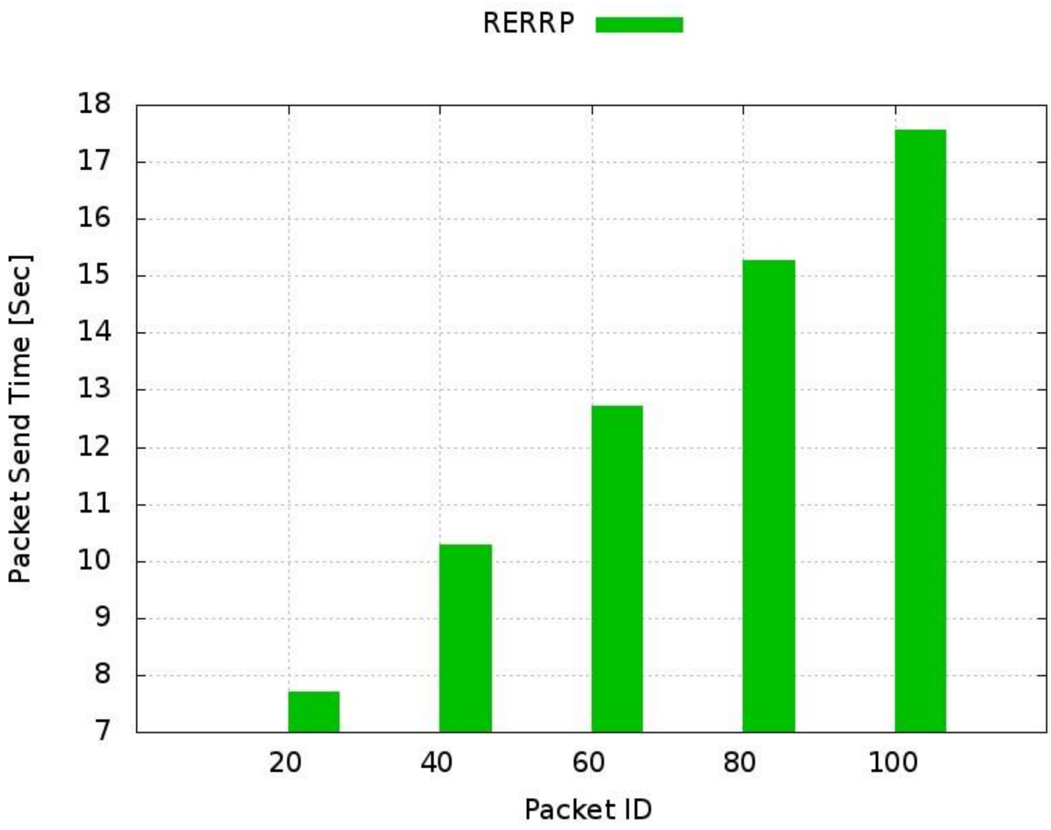

Figure 3-17: Packet Send Time vs. Packet ID

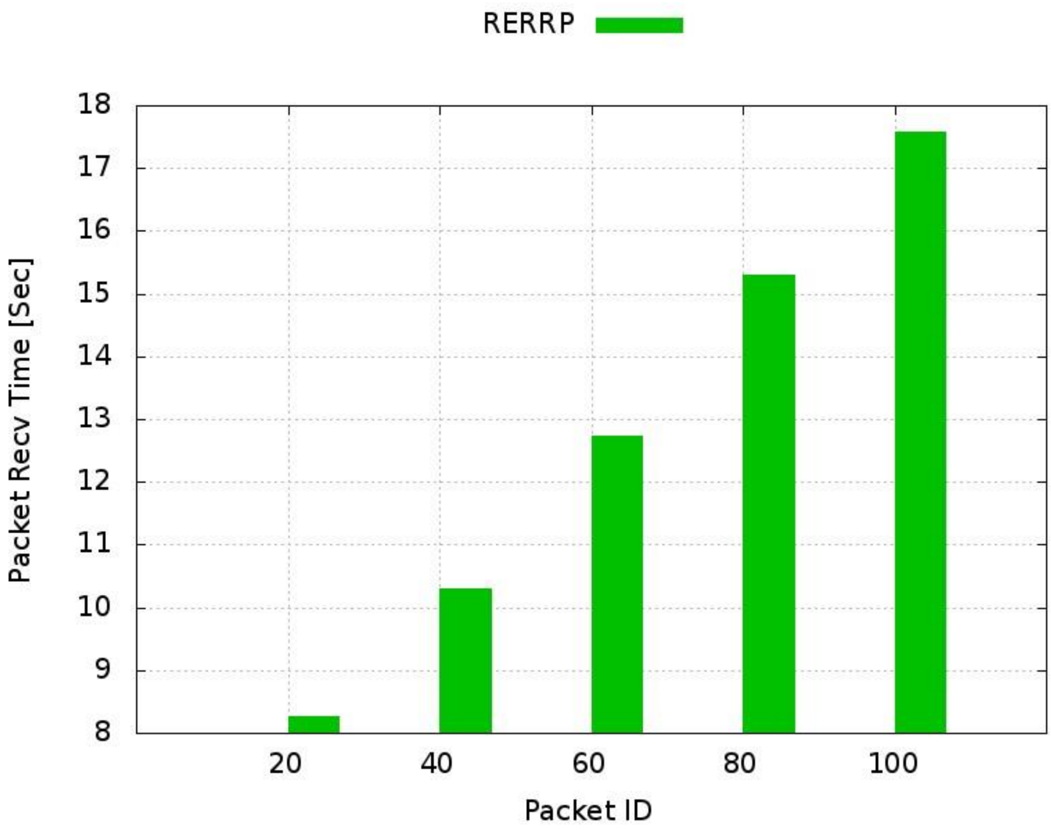

Figure 3-18: Packet Receive Time vs. Packet ID

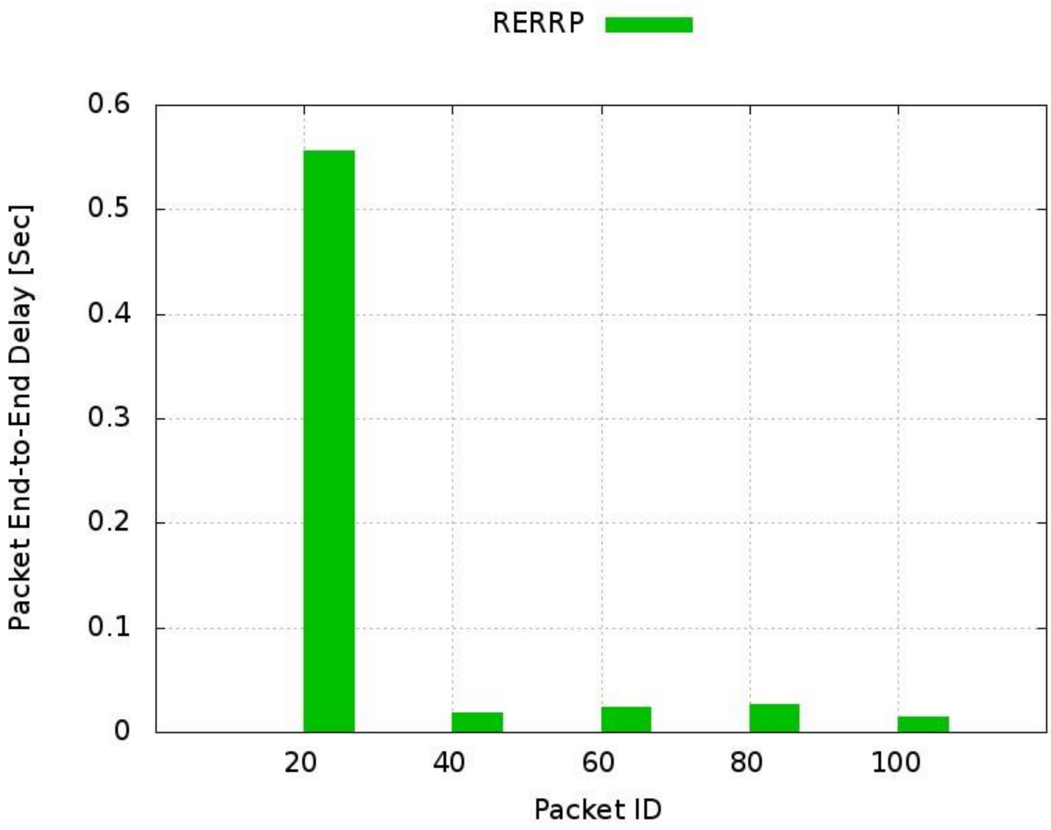

Figure 3-19: Packet End-to-End Delay vs. Node ID

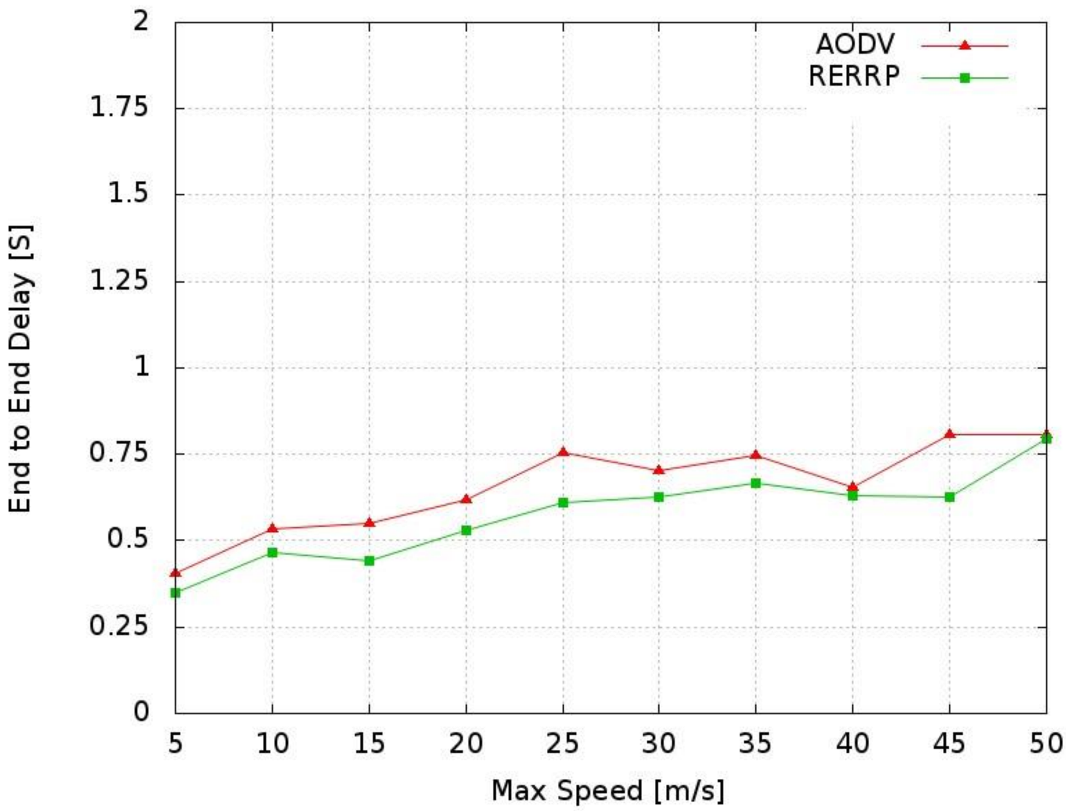

Figure 3-20 : End-to-End Delay vs. Max Speed

3.7.5 Throughput vs. Max Speed

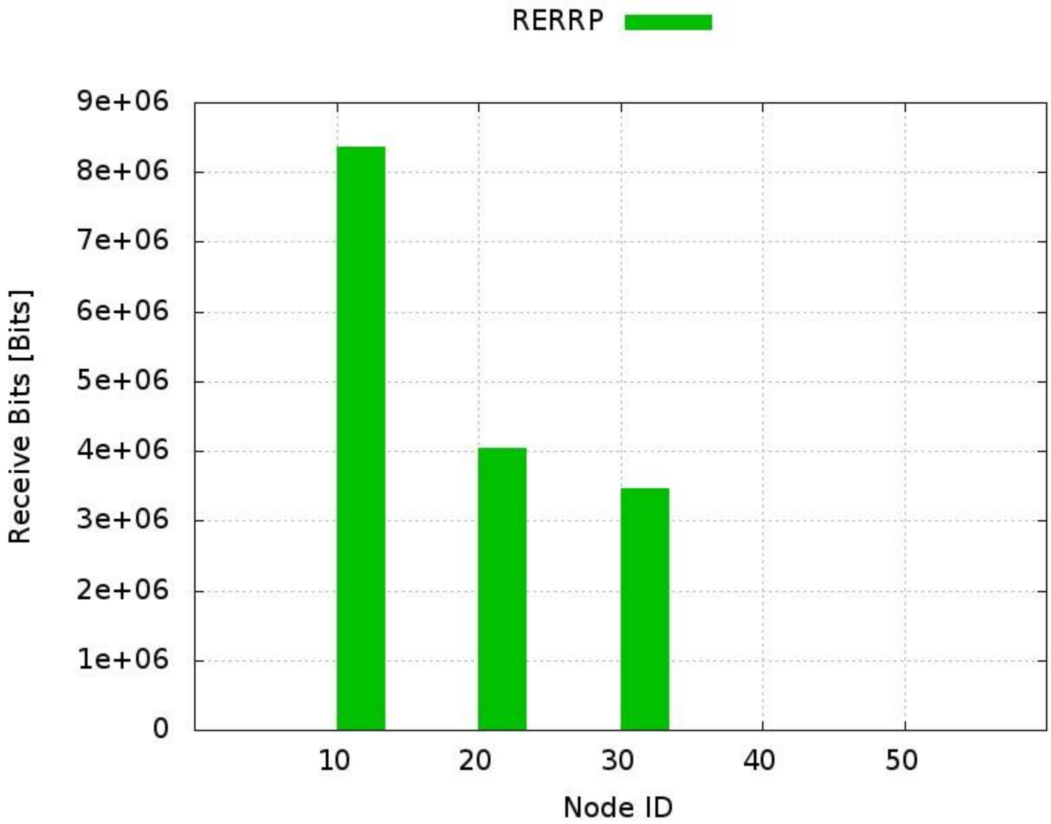

Figure 3-21: Receive Bits vs. Node ID

The amount of data received by the destinations per unit time is referred as throughput of the network. Figure 3-21 represent the number of received bits on destination nodes. For the throughput all the received bits by the destination nodes are added and divided by the consumed time. Simulation is done seven times at every node speed with different seed values and Figure 3-22 represent the average result of all the simulations. Figure 3-22 shows the effect of node speed on the throughput of the network. The simulation result shows that as the node speed increases the throughput of both protocol decreases. This is because of more route begins to break easily as the speed of node increases cf. Figure 3-11. When the node starts moving faster that makes the routing path unreliable. As RERRP selects the reliable route to transfer the data packet, therefore the throughput of RERRP is better than that of the AODV at all speeds.

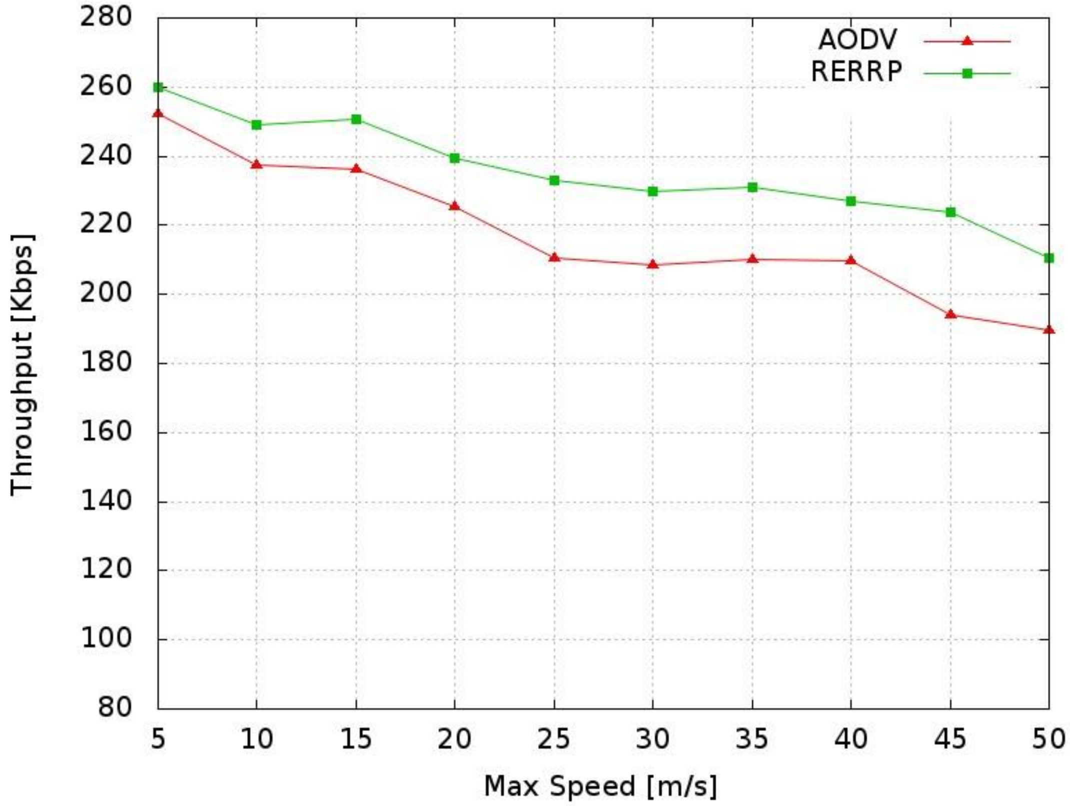

Figure 3-22 : Throughput vs. Max Speed

3.7.6 Received Packets vs Max Speed

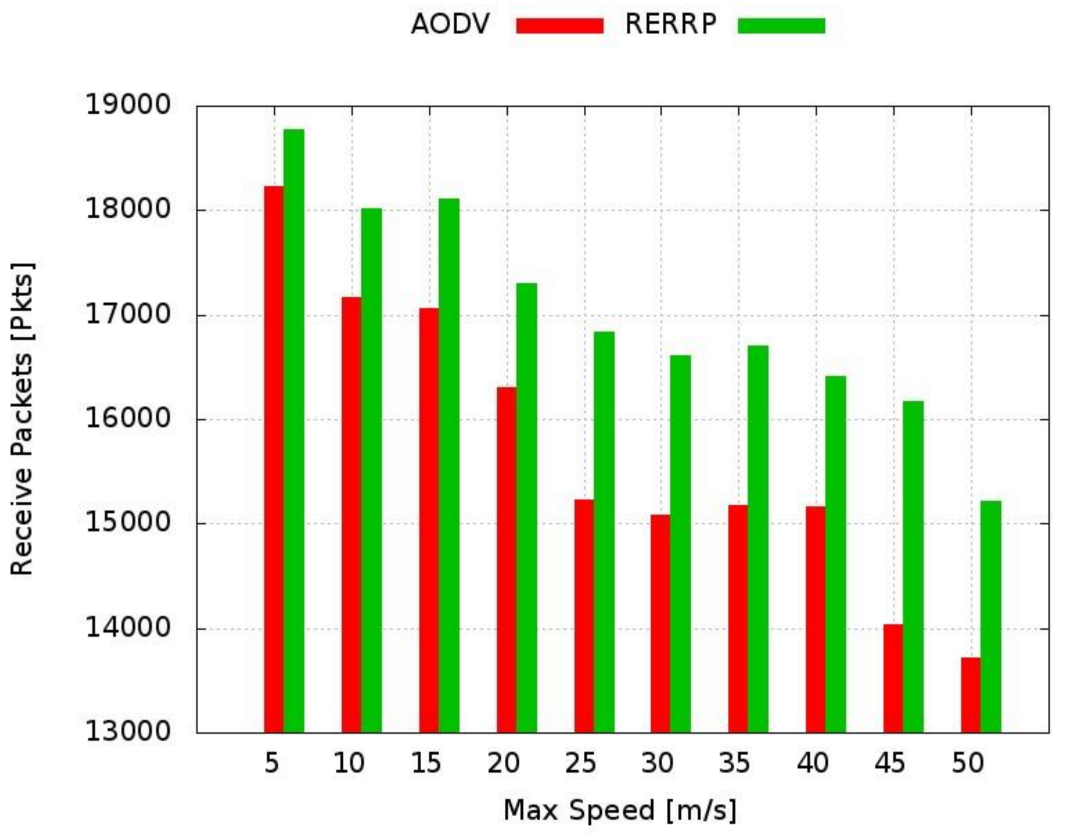

Figure 3-23 : Received Packets vs. Max Speed

Figure 3-23 illustrates the number of received packets against the node speed in the network. It shows that the number of received packets for both the protocols drops gradually while the node speed increased. But in the graph we can also see that the proposed protocol received more packets as compared to the AODV. The proposed protocol RERRP selects the reliable and efficient route that's why it has a low number of route break and eventually more packets received.

3.7.7 Routing packets vs Max Speed

The Number of routing packets is involved in the network are shown in the Figure 3-24. As the node speed increase there are more route breakage occur in the network that's why the more routing packets needed to find the route. The proposed protocol RERRP has less number of route breakages because of the selection of reliable route less number of routing packets needed as compared to AODV.

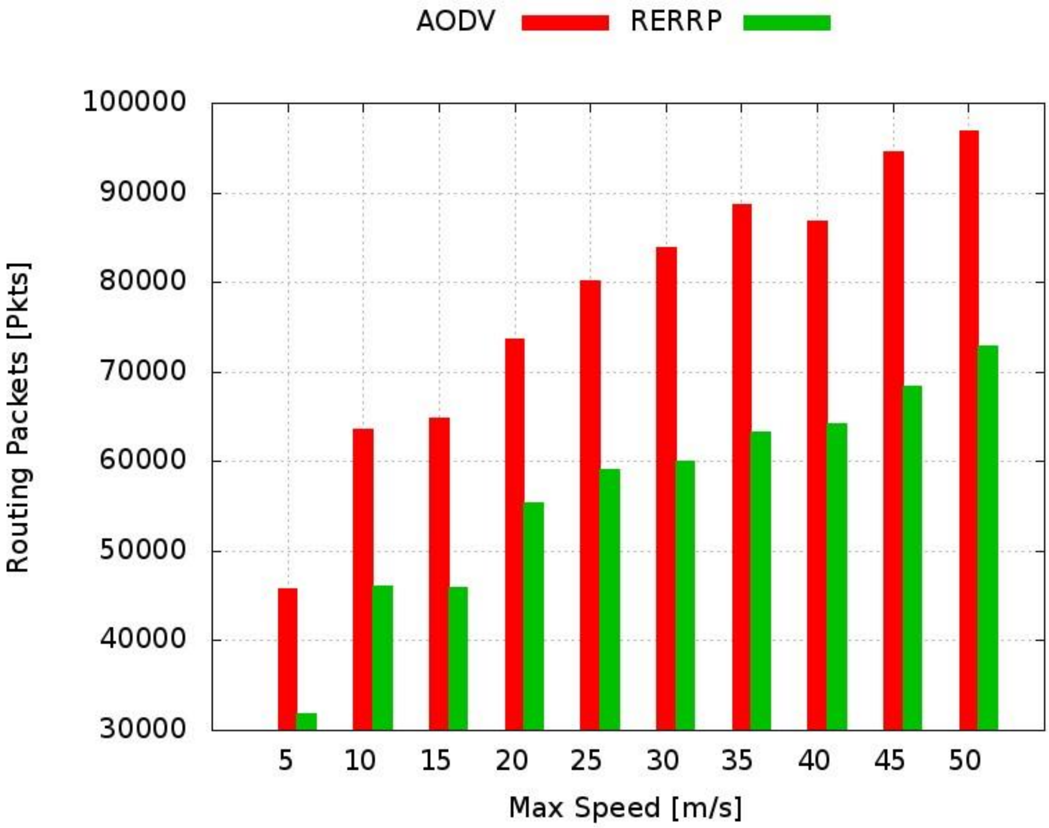

Figure 3-24 : Routing Packets vs Max Speed

3.8 Simulation Results and Discussion of Experiment – 2

This section presents the performance impact of network density on RERRP and AODV over different network density. The network density has been varied by deploying 40, 60, 80, 100, 120 and 140 nodes over a fixed area of 1000m x 1000m. Each node in the network moves with a speed of $20ms^{-1}$. The maximum connections of 25 are generated between random source destination connections (i.e. Traffic Flow), each node generating 4 data packets per second. The packet size is 512 Bytes. In the figures presented below, the x-axis represents the variations of numbers of nodes, while the y-axis represents the results of the performance metric of interest.

3.8.1 Packet Delivery Fraction vs. Number of Nodes

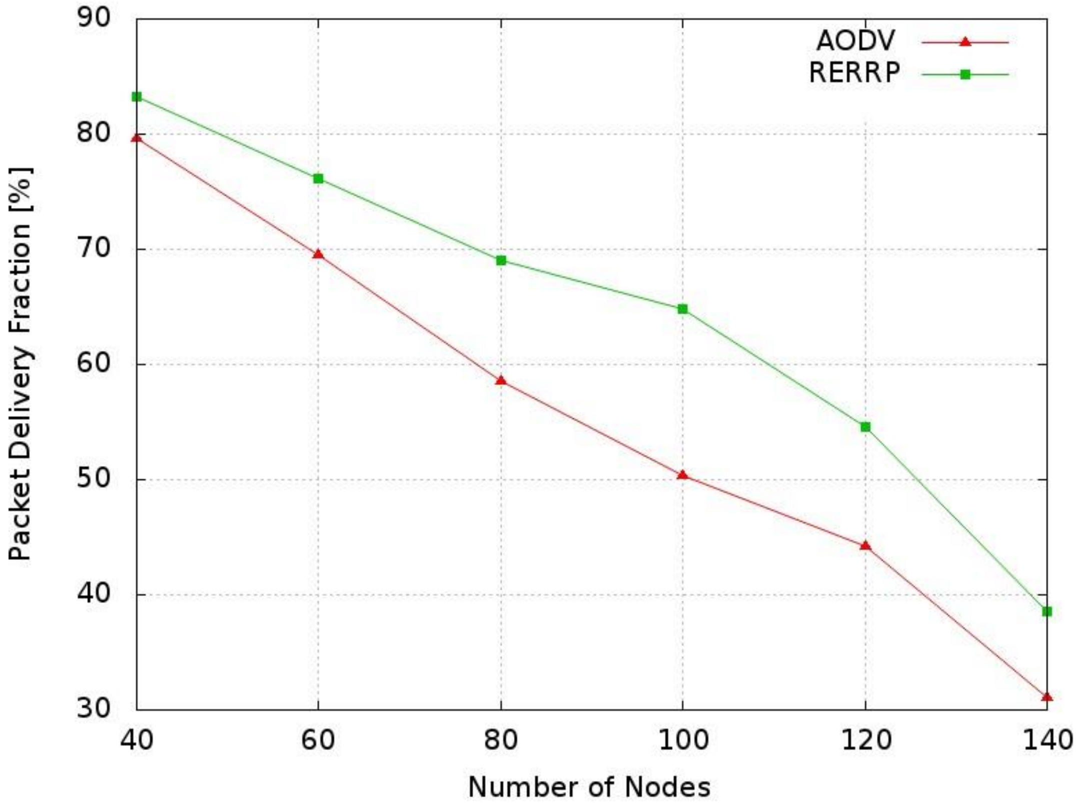

Figure 3-25 : Packet Delivery Fraction vs. Number of Nodes

Figure 3-25 shows the effects of network density on the performance of RERRP and AODV in terms of the packet delivery fraction. As the number of nodes increased we can see that both the protocols decrease the packet delivery fraction. The packet delivery of the proposed protocol RERRP is more than AODV at every density of the network. In RERRP selects the reliable routes that reduce the breakage of the link. As AODV selects the shortest route between sources and destination that does not consider the speed and direction of nodes, but the proposed protocols selects the reliable and efficient route that considers the speed and direction of the nodes that eventually increase the delivery of the data packet.

3.8.2 Network Routing Load vs. Number of Nodes

In Figure 3-26, the normalised routing load of RERRP and AODV is plotted against different network density in which nodes placed in a topology area of 1000m x 1000m. As the number of nodes increased routing load also increased gradually. In Figure 3-26 simulation result shows the network routing load of the RERRP is less than the AODV. Due to the selection of reliable route by RERRP, failures of the route were reduced. This reduction in the route failures eventually reduces the initiation of route rediscovery and maintenance procedure and hence the network routing load of RERRP is less than AODV.

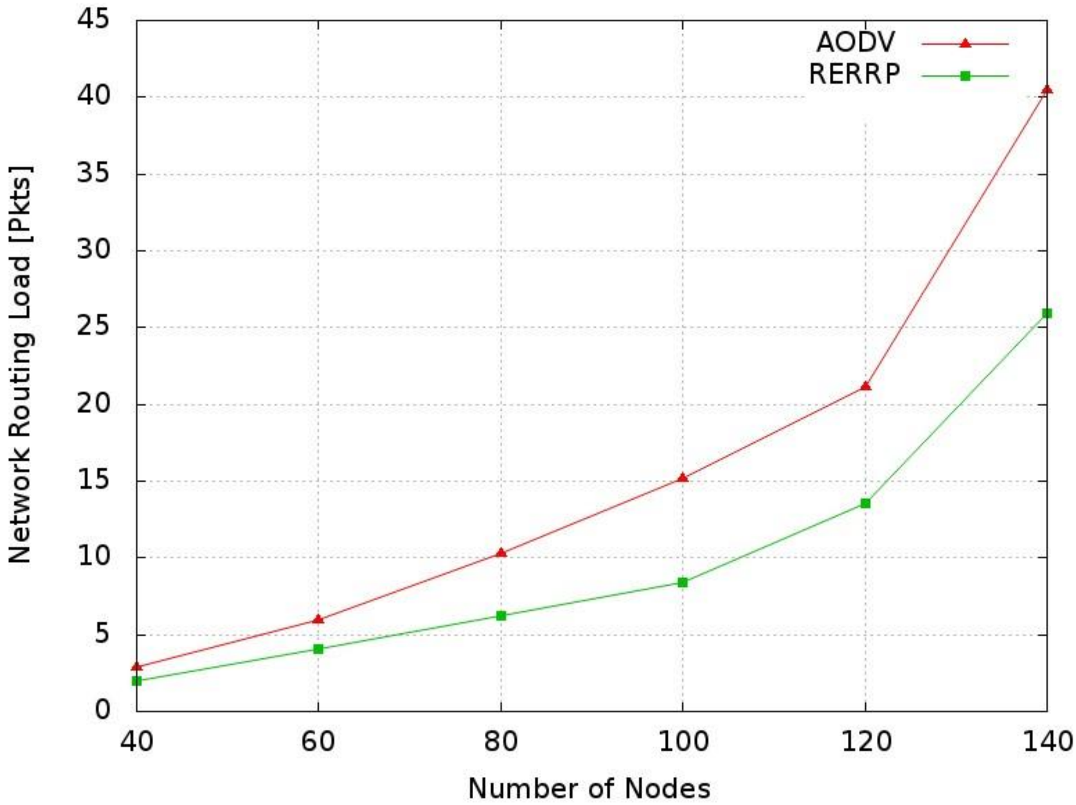

Figure 3-26 : Network Routing Load vs. Number of Nodes

3.8.3 Throughput vs. Number of Nodes

The average throughput is represented in the Figure 3-27 in which we can see that RERRP and AODV both drop the throughput when we increase the node density. Our proposed protocol gives higher throughput than the AODV at every node density. As the more nodes in the network than the destination node has more choices available to select the best route that have less chances to break the link for the data transfer. On the other hand AODV select the shortest route and don't consider the node's mobility while selecting the route that may cause the frequent link breakage that affect the overall throughput of the network.

3.8.4 End-to-End Delay vs. Number of Nodes

The Average End-to-End delay is illustrated in Figure 3-28 against the different numbers of nodes. As the number of nodes increased the end-to-end delay of both the protocols increased. Because of the selection of the reliable route the RERRP has taken less amount of time on average to transfer the data packet as compare to AODV.

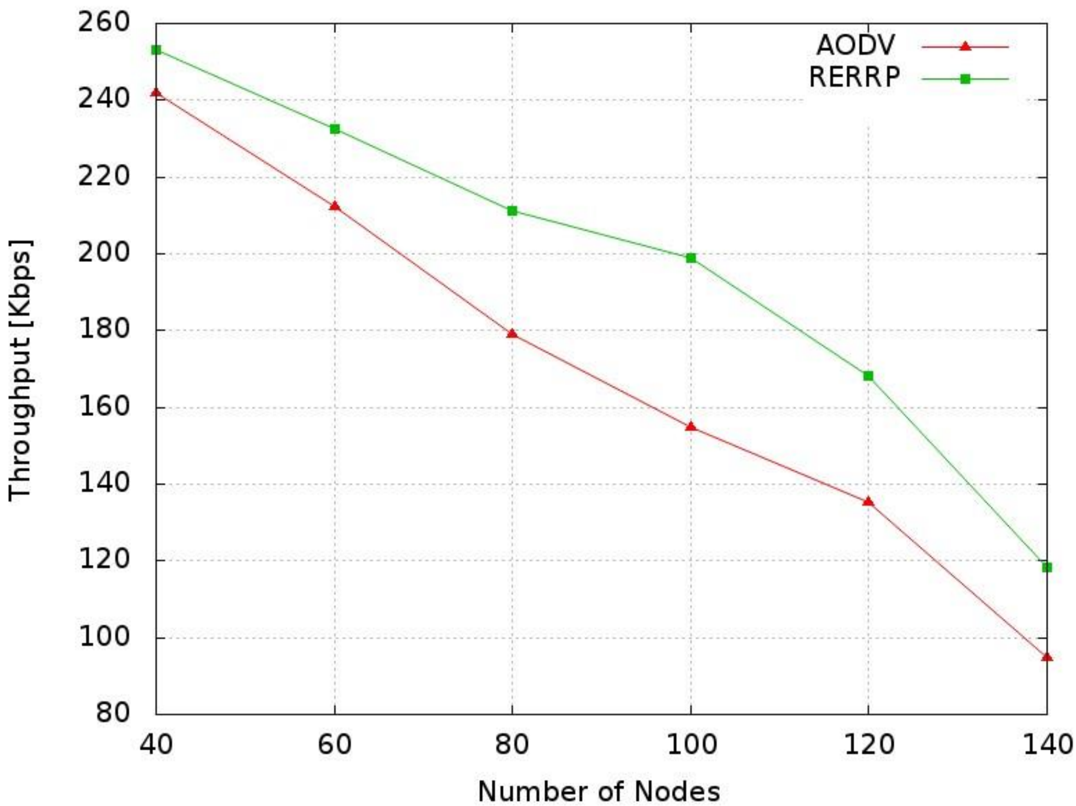

Figure 3-27 : Throughput vs. Number of Nodes

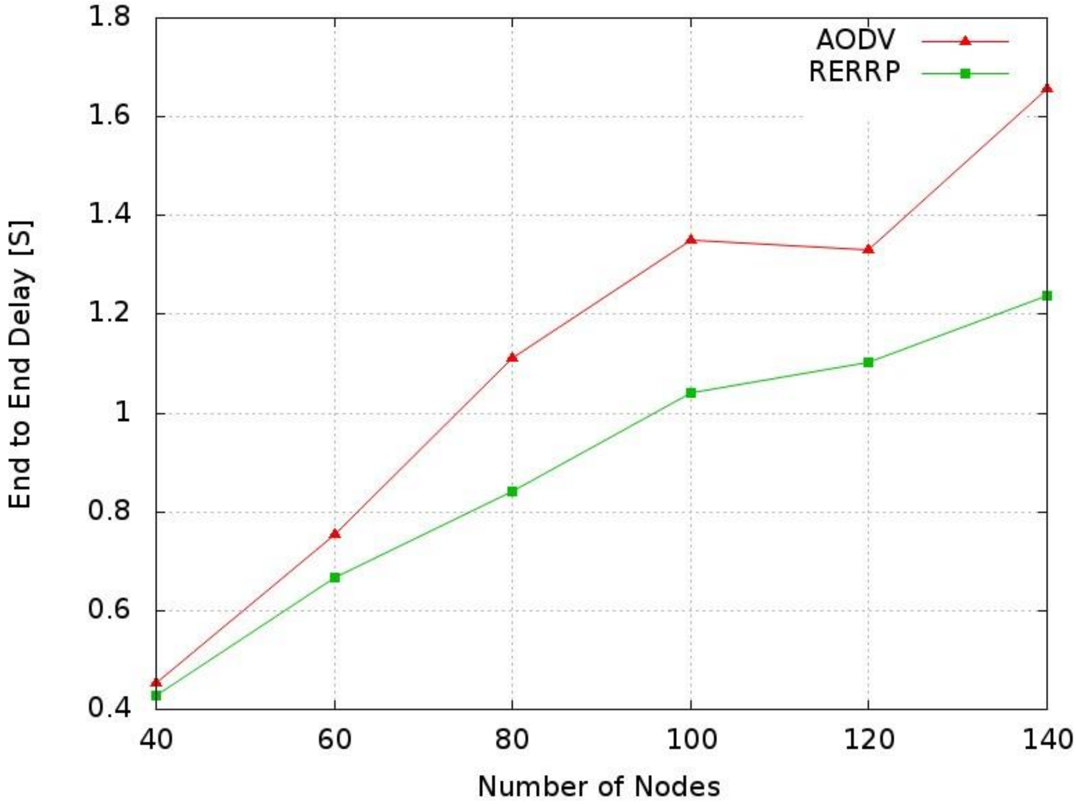

Figure 3-28 : End-to-End Delay vs. Number of Nodes

3.8.5 Receive Packets vs. Number of Nodes

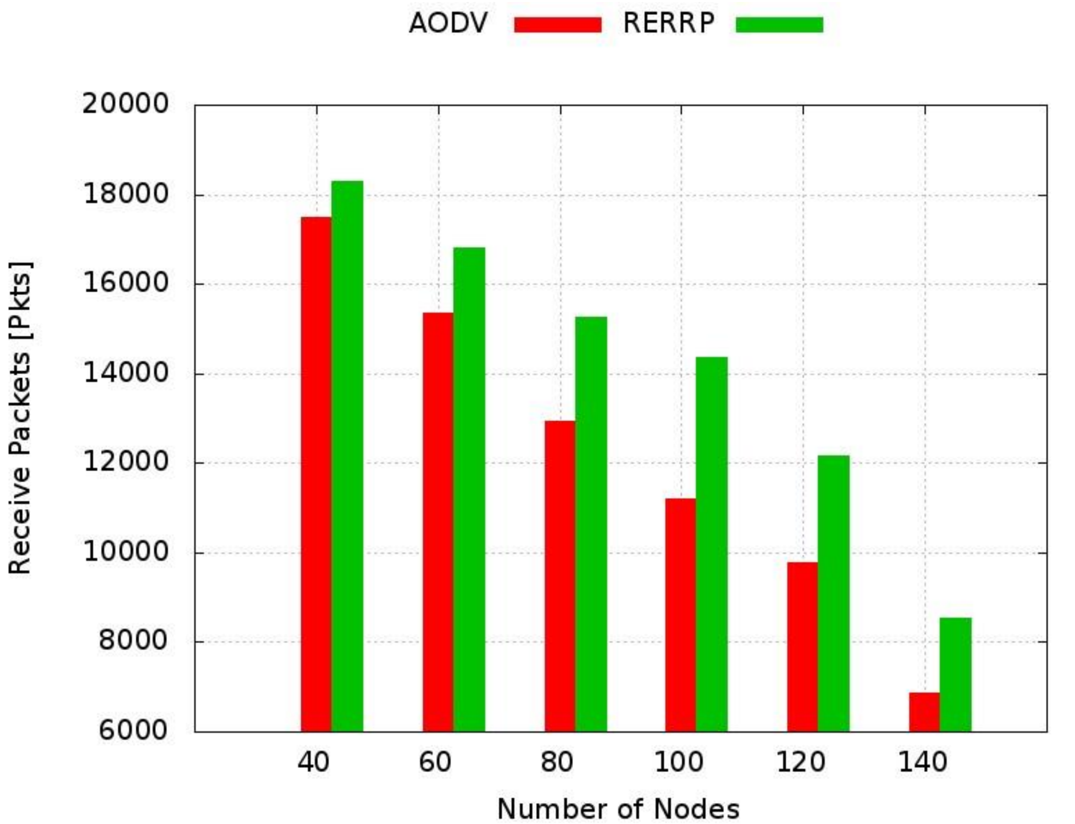

Figure 3-29: Receive Packets vs. Number of Nodes

Figure 3-29 illustrates the number of received packets against the node density in the network. It shows that the number of received packets for both the protocols drops gradually while the node density increased. But in the graph we can also see that the proposed protocol receive more number of packets as compared to the AODV. The proposed protocol RERRP selects the reliable and efficient route that's why it has low number of route break and eventually more packets received.

3.8.6 Routing Packets vs. Number of Nodes

The number of routing packets involved in the network is shown in the Figure 3-30. As the node density increased there are more broadcast or routing packet generated in the network and if the route breakage occur in the network the more routing packets needed to find the route. The proposed protocol RERRP has less number of route breakages because of the selection of reliable route less number of routing packets needed as compared to AODV.

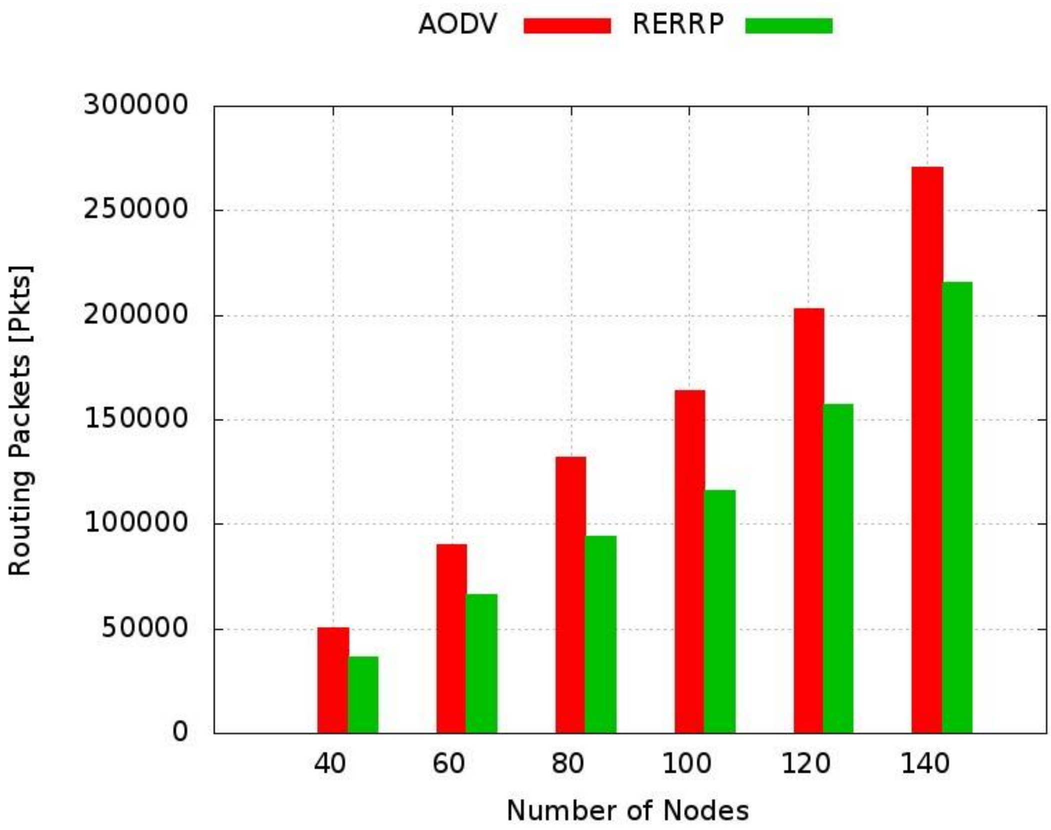

Figure 3-30 : Routing Packets vs. Number of Nodes

3.9 Chapter Summary

This chapter mainly presented a new routing protocol called Reliable and Efficient Reactive Routing Protocol (RERRP) for MANET. This scheme selects the reliable route based on the Reliability Factor (RF). RF considers Route Expiration Time and Hop Count to select a routing path with high reliability and have less number of hops. The selection of a reliable route depends upon the value of RF; a higher value of RF means the highly reliable path that can use for data transfer. RERRP always selects the most reliable path for routing in MANETs. The simulation result showed that RERRP outperforms AODV. During the study and the analysis of the simulation results it was found that AODV creates lots of routing load on the network due to blind flooding of RREQ packet in the route discovery phase. This process of flooding increases the retransmission of the RREQ packet in the network; as a result, it leads to high network congestion and significant network performance degradation. This phenomenon of retransmission of RREQ packet referred as a “Broadcast Storm” problem in the literature. In chapter-4, a routing protocol that can reduce effect of broadcast storm problem by using the concept of reliability factor is presented. Another issue faced by the MANET is the limited battery power of the mobile node. The node fails because running out of energy and as a result the established path using this node will break. Due to the path disconnection, route maintenance or route rediscovery process had to be initiated to re-establish the broken path which causes extra energy consumption of nodes and affects negatively on the performance of the network. In Chapter-5, a routing protocols based on reliability factor is presented that can balance the utilisation of energy among the mobile node and selects a highly stable route, which eventually increase the network lifetime and enhance the performance of the network.

3.10 References

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Chapter 4

Effective Broadcast Control Routing Protocol (EBCRP)

4.1 Introduction

As has been mentioned in Chapter 3, the routing overhead caused by the "Broadcast Storm" problem associated with the on-demand routing protocol can significantly affect the network performance. This chapter proposed a routing protocol that controls the "Broadcast Storm" problem. Because of the dynamic nature of MANETs, broadcasting [1, 2] played an important role in the route discovery process of on-demand routing protocols such as AODV [3] and DSR [4]. Broadcasting is a basic communication operation used in the route discovery process of many on-demand routing protocols in Mobile Ad-Hoc Network (MANET) [5]. A route discovery process in on-demand routing protocol [3, 4] was initiated by broadcasting a RREQ packet to all the neighbouring nodes. After receiving this RREQ packet by neighbouring or intermediate node, if this RREQ packet already had been processed by this node then it simply discards this RREQ packet. Secondly, if this node has a valid route to the destination, it simply generates and sends back the RREP packet towards the source node. Moreover, if there is no valid route exists in the routing table, then this RREQ packet will be rebroadcast again until the discovery of the required destination. This process increases the retransmission of the RREQ packet in the network [6]; as a result, it leads to high network congestion and significant network performance degradation. This phenomenon of retransmission of RREQ packet is referred as a "Broadcast Storm" problem in the literature [7]. Consequently, it enhances the routing overhead significantly and the network available bandwidth also unnecessarily consumed [7, 8]. Therefore, controlling the redundant re-transmission of RREQ message is a challenging task [9]. Blind flooding of RREQ packet significantly causes degradation of network performance [10]. This chapter addresses the issue of redundant re-transmission of RREQ packet and propose a routing algorithm that deal with the "Broadcast Storm" problem which is widely practiced in the reactive routing protocol. In this chapter two routing protocol has been proposed one protocol is called Effective Broadcast Control Routing Protocol (EBCRP) and the other one is an enhancement of EBCRP.

The EBCRP mainly considered link expiration time and the hop count while controlling the "Broadcast Storm" problem. This chapter is derived from chapter 3 and uses the concept of Reliability Factor, which is already explained in the previous chapter. The proposed algorithm EBCRP is an on-demand routing protocol, therefore AODV route discovery mechanism was selected as the base of this scheme [11]. The comparative study between AODV and EBCRP revealed that the EBCRP have controlled the routing overhead significantly, reduces it around 70% as compared to AODV. EBCRP also enhance the packet delivery by 13% in comparison with AODV. Simultaneously, the EBCRP also achieves better throughput with less amount of data drops as compared to AODV.

4.2 Related Work

As discussed earlier in this chapter that broadcasting of the RREQ message in the route discovery process can possibly lead to extreme redundant retransmission of the request packet. This redundant retransmission of RREQ packet greatly degrades the packet delivery and network performance. Many attempts have been made to mitigate routing overhead caused by the broadcasting in the route discovery process. Existing solutions are summarized in the following section.

In literature [8, 12] several broadcast schemes have been proposed that include probabilistic, neighbour knowledge based, counter based and location approaches. Probabilistic approaches consider certain probability when a node rebroadcast the received packets. To reduce the redundant re-transmission of the broadcast packet in neighbour knowledge based approaches is done by periodic exchange of neighbourhood information. While in counter based approach, when counter threshold value is greater than the number of duplicate packets received only than the node rebroadcast the packet. Forwarding nodes are selected in location based approaches. The selection of the forwarding node is based on the location of the node. Global Positioning Services (GPS) are commonly used in this approach for find a node location.

The scheme proposed in [13] is based on the neighbour knowledge schemes. Periodic "hello" packets are used to keep the latest information of their neighbours. This information is used to decide whether to rebroadcast the packet, or don't do anything. The simplest broadcasting techniques that are mentioned in the literature [7] and [13-15] are probabilistic broadcasting schemes. Probability "p" is assigned to all the intermediate nodes while it re-broadcasts the received packets. In these techniques assigning the accurate level of probability to every node is an important task. In [16] Sasson et. al used the transition phase phenomenon [17] and the random graph technique [18] to identify the accurate level of probability. Studies in [7] and [16] mentioned that these probabilities based schemes have reachability issues in sparse network, but on the other hand, these schemes are very useful for the reduction of the problems caused by broadcast storm [7]. The author of [19] claimed that in schemes [7] and [16] every node has same forwarding probability. This assignment of same probability is the major cause of poor reachability.

In [20] the authors used counter based and probabilistic based approaches as combination in their dynamic probabilistic scheme. The number of duplicate packets received at the node is set as a forwarding probability in the scheme mentioned in [20]. The number of duplicate packets received not necessarily equal to the number of neighbours because every neighbour has their local probability to block the rebroadcast.

The algorithm in [21] used location aided information on the nodes that helps to limit distribution of the control routing packets in a particular area. Providing the location of the destination node is the important component of the location aided system that used location based routing algorithms. Every immediate neighbour's nodes used "hello" packets to learn the location information of each other [22, 23]. To determine the location of distant nodes some centralized dedicated location servers are required. But in MANETs, this approach is not feasible because of its dynamic nature. Global Positioning System (GPS) receivers [24] are used as an alternative to centralized location servers in MANETs.

To mitigate the routing load in on-demand routing protocols, an optimization technique "Location Aided Routing" (LAR) [21] was proposed. The authors of LAR assume that, each mobile node can identify its own location, but to obtain the location of other nodes in the network they don't use any centralized location server. As an alternative to the centralized location servers they used the prior route discovery information to estimate the destination location. Route search in LAR is limited to a defined zone by the source node based on the estimated destination location.

A Semi-Proactive AODV (SP-AODV) [25] is a routing protocol based on AODV [26]. In this protocol authors presented a semi-proactive approach to find a route. The efficiency of this SP-AODV routing protocol mainly relies on the procedure of updating some sections of the routing table by the nodes depending on the value of a Counter field in the routing table. It employed Minimum Threshold (MinTH) and Maximum Threshold (MaxTH) values to control the Counter field in the routing table. The value MinTH is estimated as the number of neighbours of the node and MaxTH value is twice of the MinTH value.

To reduce the overhead caused by the exchange of routing tables in proactive routing protocols, an optimization technique Distance Routing Effect Algorithm for Mobility (DREAM) [27] was proposed. In DREAM the location of other nodes in the network is stored in the location table which maintain proactively at every node. However, DREAM exploits the distance and mobility information of the node for controlling the routing load produced by updating the location information. Closer nodes are more privileged to receive the location information as compared the distant nodes. Also, the generation of the location update information depends up on the rate of mobility of the node. Slower moving nodes generate updates less often than the fast moving nodes.

To control the number of RREQ packet forwarding in the route discovery process another algorithm called probabilistic broadcasting algorithm (PBA) [28] has been proposed. This scheme focuses on the connectivity information of the neighbour nodes. The connectivity information considers the mobility parameters of the nodes to predict the possible connection of mobile nodes. Another Routing protocol called Nominated Neighbour to Rebroadcast the RREQ (NNRR) [29] has been proposed to improve the flooding process for mobile ad hoc network. NNRR reduces the area of route discovery by utilizing the geographical position of the nodes. This protocol nominates four neighbour node to rebroadcast the RREQ packet. The scheme proposed in [30] uses the zonal concept of LAR to control the dissemination of RREQ packet. In this scheme, different zones are created by dividing the transmission range of the nodes. Location matrix is used to store the location information of each node. Only one node per zone is selected to forward the RREQ packet towards the destination. This technique helps to reduce the network overhead.

4.3 Effective Broadcast Control Routing Protocol (EBCRP)

The basic purpose of this work is to design the mechanism that can control the broadcast in the reactive routing protocol in MANETs. This algorithm is basically focused on the reduction of the redundant re-transmission of a Route Request (RREQ) packet in the route discovery process. By reducing the redundant retransmission of the RREQ packet, channel contention and the network load of the network reduce that lead to improve the overall network performance.

Normally, in an on-demand routing protocol a source node starts the route discovery by broadcasting a RREQ packet to all its neighbours. This route request packet is rebroadcasted by the receiving node this process of rebroadcasting ends when the intended destination is discovered. To find the route between source and destination in the network of ‘N’ nodes route discovery attempt maximum of (N-1) broadcasts [20]. The proposed (EBCRP) control the redundant rebroadcasting of the RREQ packet by allowing only the Reliable Nodes (RN) to rebroadcast the RREQ message. The selection of RN basically considers the position and speed of the node. The following section describes the detail of the proposed protocol.

In order to fulfil the requirements of our proposed algorithm, AODV routing request packet (RREQ), routing reply packet (RREP) and the Routing Table entries need to be extended as follows.

- The routing request (RREQ) packet of EBCRP shares the same format as RE-RREQ packet format which is described in chapter-3.

- **EB-RREP Packet:** is also extended by adding 5 fields similar to that of RE-RREQ to its structure.

- **EB-Routing Table:** is extended by 1 new field to its structure.

  - ***RET:*** Contain the expiration time of the route and later it is used by the EBCRP.

4.3.1 Route Discovery Process of EBCRP

When a source node 'S' needs a route to send a data packet to a specific destination node 'D' but unable to find a route in its routing table, then route discovery process was initiated by broadcasting a Route Request (RREQ) packet to all neighbouring nodes.

When a node receives a RREQ packet, it first creates a reverse route toward the source node if one is not already present. Finding the reverse route is necessary for sending the reply packets back to the source node later on. If the receiving node is the destination node, it simply generates and sends back the Route Reply (RREP) packet. If receiving node is an intermediate node and not the destination node 'D', and it already has a route in routing table towards the source node 'S', it applies the Reliability Factor (RF) which is calculated using equation 3-1 on the route in the routing table and also on route in the RREQ packet. For the calculation of RF please refer to section 3.3 in chapter-3 of this thesis. If the RF value of the RREQ packet (RF_{rq}) is higher than the RF value of the route already present in the routing table (RF_{rt}), the route is updated in the routing table with this new route. In case the RF value of RREQ packet is less than zero, it drops this particular RREQ and don't re-broadcast this RREQ packet any further. It also selects the minimum value of Route Expiration Time (RET) between the current node and the RREQ sending node. Finally, the RREQ packet with minimum RET was broadcasted to the neighbours cf. Figure 4-1.

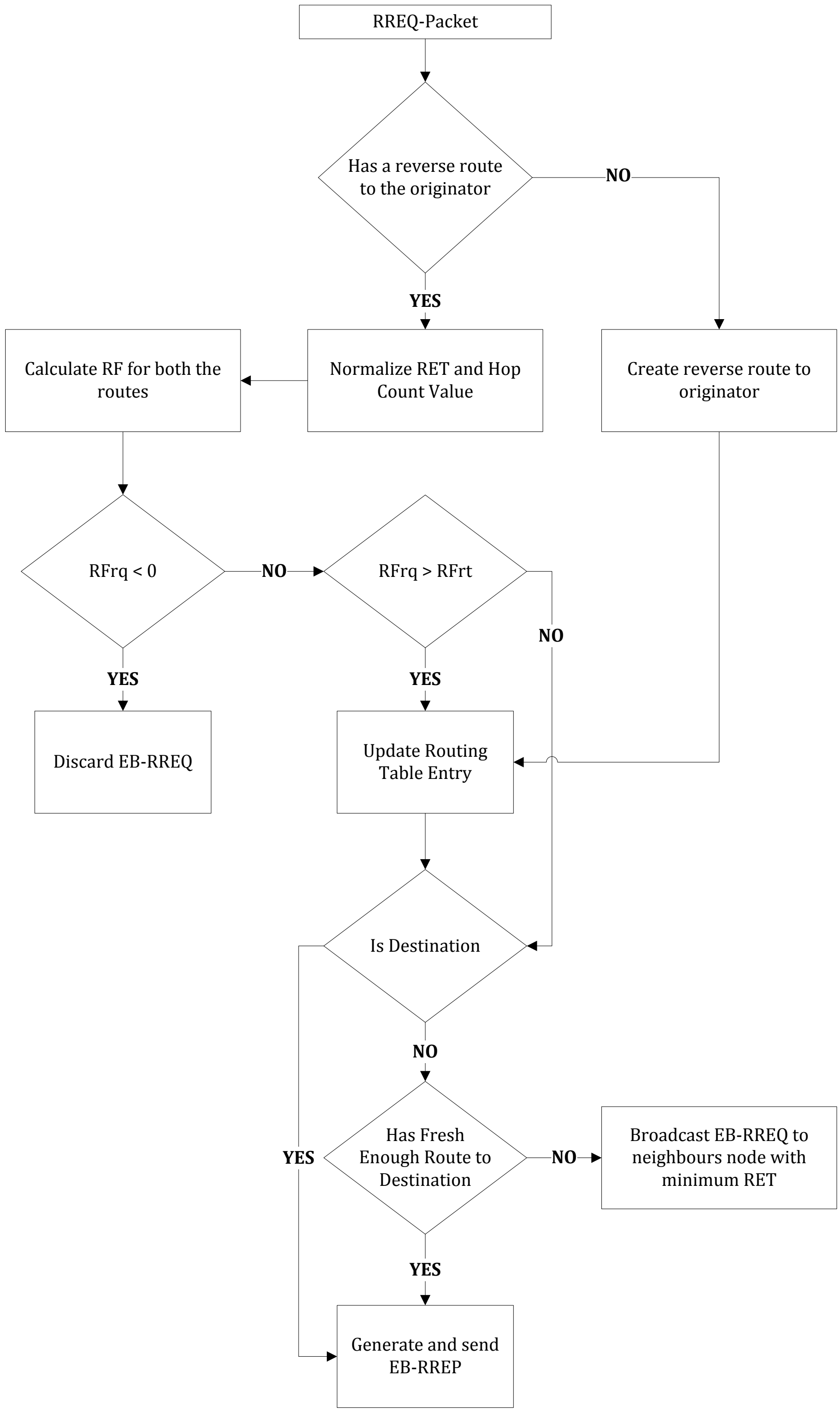

Figure 4-1: Route Discovery Process of EBCRP

A node generates a RREP packet if it is either the destination node or an intermediate node having an active route to the destination. When a node receives a RREP packet, it first updates or creates a route from the previous hop toward the destination. If this node already has a route to the destination then it calculates the RF value of the route, which is already present in the routing table and compares it to the RF value of the RREP packet (RF_{rp}) . If the RF value of the RREP packet is greater than the RF of the route already present in the routing table, then the route in the routing table is updated with the RREP packet else the routing table is not updated and the RREP is then sent to the next hop towards the source node. If the receiving node is the originator, it will send data packets to the destination through pre-determined route.

4.4 Enhanced Effective Broadcast Control Routing Protocol (E-EBCRP)

An extension of EBCRP, called Enhanced Effective Broadcast Control Routing Protocol (E-EBCRP) has a similar route discovery process as of EBCRP but with a different route selection mechanism. The route selection process of E-EBCRP is presented below.

4.4.1 Route Selection of E-EBCRP at Destination Node

When a first RREQ message reaches to destination node 'D', at the destination node a timer starts and waits for a certain amount of time and gather all the other RREQ reaches to the destination. When the timer expires, it applies Reliability Factor (RF) to each gathered route from source to destination and selects the route which has the higher RF value. For the complete explanation regarding the calculation of RF value refer to Section 3.3 of chapter 3.

4.5 Performance Evaluation

For the evaluation of EBCRP, the simulation was carried out using the Network Simulator (NS2.35) [31]. In the simulation, The Random Waypoint Mobility (RWP) model [32] was used, where each node independently chooses a random initial point and waits for a period called pause time. It then moves with a velocity chosen normally between minimum and maximum velocities to a randomly chosen destination. After reaching the destination, it waits again for the pause time and then moves to a new randomly chosen destination with a new chosen velocity. Each node repeats independently the above-mentioned movement until the simulation stops.

Simulation of the proposed scheme is performed with 100 nodes, which is enough to evaluate the required parameters in the area of 1000m X 1000m. This setting provides enough space for the mobility of nodes and to check the discovery of new routes. The simulation is set to maximum 50 connections. Traffic sources are continuous bit rate (CBR). The source-destination pairs are spread randomly over the network. 512-byte data packets are used with a rate of 4 packets per second. The shared-media radio with a nominal bit rate of 2 Mb/s and a nominal radio range of 250 m was selected. A zero pause time is used to simulate a mobility level with nodes that are continuously moving in the simulation area. Each data point represents an average of multiple runs with different seed values used for the traffic models and randomly generated mobility scenarios.

To evaluate the performance of the proposed protocol, three simulation experiments varying the node speed, the density of node and traffic load are presented in the following section.

4.5.1 Experiment – 1: Effect of Nodes Speed

In the network of 100 nodes, the speed of the mobile nodes was varied form $5ms^{-1}$ to $50ms^{-1}$ to check the effect of different speed on the proposed routing scheme. The simulation parameters of the experiment–1 are shown in Table 4-1.

4.5.2 Experiment – 2: Effect of Node Density

The number of nodes in the network was varied from 40 nodes to 120 nodes to check the effect of node density on the proposed scheme in the second experiment. Here, the maximum speed of the mobile node is $20ms^{-1}$. The simulation parameters of the experiment–2 are represented in Table 4-2.

Table 4-1: Simulation Parameters of Experiment – 1: Effect of Nodes Speed	
Parameters	**Value**
Protocols	RERRP, EBCRP, E-EBCRP and AODV
Simulation Area	1000m X 1000m
No of Nodes	100
Data Rate	4 Packets/Sec
Min Speed	1 ms^{-1}
Max Speed	5, 10, 15, 20, 25, 30, 35, 40, 45, 50 ms^{-1}
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground (TRG)
Simulation Time	300 s

Table 4-2: Simulation Parameters of Experiment – 2: Effect of Node Density	
Parameters	**Value**
Protocols	RERRP, EBCRP, E-EBCRP and AODV
Simulation Area	1000m X 1000m
Number of Nodes	40, 60, 80, 100, 120
Data Rate	4 Packets/Sec
Min Speed	1 ms^{-1}
Max Speed	20 ms^{-1}
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground
Simulation Time	300 s

4.5.3 Experiment – 3: Effect of Traffic Load

In experiment-3, the effect of increasing the number of CBR flows (Traffic Load) was evaluated. In this scenario the number of CBR flows increased from 20 to 60 and the average speed of the nodes is 10m/s. Table 4-3 shows the simulation parameters.

Table 4-3: Simulation Parameters of Experiment – 3: Effect of Traffic Load

Parameters	Value
Protocols	EBCRP, AODV and SP-AODV
Simulation Area	1000m X 1000m
Number of Nodes	50
Data Rate	4 Packets/Sec
CBR flows	40, 45, 50, 55, 60
Nodes Speed	10 ms^{-1}
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground
Simulation Time	600 s

4.6 Performance Metrics

Following metrics are used in varying scenarios to evaluate the proposed protocols.

Normalized Routing Load: This is defined as the number of routing packets transmitted per data packet delivered at the destination.

Throughput: The amount of data received by the destinations per unit time is referred as throughput of the network. Normally, it is measured in bits/sec.

Routing Packets: The total number of routing packets involved in the network.

Average End-to-End Delay: It is defined as the delay between the time at which the data packet was originated at the source node and the time it reaches the destination node. Data packets that get lost in route are not considered.

Packet Delivery Fraction: This is defined as the ratio of the number of data packets received by the destinations to those sent by the sources.

Received Packets: Received packets represent the total number of data packets received at the destination.

4.7 Simulation Results and Discussion of Experiment – 1

The performance of RERRP, EBCRP and E-EBCRP are compared with traditional AODV in terms of Packet Delivery Fraction (PDF), Network Routing Load (NRL), Average End-to-End Delay, Throughput, Number of Received Packets and Number of Routing Packets.

4.7.1 Network Routing Load vs. Max Speed

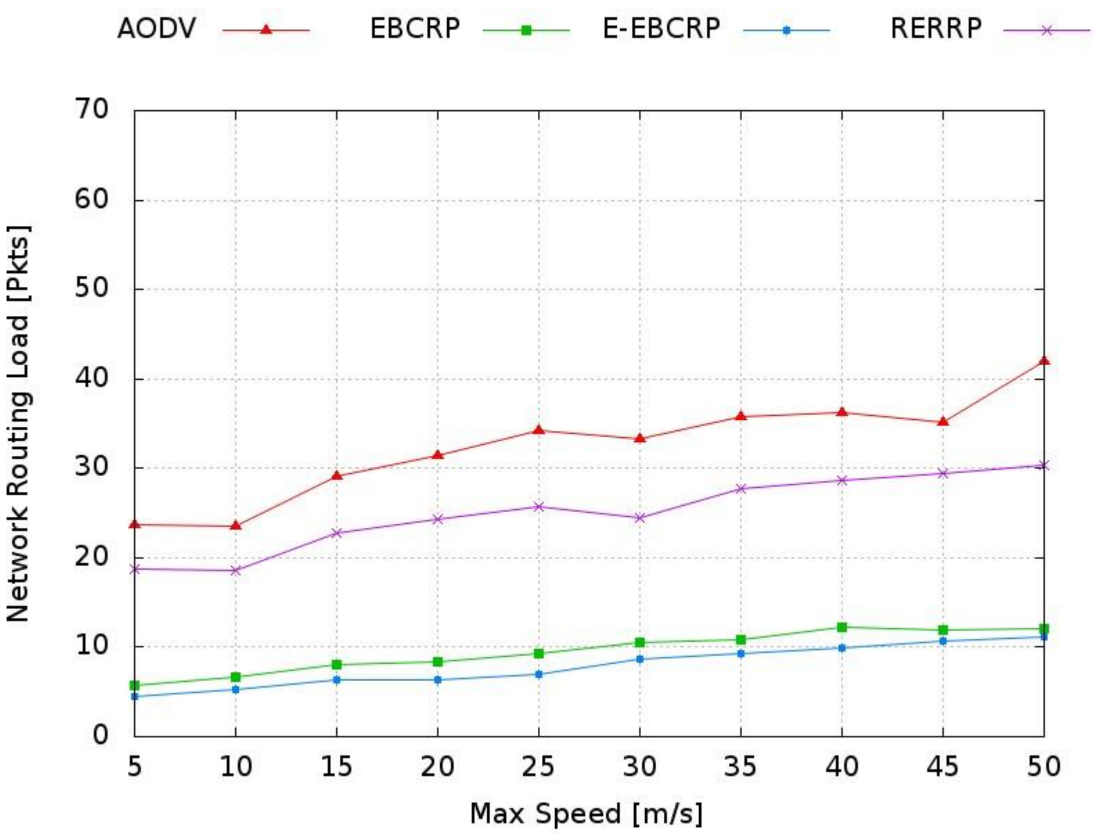

Figure 4-2: Network Routing Load vs. Max Speed

The Figure 4-2 illustrates the effect of node mobility on the performance of RERRP, EBCRP, E-EBCRP and AODV in term of Network Routing Load (NRL) or overhead. The Figure 4-2 also shows that across all the node speeds, the routing load experienced by RERRP, EBCRP, E-EBCRP and AODV increases with increased node speed. This is because of the number of broken links; due to increase in the node speed and also some of RREQ packets fail to reach their destinations. These types of failure cause additional initialisation of a route discovery process that eventually increase the network routing load or overhead. All the routing protocols impose a different amount of network routing load with increasing node speed. The comparison result among RERRP, EBCRP, E-EBCRP and AODV showed that, E-EBCRP has achieved superior performance in term of routing load. On average, E-EBCRP reduces overhead by 76% as compared to AODV whereas EBCRP reduces overhead by 70% as compared to AODV. EBCRP and E-EBCRP both reduce the redundant re-transmission of the RREQ packet. EBCRP only reduces the redundant re-transmission of the RREQ packet whereas E-EBCRP selects the reliable route at the destination with reducing the redundant re-transmission of RREQ packet. That's why E-EBCRP offered lesser routing load than the EBCRP. On the other hand RERRP offered 22% less routing load as compared to AODV, because RERRP only selects the reliable route and not controlled the redundant re-transmission of RREQ packet and broadcast storm problem is present in RERRP.

4.7.2 Throughput vs. Max Speed

One of the important metric for the measurement of network transmission ability is throughput. In Figure 4-3, the throughput of the network based on different node speed is presented. It shows that as the speed of the nodes increases the throughput starts decreasing. As in MANET all the nodes are moving, therefore the movement of destination and intermediate node the route between the source and destination node breaks. That causes to initiate RREQ retransmission, which leads to more rebroadcast and greater bandwidth consumption. As a result, throughput decreased as soon as the nodes speed increases. The Figure 4-3 also shows that E-EBCRP outperforms AODV. At every speed, E-EBCRP increased throughput by 84% as compared to AODV. This is because of less broadcast of RREQ packet that also gives smaller consumption of bandwidth. This has also affected positively on the network and reduces collisions and contentions, and eventually gives the higher throughput.

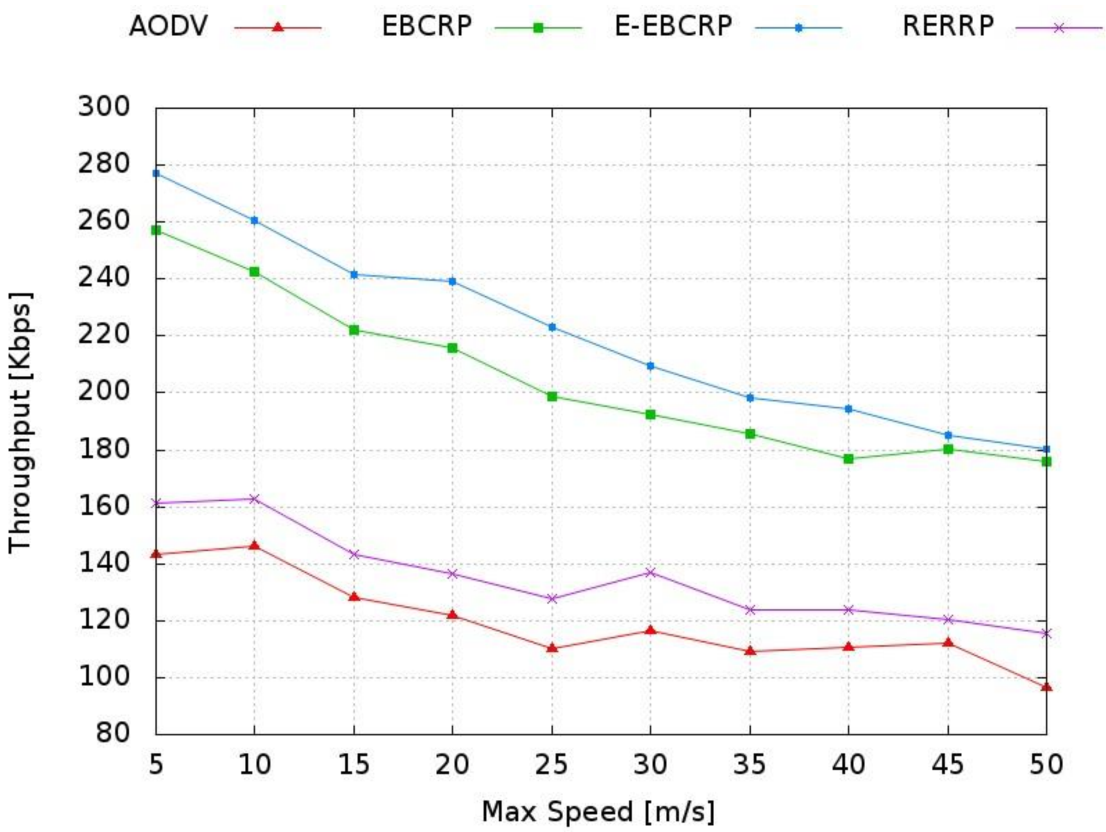

Figure 4-3: Throughput vs. Max Speed

4.7.3 End-to-End Delay vs. Max Speed

The average End-to-End delay comparison is represented in Figure 4-4, which shows that the average end-to-end delay of E-EBCRP is little bit higher than AODV. This is due to the fact that the route discovery process of E-EBCRP is a bit time consuming as compared to AODV. While in the process of discovering route the packets are in the buffer and suffer longer delay. On the other hand, E-EBCRP may selects longer but reliable route this may also contribute in higher delay.

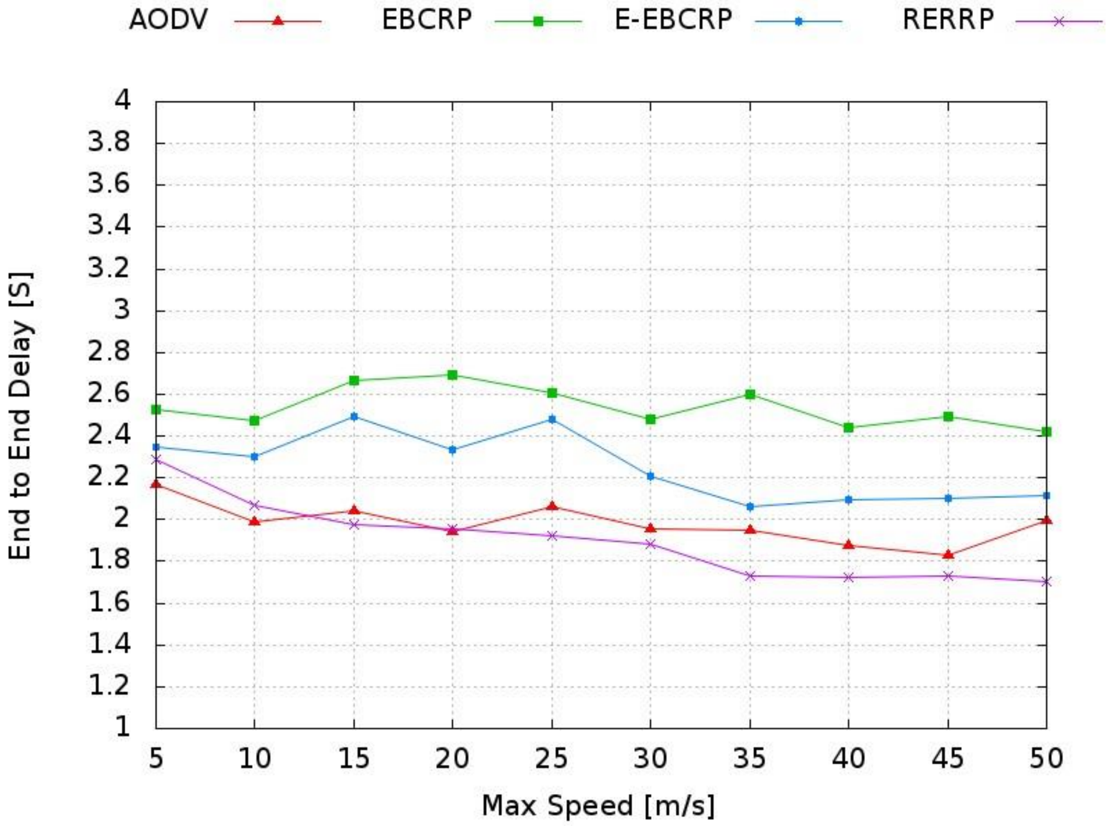

Figure 4-4: End-to-End Delay vs. Max Speed

4.7.4 Packet Delivery Fraction vs. Max Speed

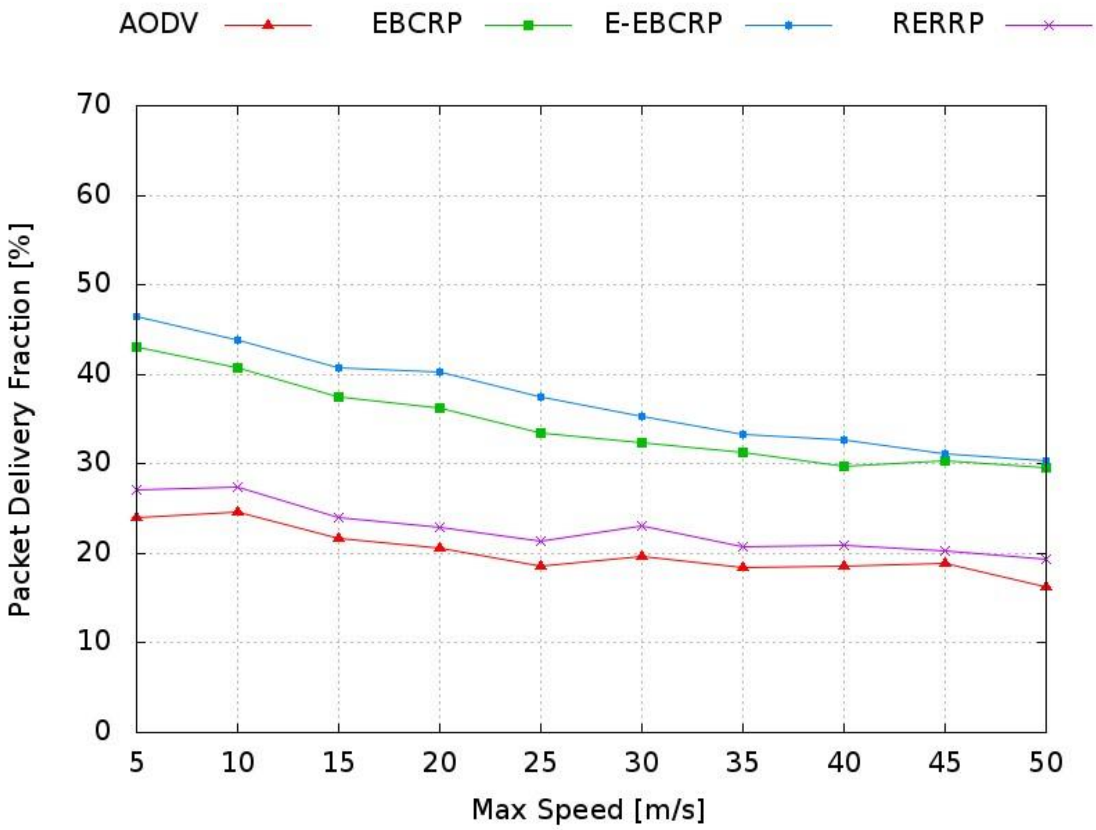

Figure 4-5: Packet Delivery Fraction vs. Max Speed

Figure 4-5 shows the effect of node speed on the Packet Delivery Fraction (PDF). As soon as the node speed increases the PDF of both protocol decreases. This is because of more route begins to break as the speed of node increases, that causes to initiate RREQ retransmission, which leads to more rebroadcast and greater bandwidth consumption. The Figure 4-5 also shows that E-EBCRP outperforms AODV. On average, E-EBCRP increased packet delivery fraction by 17% as compared to AODV. The PDF improvement of E-EBCRP is due to its reduction of rebroadcasting. The less rebroadcast of the routing message causes smaller bandwidth consumption. This has also affected positively on the network and reduces collisions and contentions, and eventually gives the higher packet delivery.

4.7.5 Routing Packets vs. Max Speed

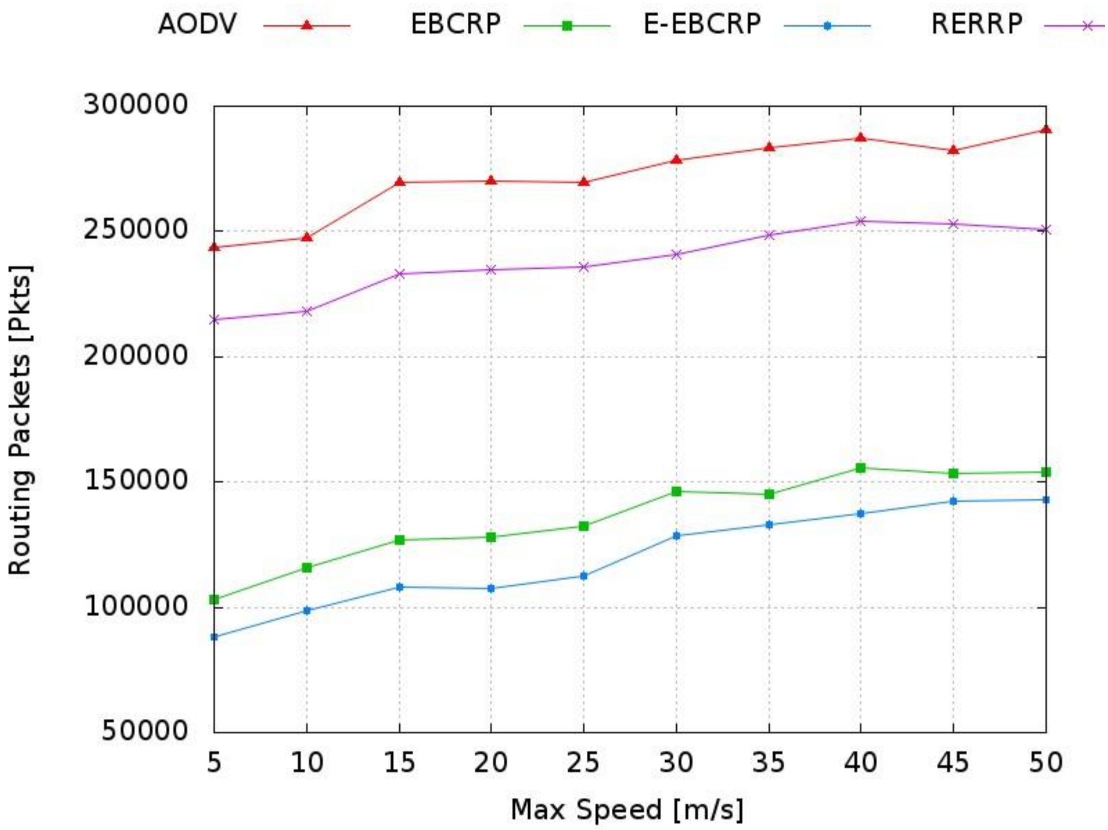

Figure 4-6: Routing Packets vs. Max Speed

The RREQ packet that generated in the route discovery process will be rebroadcast by the mobile node in AODV, if this RREQ packet was not received earlier or it has not a valid route to the destination. However, in E-EBCRP each node has some mechanism to control the rebroadcast of RREQ packet. Hence, a node running E-EBCRP produced less routing packets as compare to the node that configure with AODV. Figure 4-6 shows that as soon as the node speed increases the routing packets of all the protocols also increases. This is because of more route begins to break as the speed of node increases. Therefore, additional routing packets are required to maintain or rediscover the required route. The proposed protocol E-EBCRP has fewer routing packets as compared to AODV, because of the fact that E-EBCRP establish a longer life route between the source node and the destination node and also has a mechanism to control the dissemination or RREQ packets. This leads to the less breakage and less rediscovering of the route hence fewer routing packets are required than AODV. On average, E-EBCRP reduces the routing packets in the network by 56% as compared to AODV.

4.7.6 Received Packets vs Max Speed

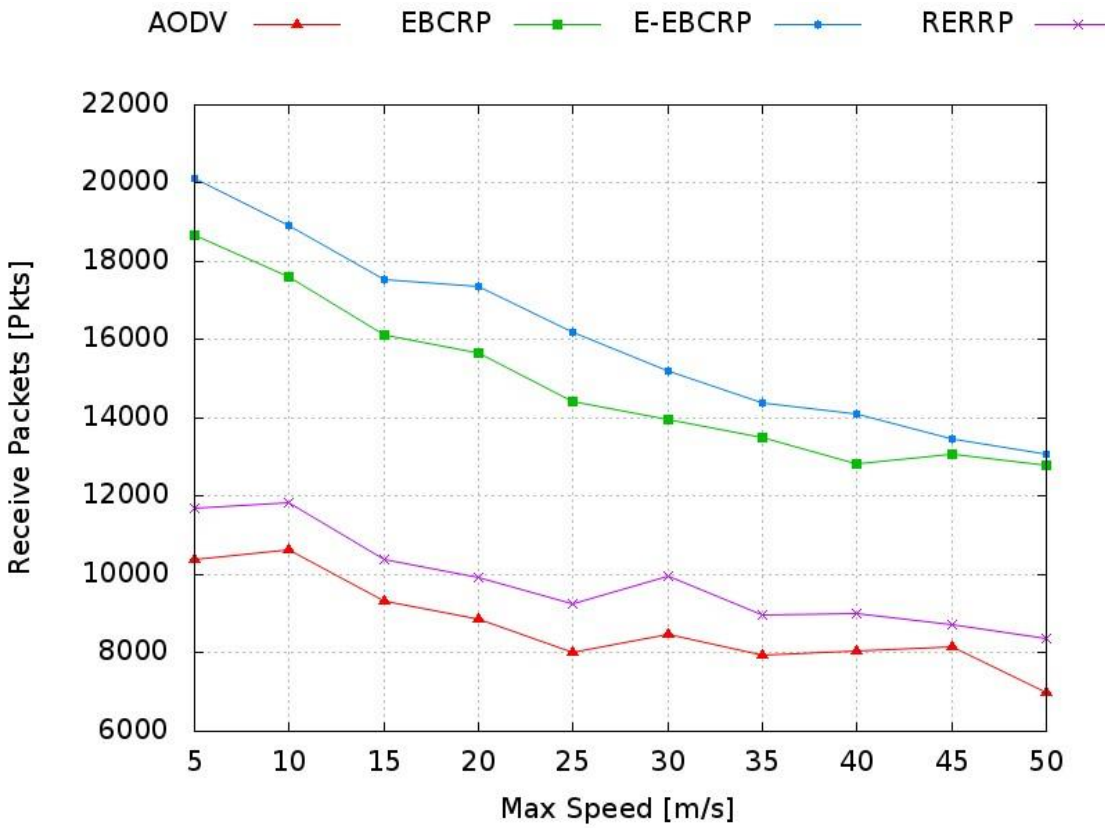

Figure 4-7: Received Packets vs Max Speed

The graph of the received packet is represented in Figure 4-7. This shows the benefit of using E-EBCRP in terms of receiving data packets on varying node speeds. When nodes moved at higher speeds, number of packets received for both the protocols decreased. The reason is that the routing path was easy to break when the speed of the node increased, that causes to initiate RREQ retransmission which leads to more rebroadcast and greater bandwidth consumption. The Figure 4-7 also shows that E-EBCRP outperforms RERRP, EBCRP and AODV. E-EBCRP on average received 84% more data packet than AODV. The more number of received packets of E-EBCRP is due to its reduction of rebroadcasting of RREP packets and the selection of reliable route. The less rebroadcast of the routing message causes smaller bandwidth consumption. This has also affected positively on the network and reduces collisions and contentions, and eventually gives the highest number of received packets.

4.8 Simulation Results and Discussion of Experiment – 2

This section presents the performance impact of network density on EBCRP and AODV over different network density. The network density has been varied by deploying 40, 60, 80, 100 and 120 nodes over a fixed area of 1000m x 1000m. Each node in the network moves with a 20msec^{-1}. The maximum connections of 50 are generated between randomly selected source and destination (i.e. Traffic flows). In each connection 4 data packets per second have been used. The packet size is 512 bytes. In the figures presented below, the x-axis represents the variations of numbers of nodes, while the y-axis represents the results of the performance metric of interest.

4.8.1 Network Routing Load vs. Number of Nodes

Figure 4-8 shows the effect of node density on the Network Routing Load (NRL) or overhead. Fixed area of 1000 m^2 was used with varying number of nodes in the network. All the routing protocols, i.e. RERRP, EBCRP, E-EBCRP and AODV increase the NRL with an increase in the network density. When the number of nodes increases redundant rebroadcast of RREQ packets are also increases that contribute to greater chances of packet collisions and thus adversely affecting the network connectivity that eventually increases the network routing load. Compared with the traditional AODV, the E-EBCRP has achieved superior performance in terms of routing overhead. At high density, E-EBCRP reduces overhead by 76% as compared to AODV. This is because of the reduction of redundant rebroadcast of the RREQ packet there is less chance of packet collisions and less network breakage.

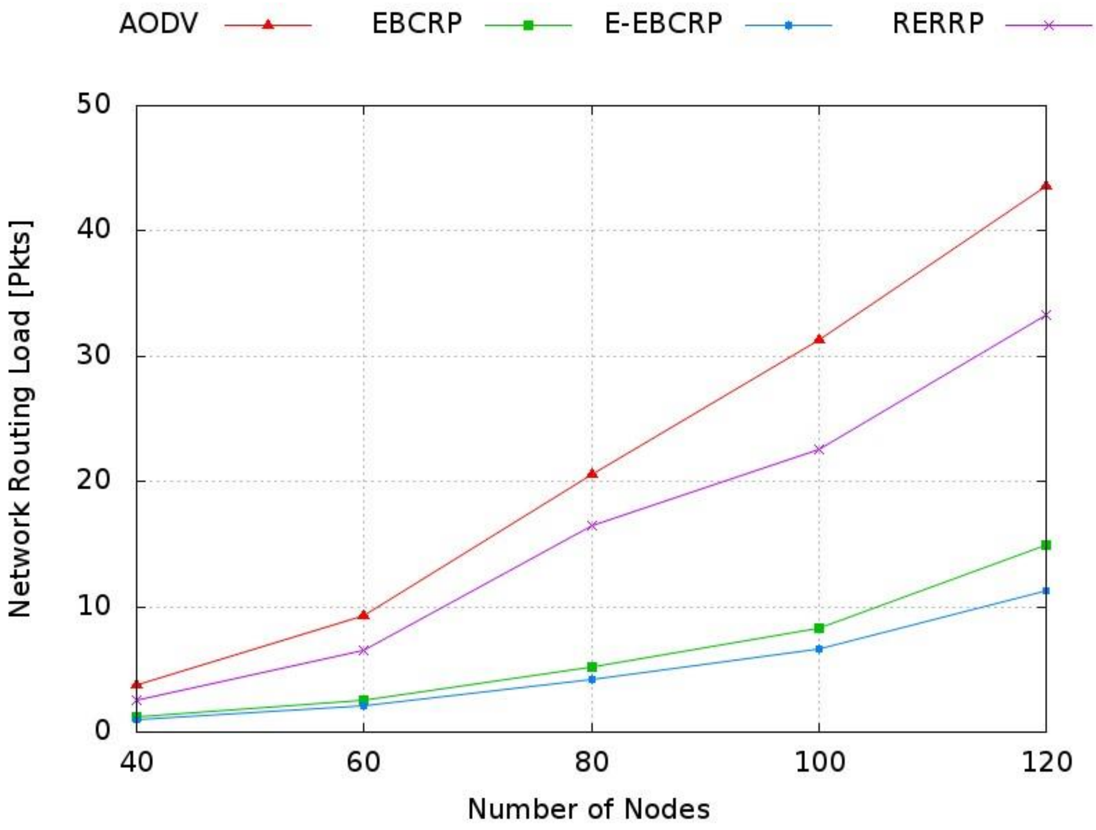

Figure 4-8: Network Routing Load vs. Number of Nodes

4.8.2 Throughput vs. Number of Nodes

Throughput of RERRP, EBCRP, E-EBCRP and AODV are compared in this section. Figure 4-9 shows throughput decreases when the number of nodes increases. As the network density increases redundant retransmissions of the request packets also increases that caused the channel contention and packet collision. Due to the channel contention and packet collision fewer packets reach to the destination, hence the throughput decreases. The Figure 4-9 also shows that E-EBCRP outperforms AODV. The throughput improvement of E-EBCRP is due to its reduction of rebroadcasting of RREQ packet. The fewer rebroadcasts results in less degree of collision and contention, which actually leads the E-EBCRP to get higher throughput.

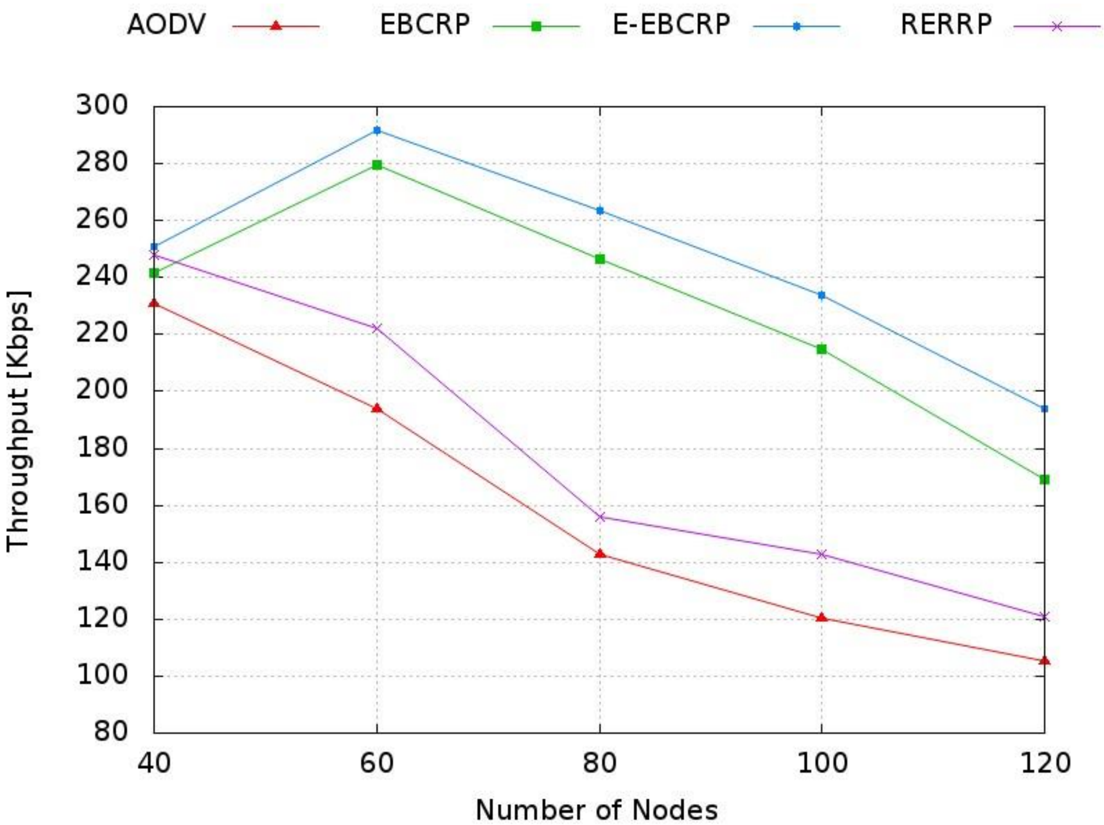

Figure 4-9: Throughput vs. Number of Nodes

4.8.3 Packet Delivery Fraction vs. Number of Nodes

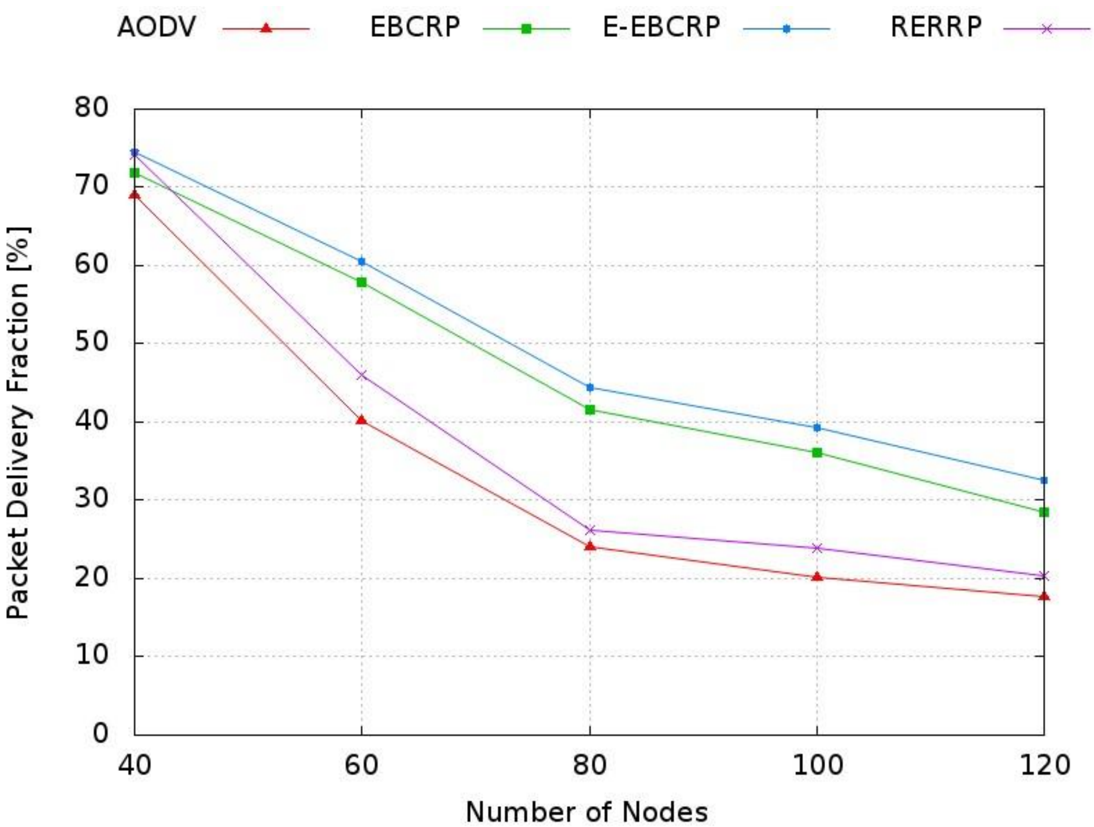

Figure 4-10: Packet Delivery Fraction vs. Number of Nodes

Figure 4-10, illustrates that packet delivery fraction of all the routing protocols decreases while the network density increases. Due to the increase in the number of nodes the probability of redundant retransmission increases that causes the channel contention and packet collision. This channel contention and packet collision, lead to drops in packet delivery. Figure 4-10 also shows that E-EBCRP outperforms AODV. At every node density, E-EBCRP increased packet delivery fraction as compared to AODV. The PDF improvement of E-EBCRP is due to its reduction of rebroadcasting. The less rebroadcast of the routing message causes smaller bandwidth consumption. This has also affected positively on the network and reduces collisions and contentions, and eventually gives the higher packet delivery.

4.8.4 Routing Packets vs. Number of Nodes

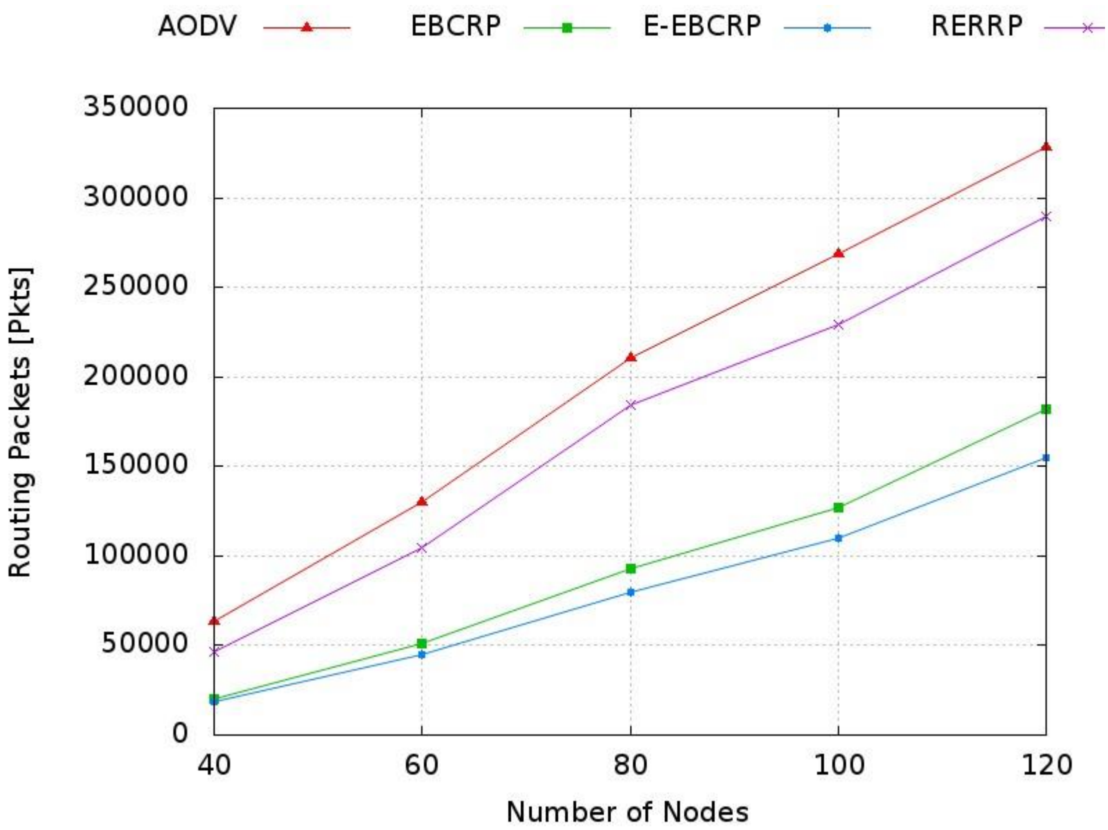

Figure 4-11: Routing Packets vs. Number of Nodes

The number of routing packets with respect to the number of nodes is shown in Figure 4-11. As the number of nodes increases in the network the routing packets are increased gradually for all the protocols. Basically, increasing in the number of nodes increases the redundant re transmission of the routing packets, cause the congestion and packet collision in the network as a result more RREQ packets and data packets drops before reaching to the destination. This triggers new route discovery processes that causing more routing packets in the network. The proposed protocol has less routing packets than AODV because E-EBCRP controls the redundant retransmission of the RREQ packets by dropping the redundant broadcast packets.

4.8.5 End-to-End Delay vs. Number of Nodes

The average End-to-End delay comparison is represented in Figure 4-12, which shows that the average end-to-end delay of E-EBCRP is little bit higher than AODV. This is due to the fact that the route discovery process of E-EBCRP is a bit time consuming as compared to AODV. While in the process of discovering route the packets are in the buffer and suffer longer delay. On the other hand, E-EBCRP may selects longer but reliable route this may also contribute in higher delay.

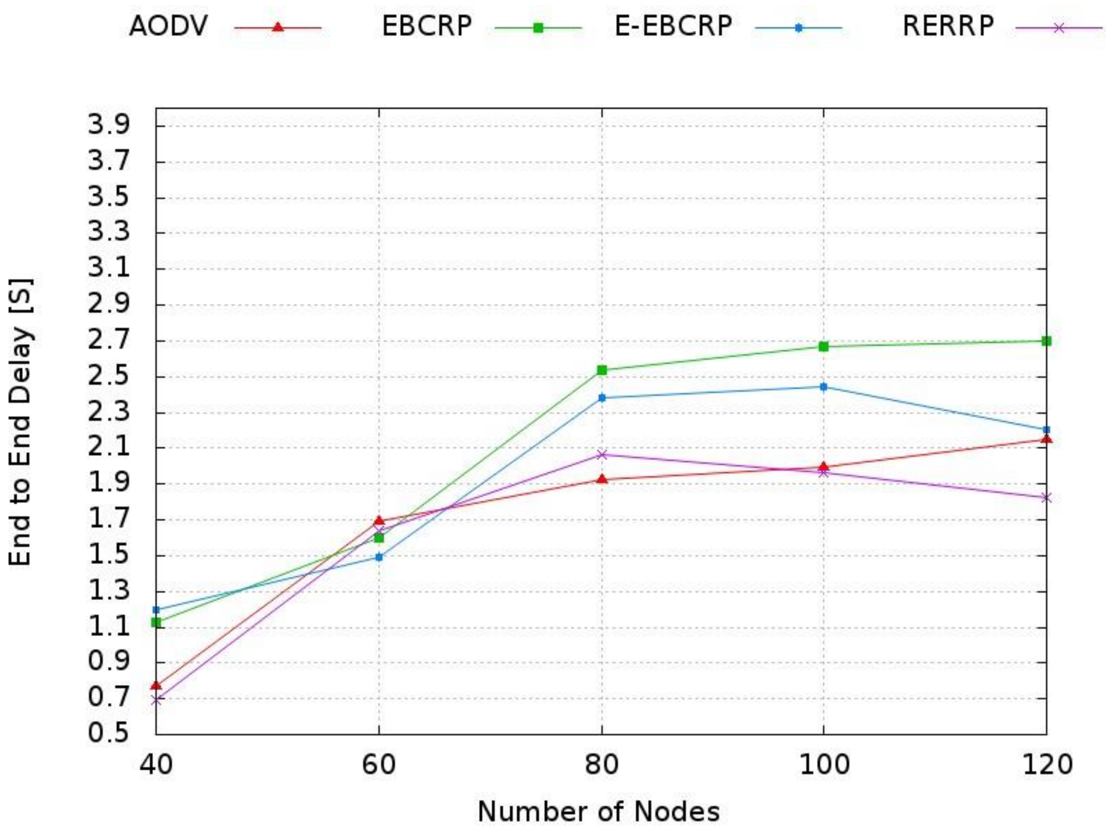

Figure 4-12: End to End Delay vs. Number of Nodes

4.8.6 Receive Packets vs. Number of Nodes

Figure 4-13 illustrates the number of received packets against the node density in the network. It shows that the number of received packets for both the protocols drops gradually while the node density increased. Basically, increasing in the number of nodes increases the redundant retransmission of the routing packets, cause the congestion and packet collision in the network as a result more RREQ packets and data packets drops before reaching to the destination. The proposed protocols EBCRP and E-EBCRP controls the redundant retransmission of the RREQ packets eventually reduces the channel congestion. Due to the reduction of channel congestion, less number of packet drops and can receive more number of packets as compare to AODV.

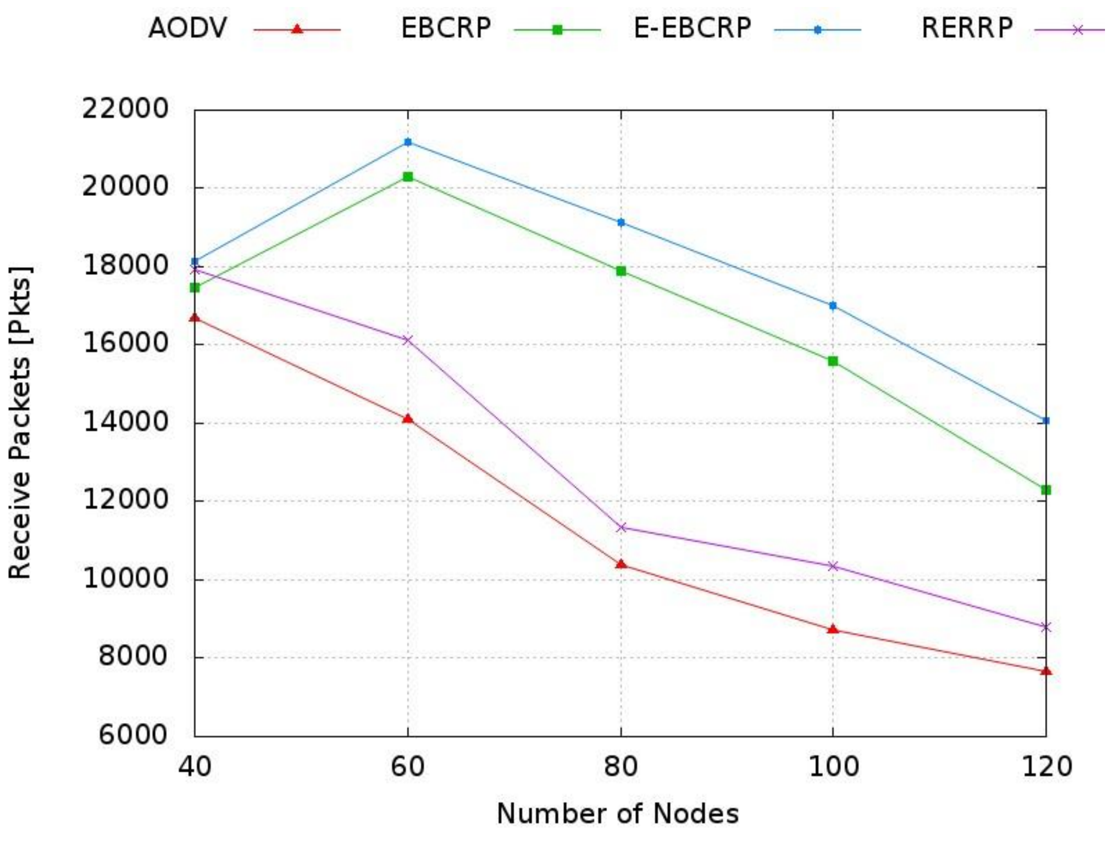

Figure 4-13: Receive Packets vs. Number of Nodes

4.9 Simulation Results and Discussion of Experiment – 3

The performance of the proposed algorithm, i.e. EBCRP is compared with traditional AODV [26] and recently proposed SP-AODV [25] in terms of control packet overhead, packet delivery fraction and average end-to-end delay. The proposed algorithm EBCRP outperforms AODV and SP-AODV protocol in term of overhead, packet delivery and end-to-end delay.

4.9.1 Packet Delivery Fraction vs. Traffic Load

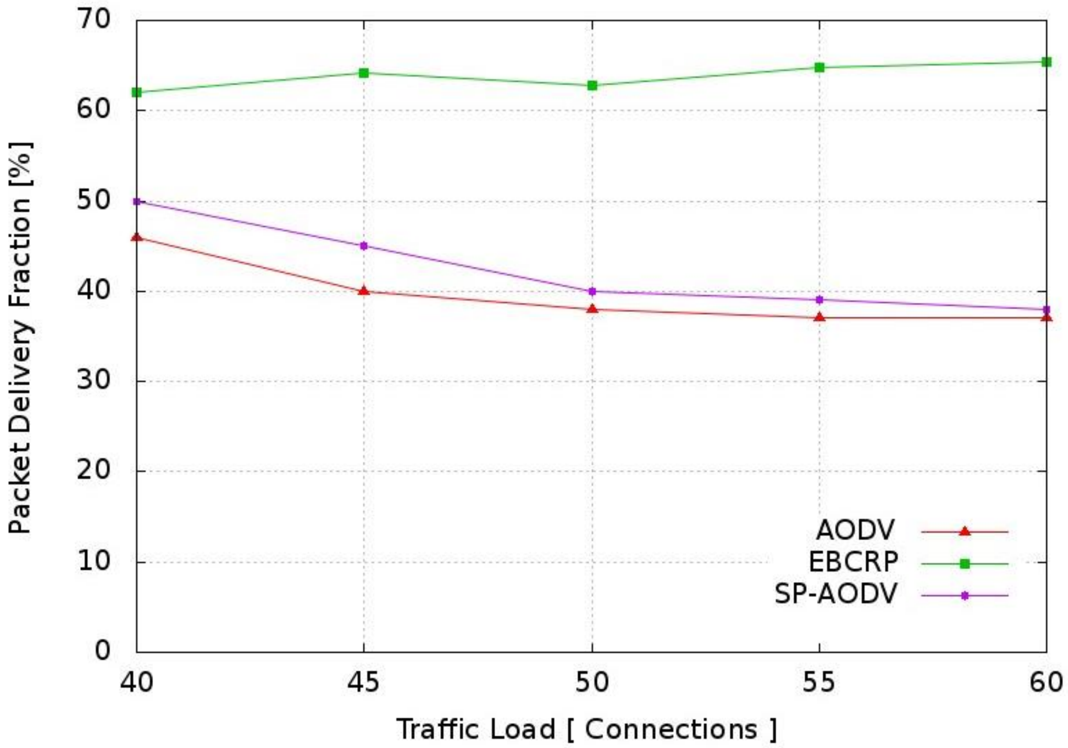

Figure 4-14: Packet Delivery Fraction vs. Traffic Load

Figure 4-14 illustrates the benefit of using EBCRP in terms of Packet Delivery Fraction (PDF) with varying traffic load. As the traffic load increases, the packet delivery fraction of AODV and SP-AODV also decreases, because of the increase in the number of routing and data packet. This increase in the number of routing and data packets caused channel contention and packet collision that leads to drop in packet delivery. Figure 4-14 also shows that EBCRP outperforms AODV and SP-AODV at every traffic load. This PDF improvement of EBCRP is due to the selection of route with longest expiration time as well as the reduction of control packets. The less rebroadcast of the routing message causes smaller bandwidth consumption. This has also affected positively on the network and reduces collisions and contentions, and eventually gives the higher packet delivery. When traffic load is 40 CBR flows, EBCRP enhances around 10% and 15% PDF as compared to SP-AODV and AODV respectively. On the high traffic load PDF enhancement of EBCRP is around 20%.

4.9.2 Control Packet Overhead vs. Traffic Load

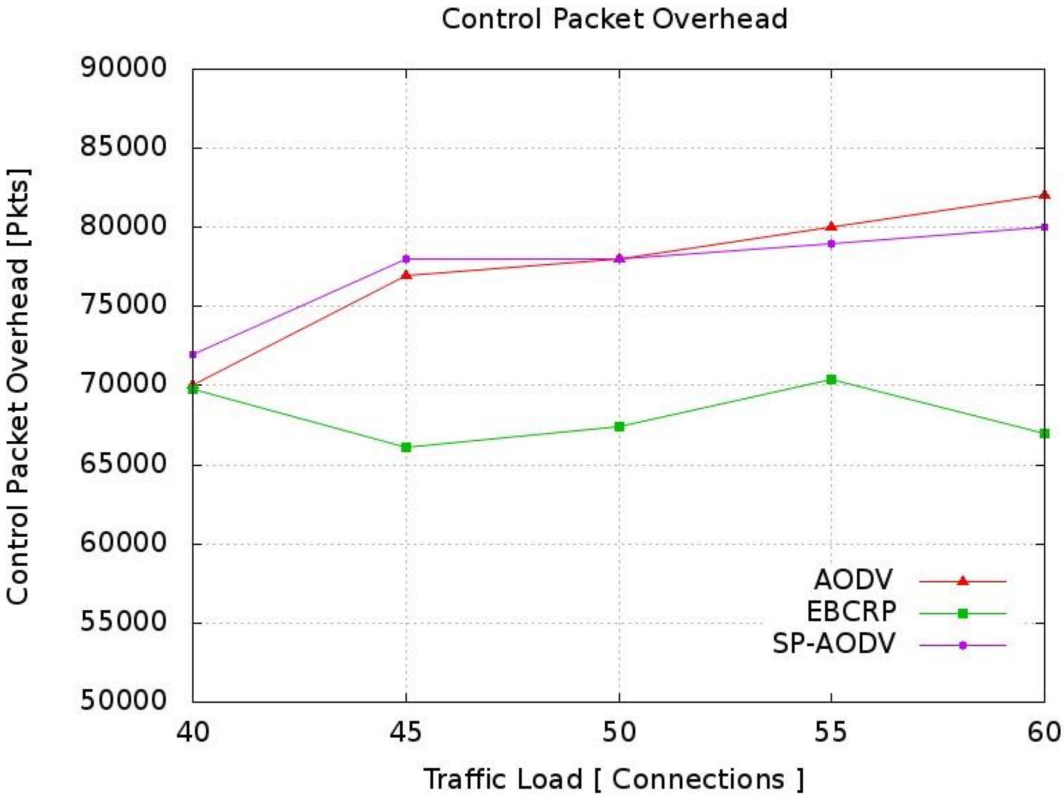

Figure 4-15: Control Packet Overhead vs. Traffic Load

The number of routing packets with respect to traffic load is shown in Figure 4-15. As the traffic load increases in the network the routing packets increases gradually for AODV and SP-AODV protocols. Basically, increasing traffic load increases the redundant re-transmission of the routing packets, causing congestion and packet collision in the network, as a result more RREQ packets and data packets are dropped before reaching the destination. This triggers new route discovery processes that cause more routing packets in the network. The proposed protocol has less routing packets than AODV and SP-AODV because EBCRP controls the redundant retransmission of the RREQ packets by dropping the redundant broadcast packets and also it selects the reliable route between source and destination. The selection of a reliable route reduces the route failures. This reduction in the route failures eventually results in reduction of route maintenance procedure, which reduces the network routing load involved in the route discovery and maintenance process. EBCRP yields a significant improvement in term of routing overhead as compared to AODV and SP-AODV.

4.10 Chapter Summary

Broadcasting in MANET could cause serious redundancy, contention, and collision of the packets. In this chapter Effective Broadcast Control Routing Protocol (EBCRP) scheme has been proposed for controlling the broadcast storm problem in a MANET. The EBCRP is mainly considered the combination of link expiration time and the hop count while controlling the redundant re-broadcast of the route request packet. The proposed algorithm EBCRP was applied on the route discovery mechanism of the AODV. The performance of the EBCRP has been analysed on three different experimental scenarios, i.e. varying node speed, varying node density and varying traffic load. Results from the extensive NS-2 simulations have shown that the speed and density of the nodes have a substantial effect on the performance of the network. Although it is difficult to ensure that there will be no redundant broadcast of route request packet in the network. However, by adopting the proposed scheme, it has been possible to control the routing overhead by reducing the number of redundant RREQ packets. The comparative study between AODV and EBCRP has revealed that the EBCRP have controlled the routing overhead significantly, reduces it around 70% and enhance the packet delivery by 13% as compared to AODV. In the traffic load study on AODV, SP-AODV and EBCRP, it is discovered that when traffic load is 40 CBR flows, EBCRP enhances around 10% and 15% PDF as compared to SP-AODV and AODV respectively. On the high traffic load PDF enhancement of EBCRP is around 20% as compared to AODV and SP-AODV.

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Chapter 5

Energy Sensible and Route Stability Based Routing Protocol

5.1 Introduction

Chapter-3 mainly focuses on the reduction of link breakage in MANET by selecting a reliable route between the source node and the destination node which is depend up on the nodes position, speed and direction. But in MANET an established link can be broken if the node dies because of its energy depletion. Since all the nodes in Mobile Ad-Hoc Networks (MANETs) are mobile and battery powered [1], and their power supplies are not permanent. Therefore, frequent link breakages in MANETs are mainly caused by failure of the node due to its energy depletion and the communicating nodes may travel out of the transmission range of each other. Because of node mobility in MANET a node loses its energy constantly cf. Figure 5-1 and makes the network topology very dynamic which causes the path disconnection.

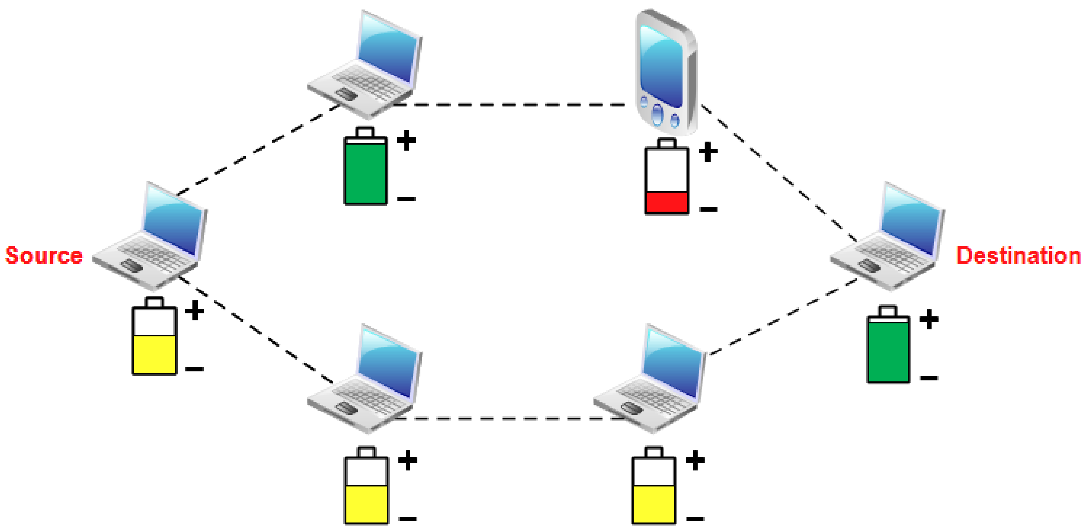

Figure-5-1: Mobile Nodes Showing Residual Battery Power

The lifetime of the network can be extended by preserving the important resource of the network, i.e. the energy of the node [2-6]. On the other hand, the selection of the stable path between a source node and destination node reduces the routing overhead that also contributes in energy saving of the mobile nodes [7-9]. However, only considering the optimization of the energy parameter in the routing protocols, it can select the more fragile or unstable routes. Thus, it is observed that considering both the above-mentioned parameters, i.e. energy consumption and the stability of a link should be considered together in the designing of routing protocol [10, 11].

Energy Sensible and Route Stability Based Routing Protocol (ESRSBRP) for Mobile Ad-Hoc Network is proposed in this chapter. ESRSBRP selects the highly stable route in term of energy as well as mobility of nodes for the individual data transmission between the source and destination. This scheme is derived from RERRP, which is already discussed in chapter 3. In ESRSBRP delay-forwarding concept is introduced and incorporated in the RERRP, which helps in balancing the utilization of node energy.

5.1 Related Work

The main objective of the energy aware routing protocol is to maximize the network lifetime by minimizing power utilisation of the node [12]. In designing of MANET routing protocols, one of the significant factor that need to be considered is the lifetime of a network [13]. In the last few years, many energy aware routing protocols have been proposed by the researchers [14, 15] with innovative and novel ideas. The majority of the energy aware routing for mobile ad-hoc network use energy related routing metric as a replacement of hop count metric [16]. This section reviews some of the many energy aware algorithms proposed by researchers in the routing field.

The research work in [17] proposed Minimum Battery Cost Routing (MBCR) which is an energy efficient routing protocol based on node residual energy. In this scheme the routing cost is defined as the inverse of the residual battery capacity of the node. The aim of the destination node is to select the path that minimizes the sum of the routing cost of all the feasible paths. Mathematical representation of the path selected in MBCR is represented in equation (5-1).

$$\min \sum \frac{1}{R_i} \text{ for node i} \in \text{path} \tag{5-1}$$

Where R_i Indicates the residual energy of node *i*. Hence, the lifetime of the network can be increased by the MBCR scheme. However, the selection of the route is the minimum of the submission of routing cost of each route. Therefore, some node with little residual energy may still be selected.

Another scheme Min-Max Battery Cost Routing (MMBCR) which is an improvement of MBCR has been proposed by S. Singh et al. [18]. The MMBCR scheme uses the same routing cost as MBCR but have a different path selection technique that avoid the selection of node with little residual energy which is expressed in equation 5-2.

$$\min \max \left\{\frac{1}{R_i}\right\} \text{for node i} \in \text{path} \tag{5-2}$$

Minimum Total Transmission Power Routing (MTPR) [19] algorithm aims to select a path that consumes minimum transmission power. Consider the generic route $R_d = N_s, N_1, N_2 \ldots N_d$ Where N_s is the source node and N_d is the destination node. A function $T_p(N_i, N_j)$ represents a transmission power between node $N_i$and node N_j. The total transmission power of feasible route is derived from equation 5-3.

$$P(R_d) = \sum_{i=0}^{d-1} Tp\ (N_i, N_{i+1}) \text{ for all nodes } N_i \in R_d \tag{5-3}$$

The optimal route R_o is the one which verifies the following condition

$$P(R_o) = \min_{R_j \in R_*} P\ (R_j)$$

Where R_* is the set of all possible routes. MTPR fails to consider the remaining power of nodes; it might not succeed in extending the lifetime of each host.

A hybrid algorithm Conditional Max-Min Battery Capacity Routing (CMMBCR) was proposed by C.K Toh [18]. The authors of this scheme combine the functionalities of MTPR and MMBCR schemes in a way that it considers both the total transmission power consumption of routes and the residual energy of nodes. When all the nodes in the feasible path have more residual energy than the threshold 'γ' than a route with minimum transmission power is selected. However, if the nodes have less residual energy than the threshold 'γ' than MMBCR scheme is applied to extend the lifetime of the nodes in the network. In CMMBCR the threshold value plays an important role, by selecting a suitable threshold value it can enhance the network lifetime and can also improve the consumption of transmission power.

The authors of PS-AODV [20] proposed an energy efficient routing protocol that makes the forwarding decision of RREQ packet based on the current load on the node. Before forwarding the RREQ packet to other neighbour nodes, this node first checks its current load. If the load of the node is too high, it simply drops this RREQ packet. When the load of the node is reduced it will again able to forward the upcoming RREQ packets.

In [21], Zhaoxiao et al. proposed a routing protocol called Energy-Aware AODV (EAODV). This protocol mainly based on AODV. In the EAODV, backup routing technique is adopted. This scheme basically selects the route based on the dynamic priority-weight($\beta_i(t)$). The calculation of dynamic priority-weight is done by equation 5-4.

$$\beta_i\,(t) = \left(\frac{R_i(t)}{C_i(t)} \right)^2 \tag{5-4}$$

$R_i(t)$ and $C_i(t)$ represents the residual and consumed battery energy of node n_i at time ‘t’ respectively. The optimal route R_o is the one which verifies the following condition

$$R_o = \max_{route_i \in r_*} (\beta_i)$$

Where r_* Contains all the possible routes.

Another routing protocol which is the modified version of the AODV protocol called a Link Stability and Energy Aware (LSEA) routing protocol [22] was proposed. The route discovery process of LSEA takes link life and the residual energy of the node into account while searching for a route towards the destination. LSEA proposed some changes in the route discovery of AODV and select only those nodes to rebroadcast the RREQ packet, which satisfies the constraint value of link life time and residual energy of the node. To estimate the link lifetime, LSEA used the previously proposed method in [23]; this method uses Global Positioning System (GPS) to gather the required information.

The routing protocol proposed by Xu et al. [1] balance the utilization of node energy and the network traffic through probabilistically controlling the broadcast. This protocol also estimates the stability of the link with the tradeoff strategy. The authors in [2] uses the concept of dividing the network into different zones by adopting one hop clustering algorithm. A reliable leader node is selected per zone, which have the highest remaining energy in the particular zone. This technique achieves the energy efficiency by controlling the unnecessary broadcasting of the routing packet in the route discovery process. In [3] another routing protocol has been proposed that consider the stability of a link and the energy consumption of nodes, while discovering a route. In this protocol authors proposed a metric that is jointly based on the energy and the stability of the node. The number of route rediscoveries is reduced by utilizing this metric in this protocol.

5.2 Energy Sensible and Route Stability Based Routing Protocol

The proposed scheme Energy Sensible and Route Stability Based Routing Protocol (ESRSBR) is an on-demand routing protocol. It initiates a route discovery process when it is needed. As discussed earlier in this chapter that the stability of the route is consists of the mobility of nodes and the energy of the node. Therefore, the main focus of the proposed scheme is to select a route that consists of nodes which have highest available battery power in the network and have longer expiration time of the links between the source node and the destination node.

In order to fulfil the requirements of our proposed scheme, AODV routing request packet (RREQ) entries need to be extended. The routing request (RREQ) packet of ESRSBR shares the same format as RE-RREQ packet format which is described in chapter-3.

5.2.1 Route Discovery Process of ESRSBR Protocol

In ESRSBR protocol when the source node 'S' want to transmit data to destination node 'D' and it has no routing entry for the particular destination than the route discovery process of the proposed protocol is initiated. The initiation of a route discovery process is done by broadcasting the route request (RREQ) packet to all neighbour nodes.

The vital objective of this scheme is to balance the utilisation of energy among the mobile node and selection of highly stable route, which eventually increase the network lifetime. For balancing the utilisation of the node energy we introduce a concept of delay-forwarding in which the route request forward decision should be based on the residual energy (RE) of the each node.

The mechanism of delay-forwarding concept is as follows:

When Route Request (RREQ) packet is received by an intermediate node which has no route to the destination in its routing table (RT-Table), then the node holds the RREQ packet for some period of time called holding time (HT) of this packet, which is calculated using equation 5-5.

$$HT_{ES-RREQ_i} = {}^{1}/_{\varrho_i} \quad (5\text{-}5)$$

ϱ_i : *Current Residual Energy of node i*

The holding time of the RREQ packet at the intermediate node is inversely proportional to its current residual energy level that is a RREQ holding time of each node depends upon its remaining energy. The remaining energy of a node is calculated by subtracting the consumed energy of the node from the initial energy of the node where consumed energy is calculated using the equation (5-6).

$$\text{Consumed Energy} = \text{Power} * \text{Time} \quad (5\text{-}6)$$

Where ,

Power = Power utilized for sending/receiving single packet

Time = Sending/receiving time for a single packet

The higher the RE level of the node, the shorter will be the holding time and vice versa. As we know the fact that if the earlier route request packet is accepted by the node, then it discards all the identical requests receive later. With the delay-forwarding concept, the RREQ packet is being broadcasted to its neighbour nodes earlier by the node which have the higher residual energy. The low residual energy nodes face the longer holding time and will transmit the RREQ packet after long delay, thus there are more chances of discarding the request packet from the lower residual energy node as compared to the packets from higher residual energy node. Meanwhile, before forwarding the RREQ packet, the intermediate node calculates Link Expiration Time (LET) between the current node and RREQ sending node by using the equation (3-2). The complete procedure of calculating the LET is already explained in chapter 3 refers to section 3.3.1. The intermediate node also selects minimum LET between the current node and the source node. Finally, after holding timer expires, it increment the hop count and broadcast the RREQ message to its neighbours refer to flow chart of route discovery process in Figure 5-2. The intermediate node may receive more than one copy of same RREQ packet from various neighbouring nodes, it discards all later duplicate RREQ packet. An intermediate node generates Route Reply (RREP) packet and sends back to the source node if it has an active route to the destination, if the intermediate node is a destination node, then it selects the stable route. The procedure for the selection of stable route is explained in the following section.

5.2.2 Route Selection of ESRSBR at Destination Node

When the first RREQ packet reaches to destination node 'D' a timer starts at 'D' and gathers all the other RREQ reaches to the destination. When the timer expires, it applies Reliability Factor (RF) to each gathered route from source to destination and selects the route which has the higher RF value. For the complete explanation regarding the calculation of RF value refer to section 3.3 of chapter 3.

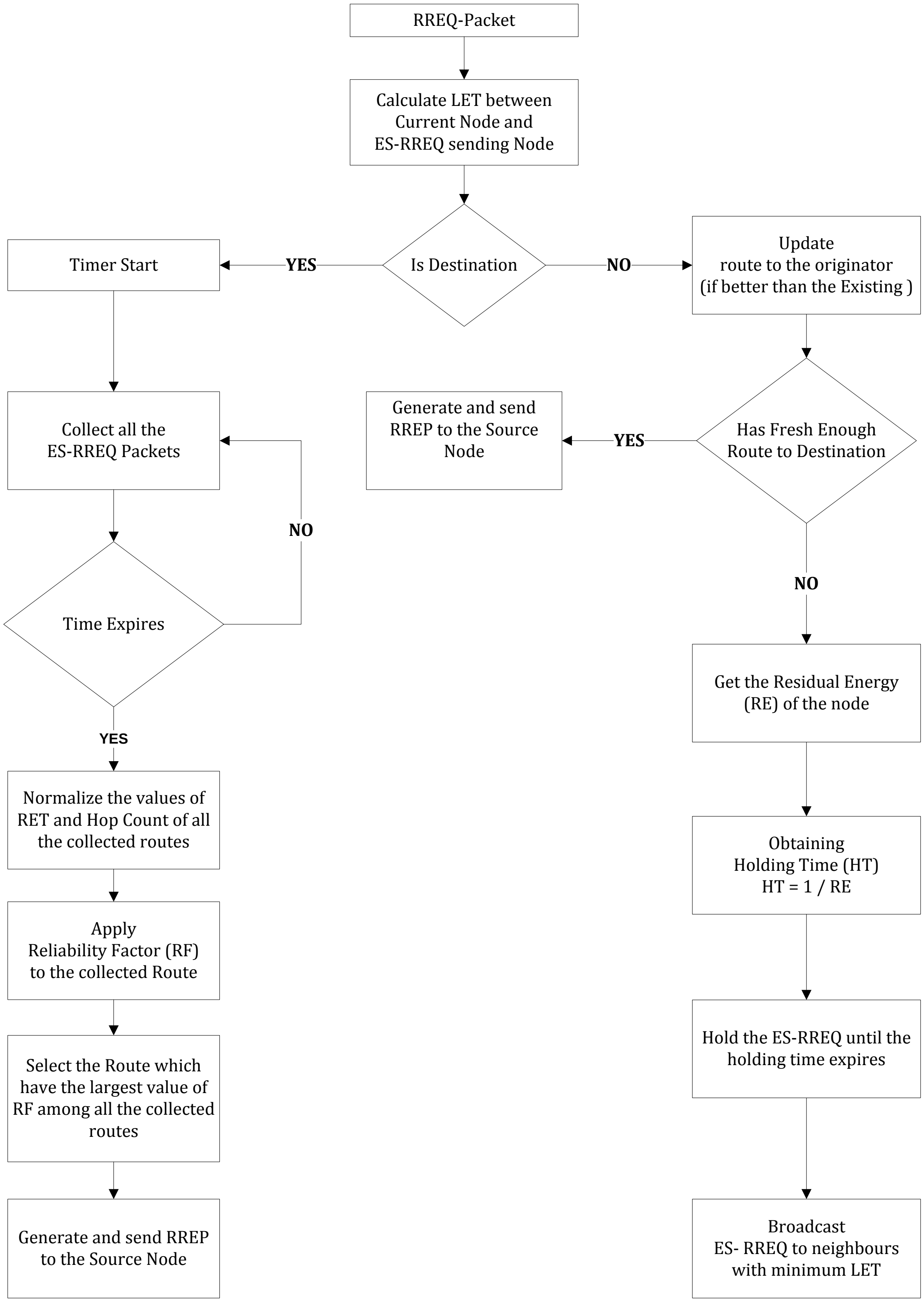

Figure 5-2 : Flow Chart of Route Discovery Process of ESRSBR

5.3 Performance Evaluation

In order to evaluate ESRSBR Protocol, simulations were carried out using Network Simulator (NS2.35) software [24]. The Random Waypoint Mobility model [25] was employed, where each node independently chooses a random initial point and waits for a period called pause time. It then moves with a velocity chosen normally between minimum and maximum velocities to a randomly chosen destination. After reaching the destination, it waits again for the pause time and then moves to a new randomly chosen destination with a new chosen velocity. Each node repeats independently the above-mentioned movement until the simulation stops.

The key simulation parameters employed in simulating the effect of varying the node speed are shown in Table 5-1. Simulation of the proposed scheme is performed with 50 nodes in the area of 1000m X 1000m. This setting provides enough space for the mobility of nodes and to check the discovery of new routes. The simulation is set to maximum 25 connections. Traffic sources are set to continuous bit rate (CBR). The source-destination pairs are spread randomly over the network. 512-Bytes data packets are used with a rate of 4 packets per second. A shared-media radio was selected with a nominal bit rate of 2 Mb/s and a nominal radio range of 250 m. A zero pause time was used to simulate a mobility level with nodes that are continuously moving in the simulation area. Each data point represents an average of multiple runs with different seed values used for the traffic models and randomly generated mobility scenarios.

5.3.1 Experiment–1: Effect of Nodes Speed on ESRSBR

In the network of 50 nodes, the speed of the mobile nodes was varied form $5ms^{-1}$ to $50ms^{-1}$ to check the effect of different speed on the proposed routing scheme. The simulation parameters of the experiment–1 are shown in Table 5-1.

Table 5-1: Simulation Parameters of Experiment – 1: Effect of Nodes Speed

Parameters	Value
Protocols	ESRSBR, AODV and LSEA
No of Nodes	50
Data Rate	4 Packets/Sec
Simulation Area	1000m X 1000m
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground
Simulation Time	300 s
Min Speed	1 ms-1
Max Speed	5, 15, 25, 35, 45 ms-1
Initial Energy	10 J
Receiving Power	31.32e-3 W
Transmitting Power	35.28e-3 W

5.3.2 Experiment–2: Effect of Node Density on ESRSBR

The number of nodes in the network was varied from 40 nodes to 140 nodes to check the effect of node density on the proposed scheme in the second experiment. Here, the maximum speed of the mobile node is $20ms^{-1}$. The simulation parameters of the experiment–2 are represented in Table 5-2.

Table 5-2: Simulation Parameters of Experiment – 2: Effect of Node Density	
Parameters	**Value**
Protocols	ESRSBR, AODV and LSEA
Simulation Area	1000m X 1000m
Number of Nodes	40, 60, 80, 100, 120, 140
Data Rate	4 Packets/Sec
Min Speed	1 ms-1
Max Speed	20ms^{-1}
Mobility Model	Random Waypoint
Traffic Type	Constant Bit Rate (CBR)
Queue Length	50
Transmission Range	250m
Propagation Model	Two Ray Ground
Simulation Time	300 s
Initial Energy	10 J
Receiving Power	31.32e-3 W
Transmitting Power	35.28e-3 W

5.4 Performance Metrics

Following metrics are used in varying scenarios to evaluate the proposed protocols.

Network Life Time: The times taken until all nodes die out due to the battery exhaustion.

Average Energy Consumption: It is the ratio between the total energy consumed in the network to the total number of nodes.

Packet Delivery Fraction: This is defined as the ratio of the number of data packets received by the destinations to those sent by the sources.

Normalized Routing Load: This is defined as the number of routing packets transmitted per data packet delivered at the destination.

Average End-to-End Delay: It is defined as the delay between the time at which the data packet was originated at the source node and the time it reaches the destination node. Data packets that get lost in route are not considered.

Throughput: The amount of data received by the destinations per unit time is referred as throughput of the network. Normally, it is measured in bits/sec.

5.5 Simulation Results and Discussion of Experiment-1

In the following section performance of ESRSBR is compared with traditional AODV and recently proposed Link Stability and Energy Aware (LSEA) [22] routing protocol.

5.5.1 Network Life Time vs. Max Speed

The plot of network lifetime is presented in Figure 5-3. It is observed that ESRSBR extends the network lifetime between 9% - 10% over LSEA and between 11% - 13% over AODV. This is because of the unique ESRSBRs route discovery and route selection mechanism. In ESRSBR's route discovery mechanism the node which has more residual energy as compared to residual energy of its neighbour nodes allows to broadcast a RREQ packet first, that means in ESRSBR protocol encourages those nodes which have more residual energy to take part in data transmission, by doing this the nodes which already have less residual energy can save energy for later use that eventually contributes in increasing the network lifetime. On the other hand the route selection mechanism of the ESRSBR protocol at the destination node also plays an important role in enhancing the network lifetime. The destination node in ESRSBR selects the stable path among all the feasible paths which have longest route expiration time and has the least number of hops. As the route with lowest expiration time is eliminated and only the route with longer expiration time is selected for data forwarding, the number of link breakage is reduced instead of choosing the shortest path in AODV. The selection of a stable route reduces the initiation of route maintenance or route re-discovery process that helps the nodes to save their energy and eventually it contributes in enhancing the network lifetime.

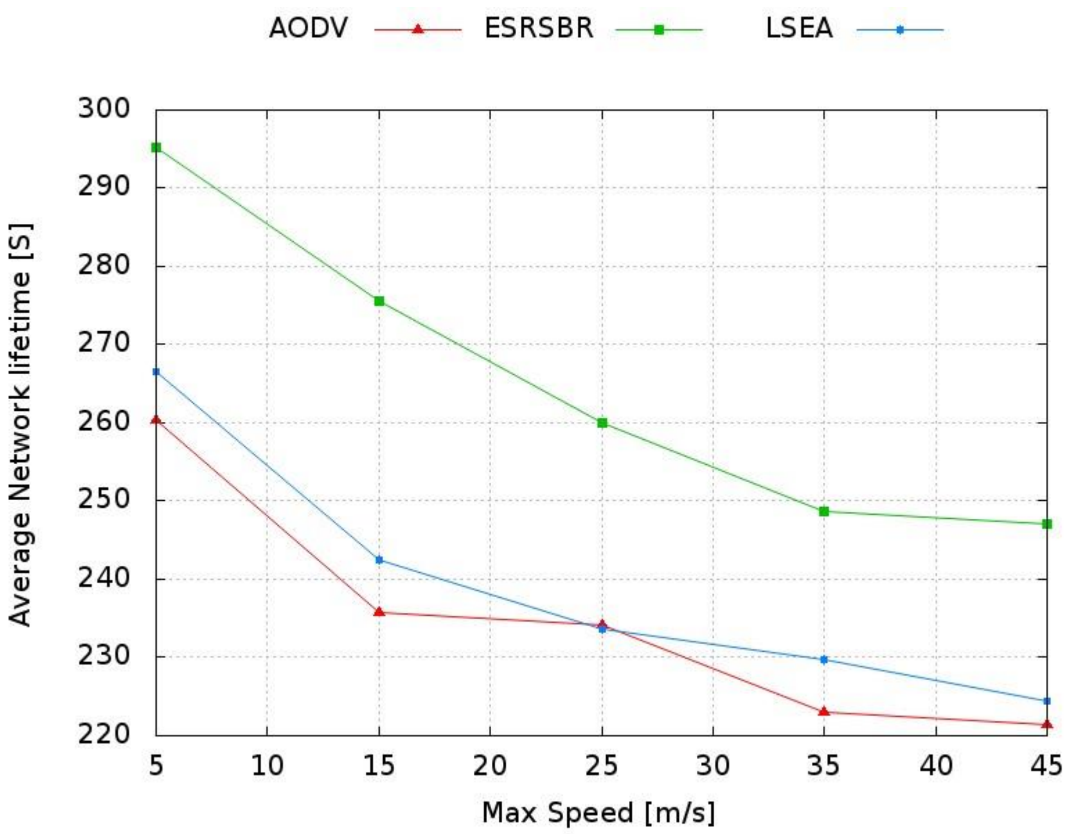

Figure 5-3: Average Network Lifetime vs. Max Speed

5.5.2 Average Energy Consumption vs. Max Speed

The Figure 5-4 illustrates the effect of node speed on the average energy consumption of the network. The Figure 5-4 also shows that, the energy consumption increases with an increase in the node speed for all the protocols i.e. ESRSBR, LSEA and AODV. This is because of the number of broken links; due to increase in the node speed. These types of failure cause additional initialization of a route discovery process that eventually increase the node computation and consume more energy of the node. The comparison result among ESRSBR, LSEA and AODV also showed that, ESRSBR has achieved superior performance in term of energy consumption. This superior performance of ESRSBR is because of the selection of reliable route which consists of reliable nodes with high link expiration time. In ESRSBR due to selection of reliable route, failures of the route were reduced. This reduction in the route failures eventually results in reduction of route maintenance procedure, which reduces energy consumption of the nodes.

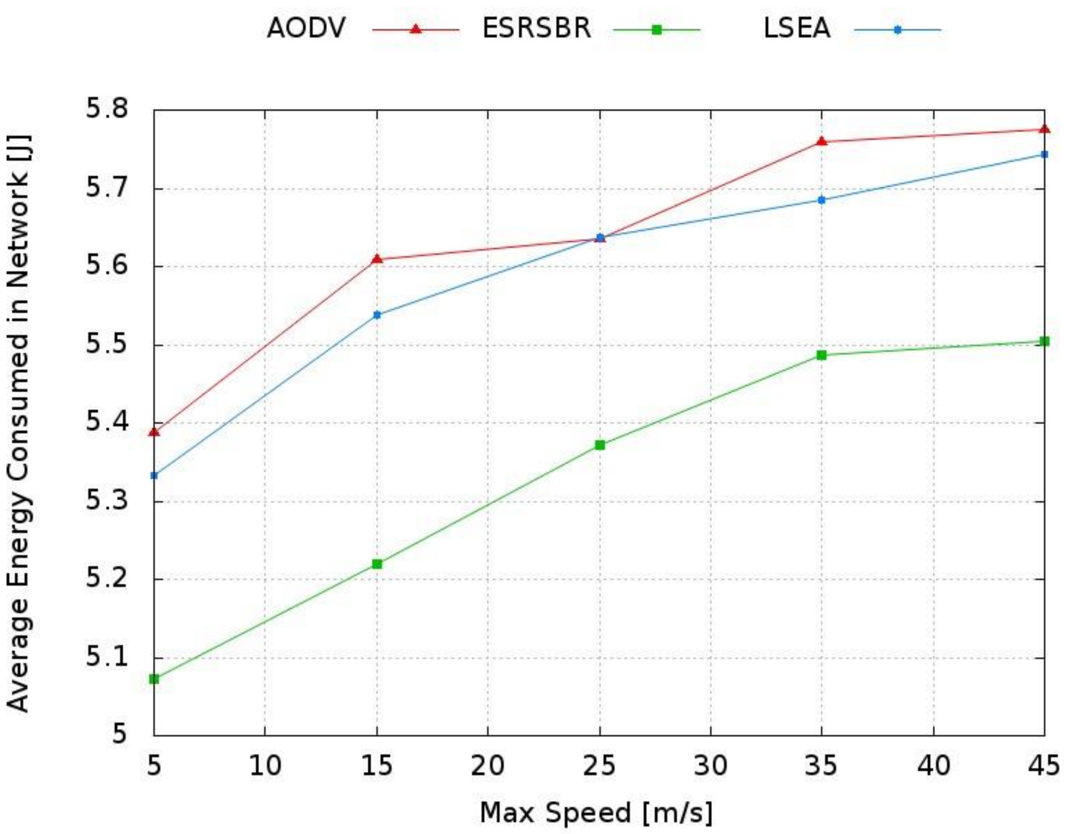

Figure 5-4: Average Energy Consumed vs. Max Speed

5.5.3 Packet Delivery Fraction vs. Max Speed

Figure 5-5, shows the advantage of the proposed protocol over AODV and LSEA in term of the packet delivery fraction, which is defined as the ratio of the number of data packets received by the destination to those sent by the CBR sources. The Figure 5-5 shows that ESRSBR protocol gives a better PDF than the AODV protocol and LSEA. It is observed that ESRSBR increase the packet delivery fraction between 4% - 6% over LSEA and between 8% - 11% over AODV. This is because of the fact that the routes selected by ESRSBR protocol are reliable and have higher rout lifetime. The proposed protocol considers paths with nodes that have the highest residual energy levels, better route lifetime and have a less number of hops. Whereas, AODV only consider the shortest path between the source and the destination and not concentrate on the residual energy of the nodes and link expiration time in the route discovery process, it simply broadcasts the RREQ packets that may select the unreliable path for data transfer, which leads to more drops of data packets.

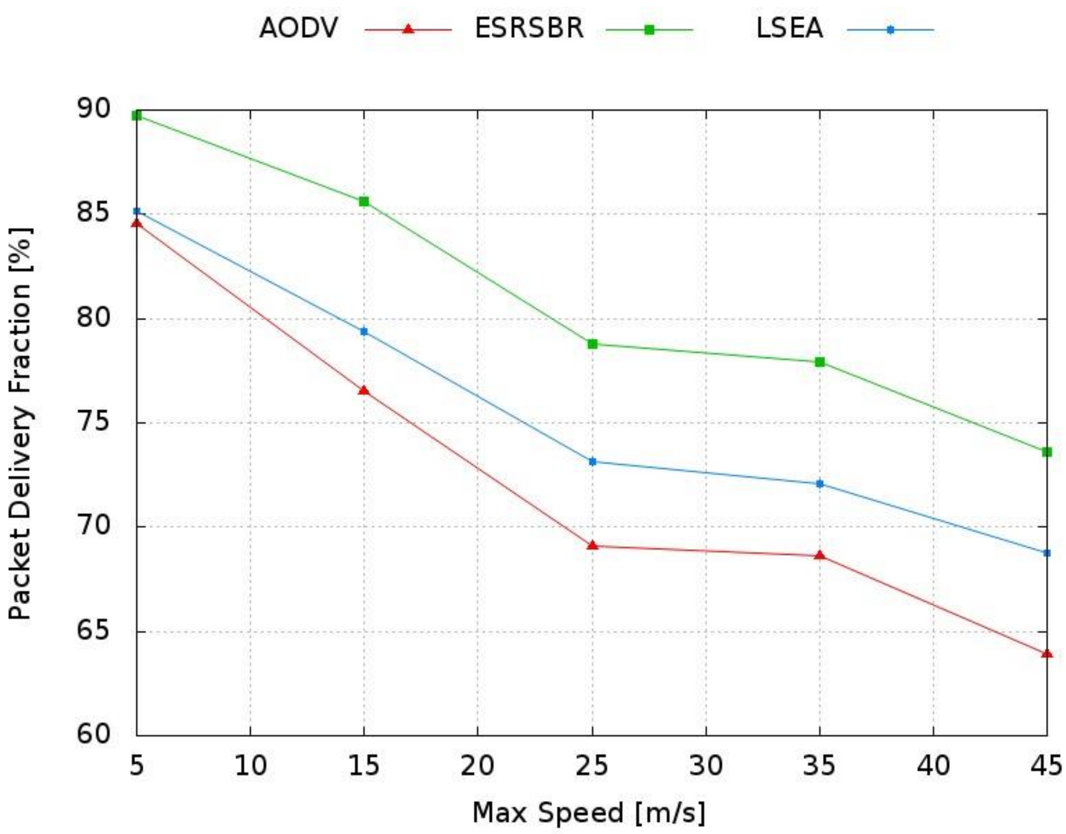

Figure 5-5: Packet Delivery Fraction vs. Max Speed

5.5.4 Network Routing Load vs. Max Speed

The Figure 5-6 illustrates the effect of node speed on the performance of ESRSBR, LSEA and AODV in term of Network Routing Load (NRL) or overhead. The Figure 5-6 also shows that, the NRL increases with an increase in the node speed for all the protocols i.e. ESRSBR, LSEA and AODV. This is because of the number of broken links; due to increase in the node speed and also some of RREQ packets fail to reach their destinations. These types of failure cause additional initialization of a route discovery process that eventually increase the network routing load or overhead. The comparison of the results of ESRSBR, LSEA and AODV also shows that, ESRSBR has achieved superior performance in term of routing load. On average, ESRSBR reduces overhead by 22% and 38% as compared to LSEA and AODV respectively. In ESRSBR due to selection of reliable route, failures of the route were reduced. This reduction in the route failures eventually results in reduction of route maintenance procedure, which reduces the network routing load involved in the route discovery and maintenance process.

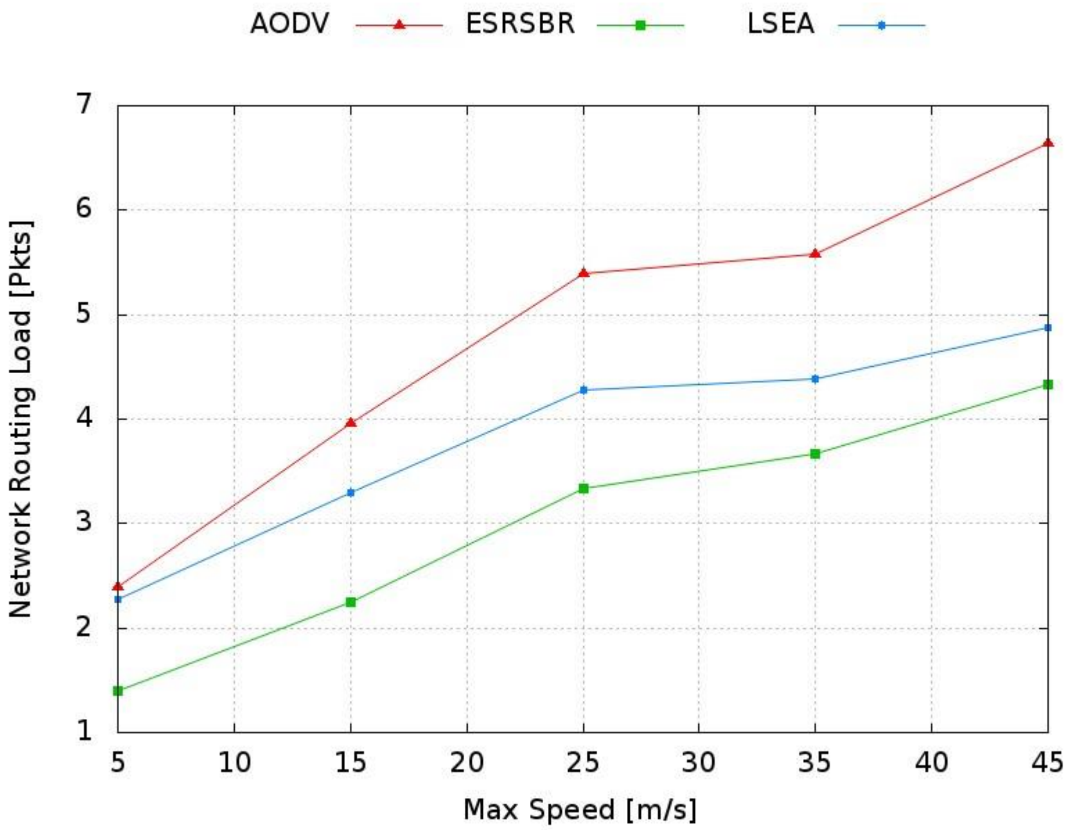

Figure 5-6 : Network Routing Load vs. Max Speed

5.5.5 End-to-End Delay vs. Max Speed

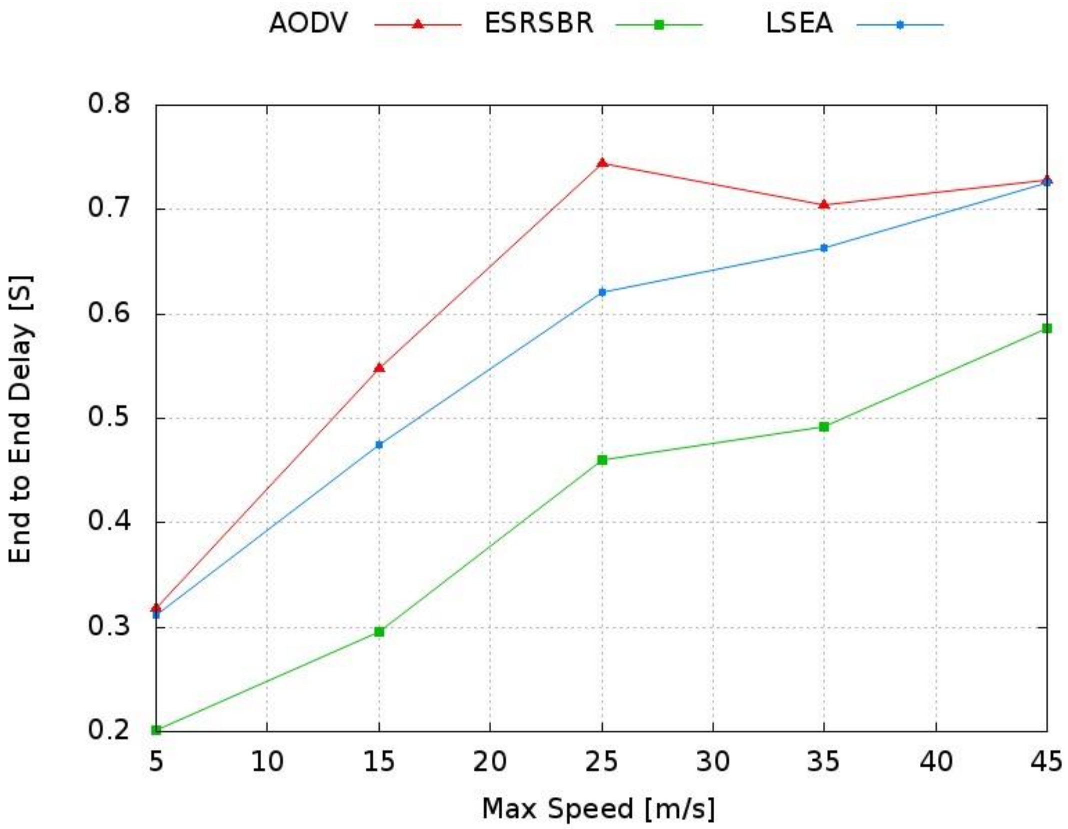

Figure 5-7 : End-to-End Delay vs. Max Speed

The Average End-to-End delay of ESRSBR, LSEA and AODV protocols are represented in the Figure 5-7. The result shows that AODV experienced more delay than ESRSBR and LSEA. Due to the selection of the best path between the source node and the destination node based on the node residual battery life, link expiration time, and the hop count the proposed protocols have less End-to-End Delay.

5.5.6 Average Throughput vs. Max Speed

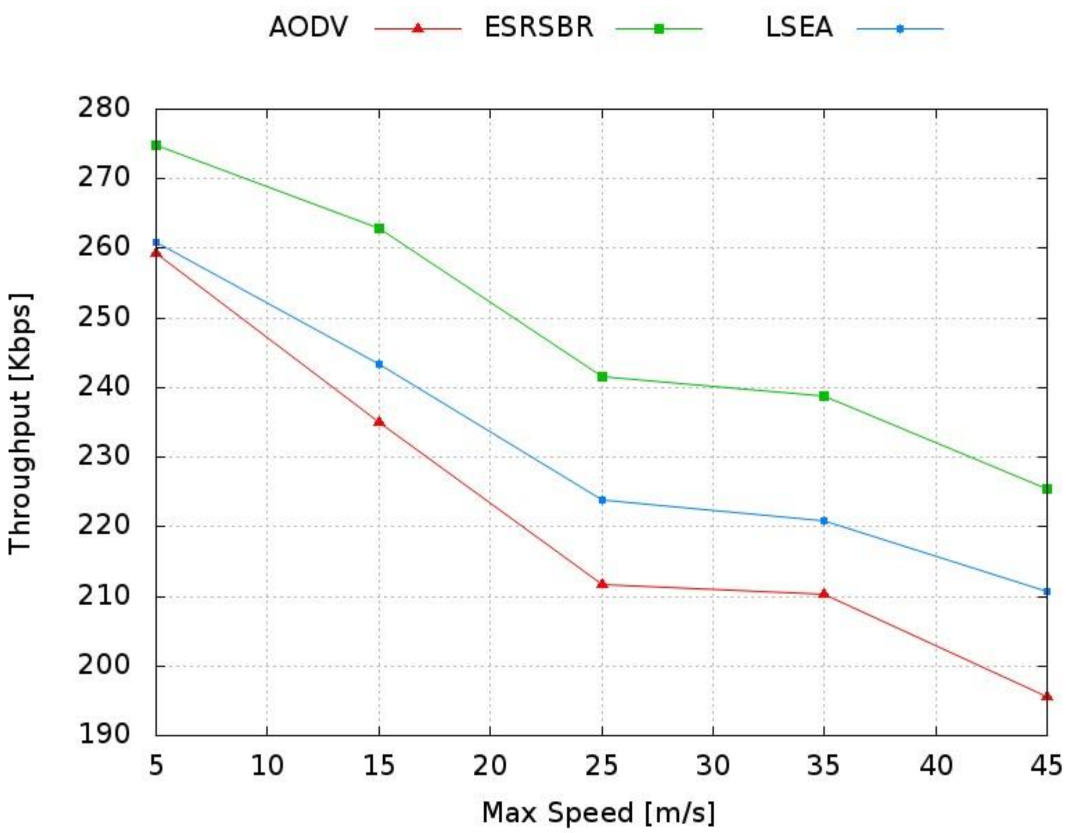

Figure 5-8 : Throughput vs. Max Speed

One of the important metric for the measurement of network transmission ability is throughput. The throughput comparison of different routing protocols based on different node speed represented in Figure 5-8. This Figure also shows that as the node speed increases the throughput of the network decreases. As in the MANET all the nodes are moving, therefore the route between the source node and the destination node breaks. The route breakage causes to initiate route maintenance, which leads to more rebroadcast and greater bandwidth consumption. As a result, throughput decreased as soon as we increase the node speed. The figure also shows that ESRSBR outperforms AODV and LSEA. At every speed, ESRSBR increased throughput by 13% and 7% as compared to AODV and LSEA respectively. The throughput improvement of ESRSBR is due to selection of reliable route with better link lifetimes.

5.6 Simulation Results and Discussion of Experiment – 2

This section presents the performance impact of network density on ESRSBR and AODV over different network density. The network density has been varied by deploying 40, 60, 80, 100, 120 and 140 nodes over a fixed area of 1000m x 1000m. Each node in the network moves with a speed of 20msec^{-1}. The maximum connections of 25 are generated between random source destination connections (i.e. Traffic flows). At every connection 4 data packets per second have been used. The packet size is 512 bytes. In the figures presented below, the x-axis represents the variations of numbers of nodes, while the y-axis represents the results of the performance metric of interest.

5.6.1 Network Life Time vs. Number of Nodes

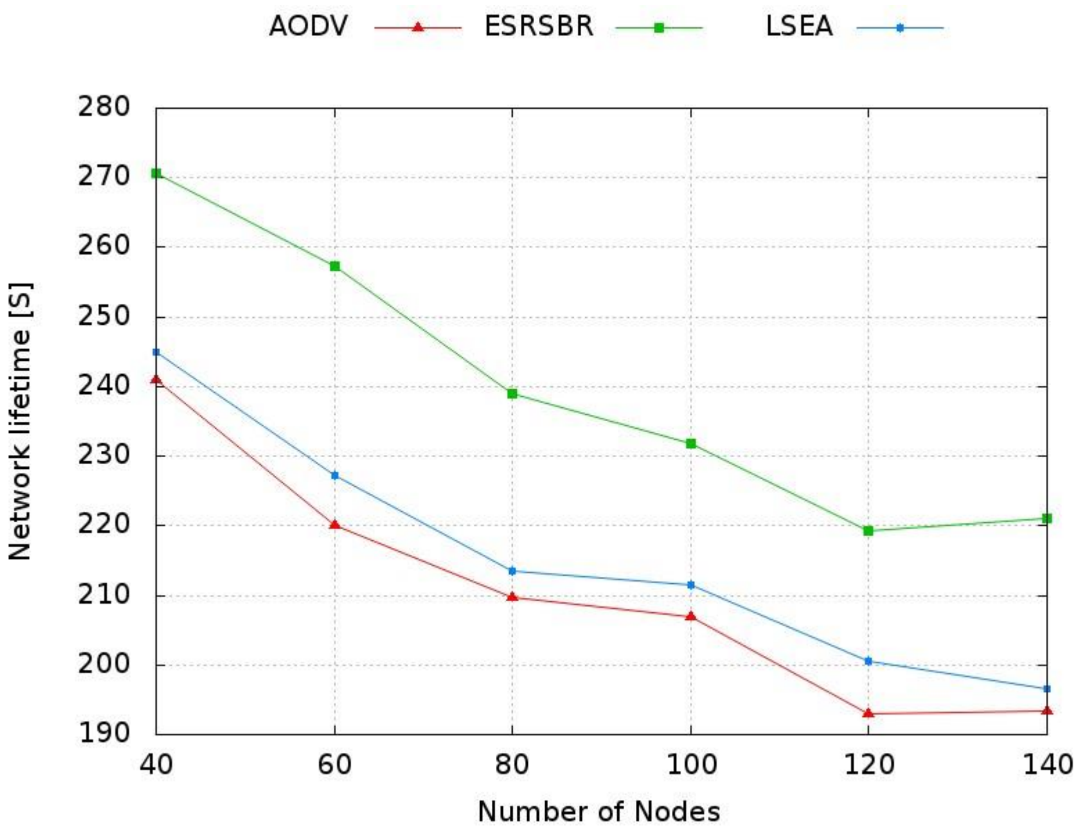

Figure 5-9: Network Lifetime vs. Number of Nodes

Figure 5-9 shows the effects of network density on the performance of ESRSBR, LSEA and AODV in terms of the network lifetime. The Figure 5-9 shows that as the network density increases the lifetime of the network decreases. This is because of more RREQ packets are travelling in the network and every node needs to process more routing packets that consume node energy. Because of this nodes are starting to die early. The Figure 5-9 also shows that ESRSBR has better remaining lifetime as compared to LSEA and AODV routing protocols. The LSEA is a recently proposed routing protocol shows some improvement in the remaining lifetime of the network as compared to the AODV. The LSEA routing protocol uses some threshold value while controlling the broadcast of RREQ packets. The ESRSBR protocol eliminates the lower energy nodes from the route discovery process. The selective-forwarding concept of ESRSBR helps in balancing the utilization of node energy by cutting off those nodes that have less remaining energy. Moreover, in ESRSBR due to selection of reliable route, failures of the route were reduced. This reduction in the route failures eventually results in reduction of route maintenance procedure, which reduces the network routing load involved in the route discovery and maintenance process thus less energy is consumed. The comparison of result of ESRSBR, LSEA and AODV also showed that, ESRSBR has achieved superior performance in term of network lifetime. On average, ESRSBR increases the network lifetime by 14% and 11% as compared to AODV and LSEA respectively.

5.6.2 Average Energy Consumption vs. Number of Nodes

The Average Energy Consumption (AEC) of ESRSBR, LSEA and AODV protocols are represented in the Figure 5-10 which increases with increasing network density. When the number of nodes increases the rebroadcast of RREQ packets is also increases, so the increase in the number of nodes contributes in enhancing the processing of nodes which consume energy. In Figure 5-10 simulation result shows that the energy consumption of the ESRSBR is less than AODV and LSEA routing protocol. The reason is that in ESRSBR the number of requests for route discovery is reduced because of reducing the route failures which eventually save the energy consumption. The comparison of results of ESRSBR, LSEA and

AODV showed that, ESRSBR has consumed the least amount of energy in the network.

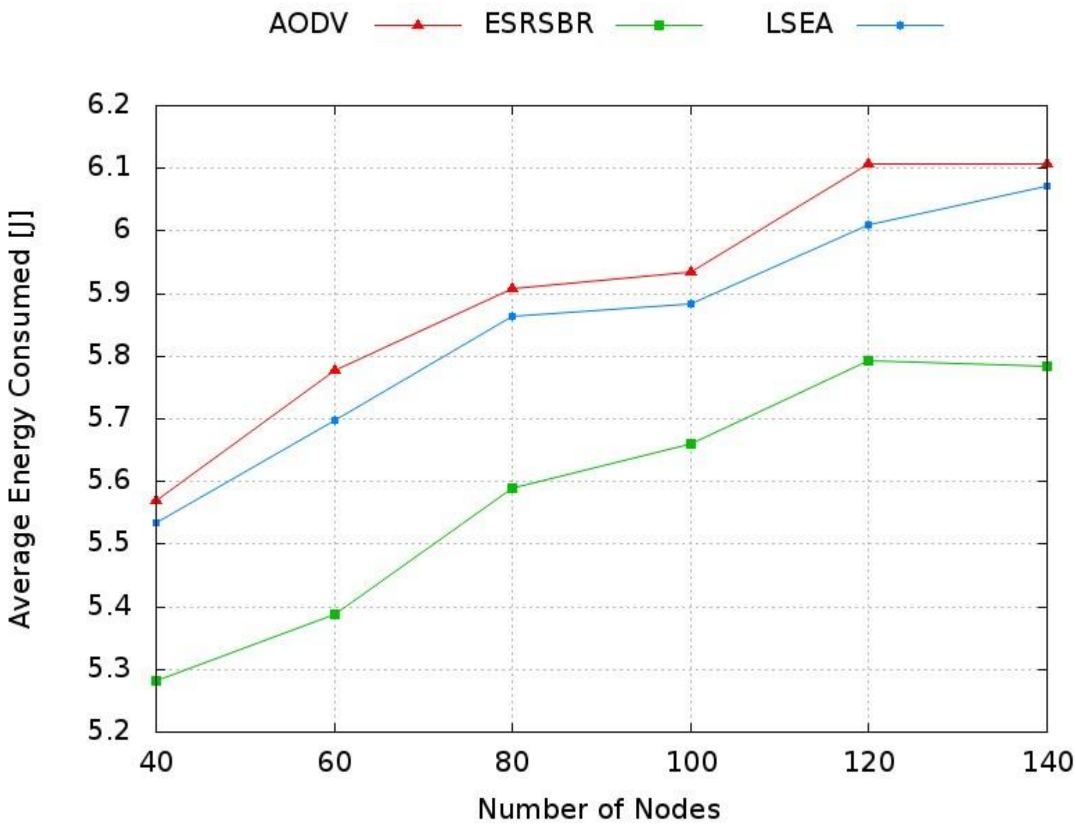

Figure 5-10: Energy Consumption vs. Number of Nodes

5.6.3 Packet Delivery Fraction vs. Number of Nodes

Figure 5-11 shows the effects of network density on the performance of ESRSBR, LSEA and AODV in terms of the packet delivery fraction. We can observe from the Figure 5-11 that packet delivery fraction decreases with the increase in the number of nodes in all protocols. But the packet delivery of the proposed protocol ESRSBR is more than LSEA and AODV at every density of the network. The ESRSBR selects the stable routes in which the nodes that have more residual energy are encouraged to participate in the data transmission. Apart from selecting the highly residual energy node, the ESRSBR protocol also considers the link lifetime and the number of hops while selecting the route for data transfer, which makes ESRSBR to select stable route and reduces the data drops. LSEA somehow also consider the link life and energy of the node while considering the some threshold values and select the path that is first reaches to the destination. AODV selects the shortest path between the source node and the destination node and it does not concentrate on the link expiration time and the nodes residual energy while discovering the route. Thus, the path selected by AODV may have some unreliable links that lead to more drops of data packets. It is also observed that on average, ESRSBR increase the packet delivery fraction by 12% and 14% over LSEA and AODV respectively.

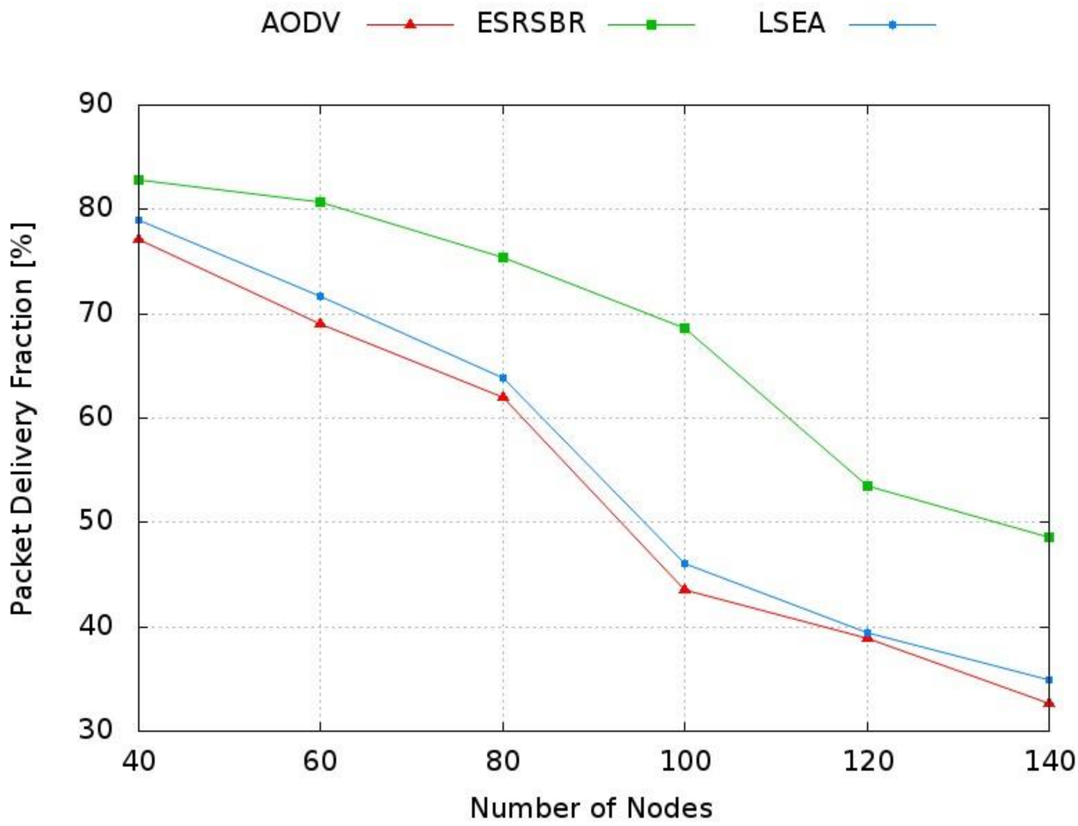

Figure 5-11: Packet Delivery Fraction vs. Number of Nodes

5.6.4 Network Routing Load vs. Number of Nodes

Figure 5-12 illustrates performance measures of the protocols in terms of routing overhead with varying network density. The network density was varied by increasing the number of nodes deployed in a fixed area of 1000m x 1000m. The network routing load (NRL) of the protocols in the Figure 5-12 increases with the increase in the network density. When the number of nodes increases rebroadcast of RREQ packets are also increases that contribute in enhancing the routing load. In Figure 5-12 simulation result shows that the network routing load of ESRSBR is less than AODV and LSEA routing protocols. The reason is that in ESRSBR the number of requests for route discovery is reduced because route failures are reduced. The ESRSBR protocol eliminates the lower energy nodes from the route discovery process. The selective-forwarding concept of ESRSBR helps to reduce the link failure that happens due to the node running out of the battery power. Moreover, in ESRSBR due to selection of reliable route, failures of the route were reduced. This reduction in the route failures eventually results in reduction of route maintenance procedure, which reduces the network routing load involved in the route discovery and maintenance process. The comparison results of ESRSBR, LSEA and AODV also shows that, ESRSBR has achieved less routing load. On average, ESRSBR decreases the network routing load by 28% and 20% as compared to AODV and LSEA respectively.

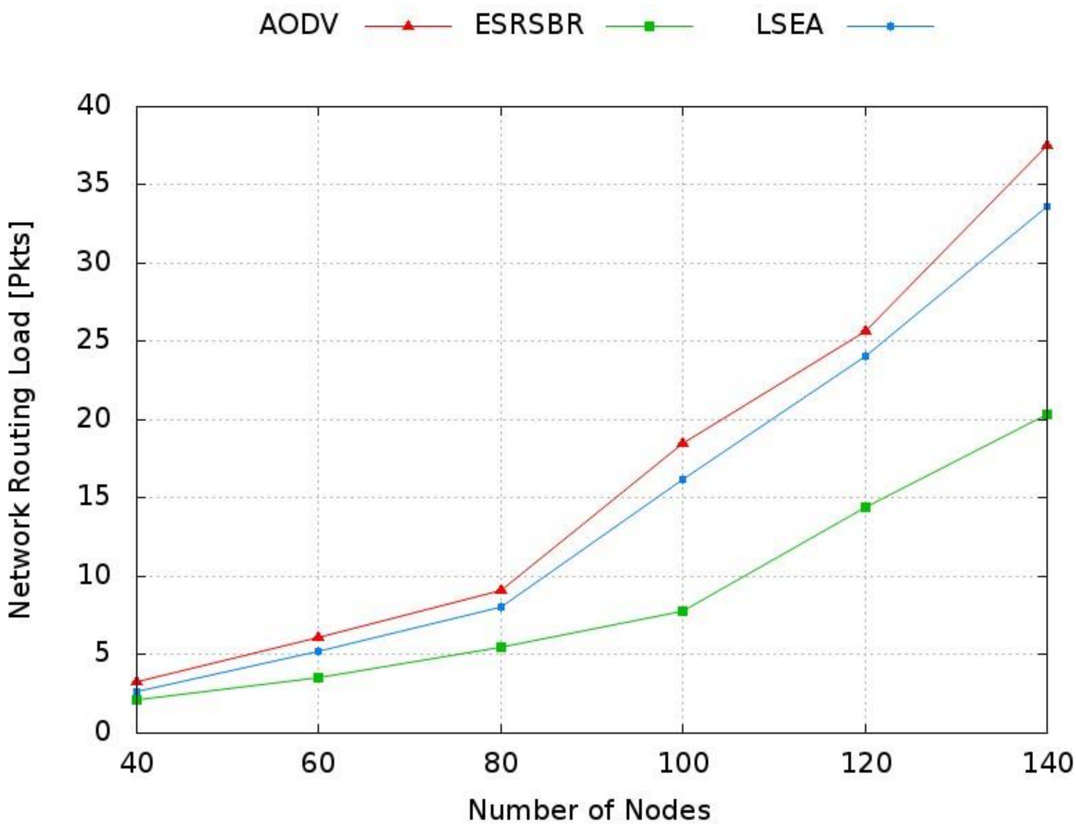

Figure 5-12: Network Routing Load vs. Number of Nodes

5.6.5 End-to-End Delay vs. Number of Nodes

The average End-to-End delay comparison is presented in Figure 5-13. As the number of nodes increases the end-to-end delay of the protocols also increases. The delay experienced by the ESRSBR is less than that of AODV and LSEA protocols. This is because ESRSBR selects best path between the source node and the destination node based on the node residual battery life, link expiration time, and the hop count.

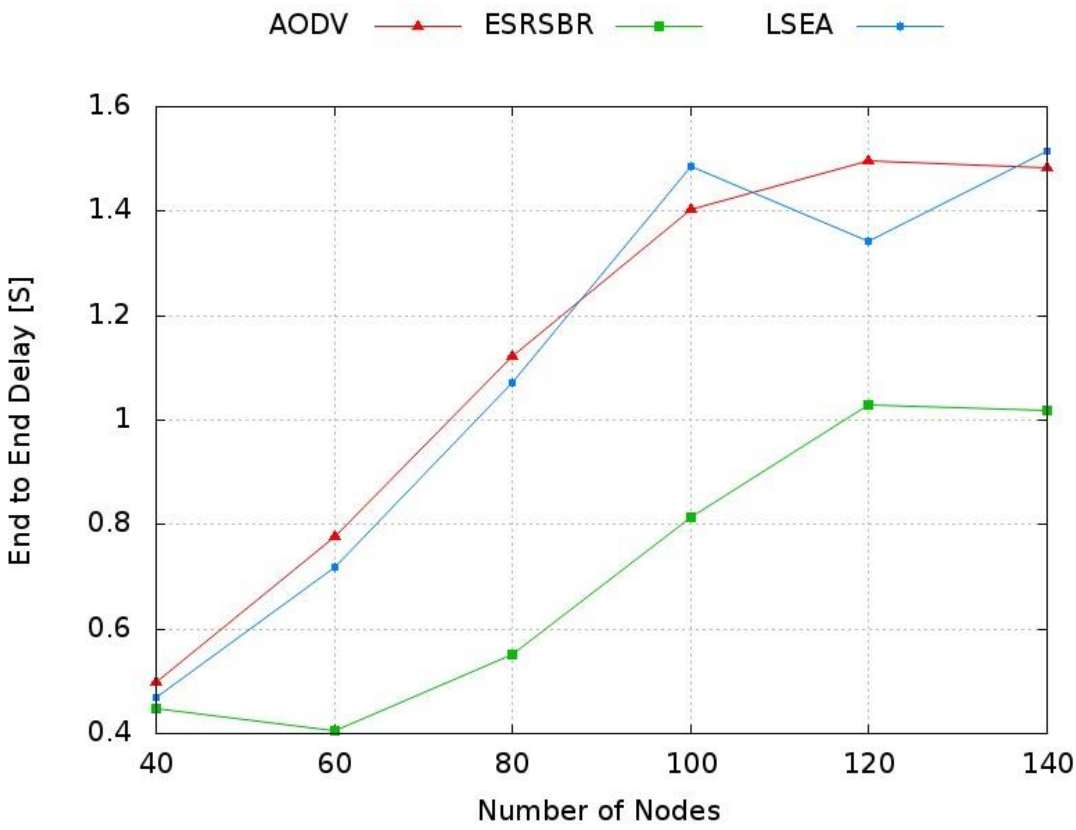

Figure 5-13: End-To-End Delay vs. Number of Nodes

5.6.6 Average Throughput vs. Number of Nodes

The average throughput is presented in the Figure 5-14 The Figure illustrates that ESRSBR, LSEA and AODV drop the throughput when the node density is increased. The Figure 5-14 also shows that on average, ESRSBR increases the throughput by 30% and 26% as compared to AODV and LSEA respectively. The Figure also shows that the ESRSBR gives the higher throughput than the AODV and LSEA at every node density. With the larger number of nodes in the network destination node has more choices available to select the best route that have less chances to break the link for the data transfer. The proposed protocol ESRSBR selects the stable routes in which the nodes with more residual energy are encourage to participate in the data transmission. Apart from selecting the highly residual energy node, the ESRSBR protocol also consider the link lifetime and the number of hops while selecting the route for data transfer, which makes

ESRSBR to select stable route and reduces the data drops. Hence, it enhances the throughput of the network. On the other hand AODV select the shortest route and doesn't consider node mobility parameters while selecting the route. The selection of shortest route may cause frequent link breakage that affects the overall throughput of the network.

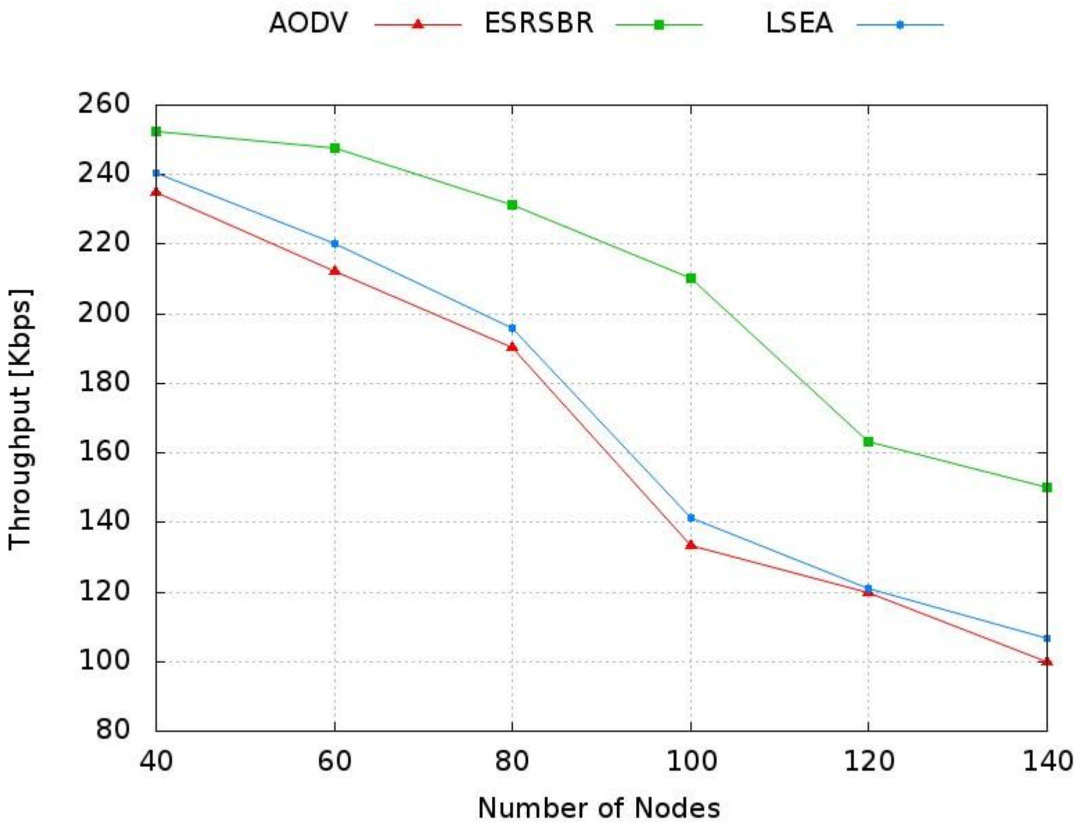

Figure 5-14: Throughput vs. Number of Nodes

5.7 Chapter Summary

The MANETs are comprised of groups of mobile nodes which are battery powered and their power supplies are not permanent. Therefore, frequent link breakages in MANETs are mainly caused by failure of the node. The node fails because running out of energy on one hand and moving out of the transmission range on the other hand. Moreover, due to the path disconnection, route maintenance or route rediscovery process had to be initiated to re-establish the broken path which causes extra energy consumption of nodes and affects negatively on the performance of the network. In this chapter, an Energy Sensible and Route Stability Based Routing protocol (ESRSBR) has been proposed. The vital objective of this scheme is to balance the utilisation of energy among the mobile node and selection of highly stable route, which eventually increase the network lifetime and enhance the performance of the network. For balancing the utilisation of the node energy ESRSBR introduced a concept of delay-forwarding in which route request message was held for some duration of time called the Holding Time (HT) before forwarding it further. The calculation of HT is depends up on the node Residual Energy (RE). This technique helps the route discovery process to select only those nodes which have more residual energy as compared to their neighbour nodes. Among the feasible routes gathered at the destination node, ESRSBR selects the route with the highest Reliability Factor (RF) value. The performance of the ESRSBR has been analysed on two different experimental scenarios, i.e. varying node speed and varying node density. Extensive NS-2 simulation has been done to evaluate the performance of the proposed protocol. The comparative analysis of ESRSBR with AODV and LSEA revealed that the proposed protocol ESRSBR has a significant effect the network lifetime, increases it around 10% and 13% as compared to LSEA and AODV protocols respectively. The ESRSBR also decreases the routing overhead by 22% over LSEA and by 38% over AODV.

5.8 References

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Chapter 6

Conclusion and Future Direction

The focus of this research work was the improvement of routing protocols for mobile ad-hoc networks. Various existing algorithms and design strategies were thoroughly investigated. The mobility of the node and its impact on the performance of the routing was the main area of our work.

This research proposed a number of different approaches for the improvement of the routing performance and evaluates the performance of the proposed algorithms. The proposed routing protocols have exhibited significant improvements in the routing, but it is also felt that there is room for further potential improvements related to the work done.

The summary of the research done and possible direction for future work related to the contributions are presented in this chapter.

6.1 Conclusions

This thesis is the end result of research efforts put into addressing the issues found in reactive routing protocols for MANETs. This work introduces three on-demand routing techniques which improve overall performance of the network.

The proposed techniques are summarised below:

6.1.1 Reliable and Efficient Reactive Routing Protocol (RERRP)

The mobility of nodes is an important feature of the MANET. Due to the mobility of node the network topology becomes very dynamic that causes the path disconnection between the data sending and receiving nodes. The frequent breakage of the established path degrades the network performance. When an active or established route between the source node and the destination node is broken, the routing protocol executes route maintenance procedure which consumes a good amount of network resources that eventually influence negatively on the performance of the network. A Reliability-Based routing protocol called Reliable and Efficient Reactive Routing Protocol (RERRP) has been proposed in this thesis. RERRP is specifically designed to minimise the frequent link breakage and enhances the packet delivery ratio in MANETs. The selection of Reliable Route (RR) depends upon the value of Reliability Factor (RF). RF basically calculates the reliability value of each feasible route between source and destination. It focuses on the route expiration time and the number of hops between the source and destination. At the destination node all the feasible routes are collected. Reliability value of each of the route is calculated using RF. The route with the highest reliability value among all the feasible routes is selected for data communication. By the selection of Reliable route, high packet delivery ratio is achieved. The selection of RR also minimizes the frequent link breakage that eventually reduces the network routing load and enhances the packet delivery. The simulation result shows that RERRP outperforms AODV and enhance the packet delivery fraction (PDF) by around 6 % and reduces the network routing load (NRL) by around 30%.

6.1.2 Effective Broadcast Control Routing Protocol (EBCRP)

Broadcasting is a basic communication operation used in the route discovery process of many on-demand routing protocols for Mobile Ad-hoc Network (MANET). This process has potentially increased the retransmission of the RREQ message in the network; as a result, it leads to high network congestion and significant network performance degradation. This phenomenon is also referred as a broadcast storm problem. An Effective Broadcast Control Routing Protocol (EBCRP) has been proposed in this thesis for controlling the broadcast storm problem in MANET. The EBCRP is mainly considered the mobility parameters of a node while controlling the redundant re-broadcast of the route request packet.

The proposed scheme has the following characteristics.

a. It is based on the Ad-hoc On Demand Distance Vector (AODV) routing protocol and paths are established whenever it is required.

b. The network wide flooding of RREQ packets associated with the on demand routing protocols has been controlled in the proposed scheme based on selective forwarding. The proposed (EBCRP) control the redundant rebroadcasting of the RREQ message by allowing only the Reliable Nodes (RN) to rebroadcast the RREQ message. The selection of RN basically depends upon the position, direction and speed of the node.

The performance of the EBCRP has been analysed on three different experimental scenarios, one with varying node speed, varying node density and on different traffic load. Results from the extensive NS-2 simulations have shown that the node speed, node density and traffic load have a substantial effect on the performance of the network. Although it is impossible to guarantee that there will be no redundant broadcast of route request packet in the network. However, by adopting the proposed scheme, it has been possible to reduce the number of redundant RREQ packets. The comparative study between AODV and EBCRP revealed that the proposed protocol EBCRP have a significant effect on the network routing overhead reduces it around 70% and enhance the packet delivery by 13% as compared to AODV.

6.1.3 Energy Sensible and Route Stability Based Routing Protocol (ESRSBR)

Since all the nodes in Mobile Ad-Hoc Networks (MANETs) are mobile and battery powered and their power supplies are not permanent. Therefore, frequent link breakages in MANETs are mainly caused by failure of the node because it is running out of energy and the mobility of node make the network topology very dynamic which leads to frequent path disconnections. Restoring or recharging batteries are generally unimaginable in critical situations like in military or relief missions. Battery decaying of a node does not affect itself only, but the overall lifespan of a system is also affected. Link failure in the network needs re-routing and establishing a fresh route from source to destination; so frequent route discoveries to re-establish broken path can cause additional power utilization of nodes. Thus, to extend the lifetime of the network considering the node energy in the routing process is one of the important solutions. Energy Sensible and Route Stability Based Routing Protocol (ESRSBR) has been proposed to address the battery decaying issue. ESRSBR is an on-demand routing protocol. It initiates a route discovery process when it is needed. Residual Energy (RE) of the nodes and the stability of the paths are simultaneously considered in this scheme for the establishment of end-to-end route between source and destination. The main focus of the proposed scheme is to select a route that consists of nodes which have the highest available energy level in the network on one hand and longer expiration time of the links on the other hand. Following are the key concepts behind the ESRSBR protocol.

- On receiving the RREQs packet the intermediate node checks its (nodes) remaining energy. If the intermediate node has an active route to the destination than it simply send the RREP packet to the source node.

- If an intermediate node doesn't have a route to the destination, it calculates the link expiration time between the sender of RREQ packet and itself.

- The node holds the RREQ packet for the time period, depending on its remaining energy and then broadcast the RREQ packet to its neighbours.

- Destination nodes collect all the feasible routes and then select the best stable route among all collected routes.

The simulation results show that, the ESRSBR increases the network lifetime by 10% and 13% as compared to LSEA and AODV respectively. It is also observed that ESRSBR increase the packet delivery fraction between 4% - 6% over LSEA and between 8% - 11% over AODV. The routing load of the proposed protocol is also very low as compared to LSEA and AODV.

6.2 Future Research Directions

The research work presented in this thesis focussed on the improvement of routing performance. Three routing protocols were proposed, simulation results are compared with some of the available alike protocols. The results of these comparisons are encouraging and have shown reasonable improvement in the routing performance in the MANETs. During the attempt to design the proposed protocols, several thoughts derived about the possible future work that can be done in order to further improve the routing performance in MANETs. Following is a summary of the possible future research work:

- The research presented in this thesis can be extended in the future by combining the functionalities of proposed routing protocols i.e. EBCRP and ESRSBRP. The resulting new routing protocol controls the broadcast storm problem as well as efficiently utilize the node energy that helps to enhance the network lifetime.

- This thesis has offered an intensive performance evaluation of the proposed schemes which have been implemented in AODV. It would be a fascinating prospect to look the impact of these schemes on other reactive routing protocols, such as DSR.

- In order to simulate node mobility and its impact on the performance of the proposed schemes, random waypoint mobility model has been extensively used. As a future work, these proposed schemes can also be tested on other mobility models such as Manhattan Grid Mobility (MGM) model which model vehicular mobility on a structured road in the city.

- This research has been conducted assuming CBR traffic that relies on UDP. A natural extension of the research work would be to analyse the performance behaviour of the proposed algorithms for other traffic types, those relying on transmission control protocol (TCP).

- This work uses GPS to obtain the node mobility parameters for the prediction of link expiration time (LET). It would be a favourable research direction to use an alternate method to obtain the mobility parameters without using GPS.

- In the research work performance of routing protocols for MANETs is evaluated using simulation as a tool, it will be an interesting avenue to explore and develop a test bed to obtain realistic results.