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Improved AODV Routing Protocol to Cope with High Overhead in High Mobility MANETs

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Dedication

To my parents and aunt with respect and gratefulness,

To my wife with love,

To my beloved children, Mohammed, Maria, and Yazan, and

To my brothers and sisters,

I dedicate this work

ACKNOWLEDGEMENT

Praise and thanks be to Allah, Lord of the worlds. Praise be to him, who gifted me with the blessing of health, reason and mind. Thanks of those who are thankful, righteous and knowledgeable are due to Allah for everything.

Then, I would like first to express my great reverence and indebtedness to my supervisor professor doctor Mohammed Mikki for his constant guidance and practical advice, without which this work would not have been accomplished.

I am also greatly indebted to the Computer Engineering Department instructors, particularly Dr. Ayman Abu Samra, Prof. Ibrahim Abuhaiba, Prof. Hatem Hamad, and Dr. Mohammed El Hanjoury for their support and guidance during my study.

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Finally, warm thanks and love to my wife for being patient and tolerant and for supporting me through the different stages of my study.

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LIST OF ACRONYMS

MANETs	Mobile Ad hoc NETworks
AODV	Ad-hoc On-demand Distance Vector routing protocol
WRP	Wireless Routing Protocol
DSDV	Destination-Sequenced Distance-Vector routing protocol
STAR	Source Tree Adaptive Routing
DSR	Dynamic Source Routing protocol
ZRP	Zone Routing Protocol
HSR	Hierarchical State Routing
CGSR	Cluster-head Gateway Switch Routing
GPS	Global Positioning System
LAR	Location Aided Routing
RREQ	Route REQuest
RREP	Route REPly
RERR	Route ERRor
GeoAODV	GPS-Enhanced AODV routing protocol
DREAM	Distance Routing Effect Algorithm for Mobility
GPSR	Greedy Perimeter Stateless Routing for wireless networks
TTL	Time To Live
PDF	Packet Delivery Ratio
NRL	Normalized Routing Load

ملخص البحث

يعتبر بروتوكل التوجيه عند الطلب المعتمد على أقصر الطرق (AODV) من أكثر البروتوكولات شيوعاً في الشبكات الاسلكية العشوائية. عندما يريد المرسل إرسال بيانات إلى مستقبل ما و لا يتوفر لديه مسار للمستقبل ، يقوم البروتوكول بعملية بحث عن مسار لهذا المستقبل. أثناء عملية البحث عن مسار يقوم هذا البوتوكول بإغراق الشبكة برسائل البحث عن مسار (RREQ) و رسائل الرد بتوفر مسار (RREP) و هذا يؤدي إلى انتشار عدد كبير من رسائل التحكم الغير ضرورية مما يؤثر على موارد الشبكة.

تقوم فكرة هذا البحث على تطوير هذا البروتوكول بحيث تحد من رسائل التحكم المرسلة عبر الشبكة أثناء عملية البحث عن مسار.

بإستخدام نظام تحديد المواقع العالمي (GPS) يمكن أن يعرف كل جهاز متنقل مكانه و سرعته و الوقت. و يقوم كل جهاز متنقل بنشر مكانه و سرعته و الوقت الذي اخذت فيه هذه البيانات إلى الأجهزة المتنقلة الأخرى عن طريق اضافتها إلى رسائل طلب المسار (RREQ) و رسائل الترحيب (HELLO). و يقوم كل جهاز في الشبكة بحفظ معلومات الأماكن الخاصة بالأجهزة الأخرى.

هذا البحث يقدم بروتوكولين جديدين يعملان على الحد من رسائل التحكم التي تغرق الشبكة اللاسلكية العشوائية في بروتوكل (AODV) . البروتوكول الأول يسمى (AODV–LAR) و يعتمد على حصر عملية البحث عن مسار للمستقبل في مساحة مستطيلة أصغر من مساحة الكلية للشبكة، بحيث يستخدم هذا البروتوكول المعلومات الخاصة بمكان المستقبل ليتوقع مساحة البحث عن مسار للمستقبل. و لزيادة دقة التوقع يأخذ هذا البروتوكول في الحسبان المسافة التي يقطعها المستقبل أثناء عملية البحث عن مسار للمستقبل.

أما البروتوكول الثاني المسمى (AODV–Line) فإن الأجهزة المتنقلة الوسيطة تقرر المشاركة في عملية البحث عن مسار للمستقبل بناء على بعدها عن الخط المستقيم الواصل ما بين المرسل و المستقبل.

عملية تحديد مساحة البحث عن مسار في البروتوكولين السابقين تتم بناء على معلومات الاماكن الخاصة بالمرسل و المستقبل. و لتقليل الزمن اللازم للبحث عن مسار في بروتوكول (AODV–LAR) قمنا بتطوير معادلة لتحديد زمن الحياة (TTL) الخاصة برسالة طلب المسار (RREQ).

لقياس جودة الأداء الخاصة بهذين البوتوكولين ، قمنا بعمل محاكاة للبروتوكولين بإستخدام المحاكي المسمى (JIST/SWANS). و بإستخدام سيناريوهي محاكاة مختلفين. و قد تم قياس معايير جودة الأداء التالية : عبء البروتوكول، و عدد رسائل طلب المسار، و زمن البحث عن مسار.

و قد أظهرت النتائج أن البروتوكولين المقدمين في هذا البحث كانا أفضل أداءً من بروتوكول (AODV) الأصلي حيث بينت هذه النتائج انحصار واضح في عبء البروتوكول و نقص عدد رسائل طلب المسار مقارنة ببروتوكول (AODV) الأصلي . كما بينت النتائج تحسن في الزمن اللازم للحصول على مسار. و قد جاءت نسبة توصيل البيانات متقاربة بين البروتوكولين المقدمين في البحث و بروتوكول (AODV) الأصلى متقاربة بشكل كبير.

كلمات مفتاحية : شبكات لاسلكية عشوائية ، بروتوكول عن الطلب المعتمد على اقصر الطرق ، نظام تحديد المواقع ، البحث عن مسار ، رسائل طلب المسار، رسائل الرد بمسار ، زمن الحياة لرسالة طلب المسار.

ABSTRACT

Ad-hoc On-demand Distance Vector (AODV) is the most popular routing protocol for mobile ad-hoc networks (MANETs). According to its nature, AODV makes route discovery when there is data to send at source and source doesn't have route to the specified destination. To discover a route to a destination, AODV floods the network with control messages like RREQ, and RREP which may result in unnecessarily large number of control messages that travel through the network and consume network resources such as bandwidth, and node processing power. This thesis improves AODV protocol by limiting the number of AODV control messages forwarded though the network during the route discovery process. By using Global Positioning System (GPS), each node knows its location and its traveling speed stamped by time. Each source node propagates its location and speed stamped by time to other nodes in the network by adding its location information to the generated RREQ packet and HELLO messages. Each node in the network stores location information of other nodes. We propose two protocols to limit control messages flooding in the Ad-hoc networks.

The first proposed protocol which is called AODV-LAR uses alternative request region defined in LAR. It uses location information to estimate the location of the destination and then estimates the rectangular search region. To increase the accuracy of the estimation of the search region, the first proposed protocol takes into account the distance that destination node moves during discovery process by adding tolerance factor to the search region.

In the second proposed protocol which is called AODV-Line, the intermediate nodes decide to participate in route discovery process according to their distance from the line connecting the source and destination locations without the need of the information about the destination traveling speed. The route discovery search region is adjusted based on the location information of both source and destination. To reduce the delay of route discovery process, AODV-LAR defines an equation to estimate the initial TTL of the RREQ message.

We evaluate the performance of the two proposed protocols using two simulation scenarios. The simulation was done using JIST/SWANS simulator. Different performance metrics were measured including routing overhead, number of RREQ messages, delivery ratio, normalized routing load, and delay. The results were compared to the original AODV routing protocol. The results shows that the two proposed protocols outperform the original AODV, where the results report a valuable reduction of overhead , number of RREQ messages sent through the network, and reduction in delay compared to the original AODV. Results also show that the delivery ratio in the proposed protocols is comparable to the delivery ratio in the original AODV protocol.

Key Words: Ad hoc networks, AODV, GPS, route discovery, search region, RREQ, RREP, HELLO messages, TTL.

CHAPTER 1

INTRODUCTION

1.1 Chapter Overview

Nowadays, Ad-hoc Networks are one of the hottest research topics in the wireless communication area. The importance of Ad-hoc networks comes from their nature of work where they are configured without predefined infrastructure and the widely use of mobile devices like PDA's, Laptops, I-Phones, etc. An Ad-hoc network is managed by many popular routing protocols, but these protocols suffer from many problems that need to be addressed. One of the most popular and efficient protocols for Ad-hoc networks is Ad hoc On Demand Distance Vector protocol (AODV) [1][2]. In this thesis we address one of the most important problems in AODV routing protocol. High overhead is one of main problems of AODV. This overhead mainly comes from the flooding strategy used in AODV, where AODV uses flooding in instance to find new route to the destination or in the maintenance of the route when there is a link failure in intermediate nodes between source and destination [3]. There are many papers that try to solve the overhead problems in AODV and other routing protocols using location information. Location information for a node can be found by many ways, like using GPS information, smart antenna, etc.

In this thesis we will employ the location information of network nodes to develop an efficient enhanced AODV that reduces the overhead of the original AODV protocol.

1.2 Ad-Hoc Networks

A mobile ad hoc network (MANET) is an autonomous system of mobile hosts connected by wireless links. There is no static infrastructure such as base stations. Each node in the network also acts as a router, forwarding data packets to other nodes. Thus, it is a temporary network with no wires and no administration intervention required [4]. A central challenge in the design of ad-hoc networks is the development of dynamic routing protocols that can efficiently find routes between two communicating nodes. The routing protocols must be able to cope up with the high degree of node mobility that often changes the network topology drastically and unpredictably [5]. Figure 1.1 presents a simple Ad-hoc network, which consists of several wireless nodes. These nodes can be laptops, PDAs, I-Phone or any mobile devices that have wireless adapter and support for Ad-hoc.

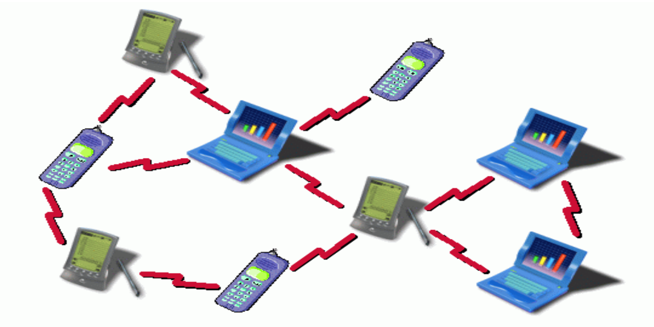

Figure 1.1: Simple Ad-hoc network

1.3 Ad-hoc Routing Protocols

Ad-hoc routing protocols are classified into three categories according to their nature of work. As figure 1.2 presents, these categories are: Flat, Hierarchical, and Geographic Position assisted Routing [6].

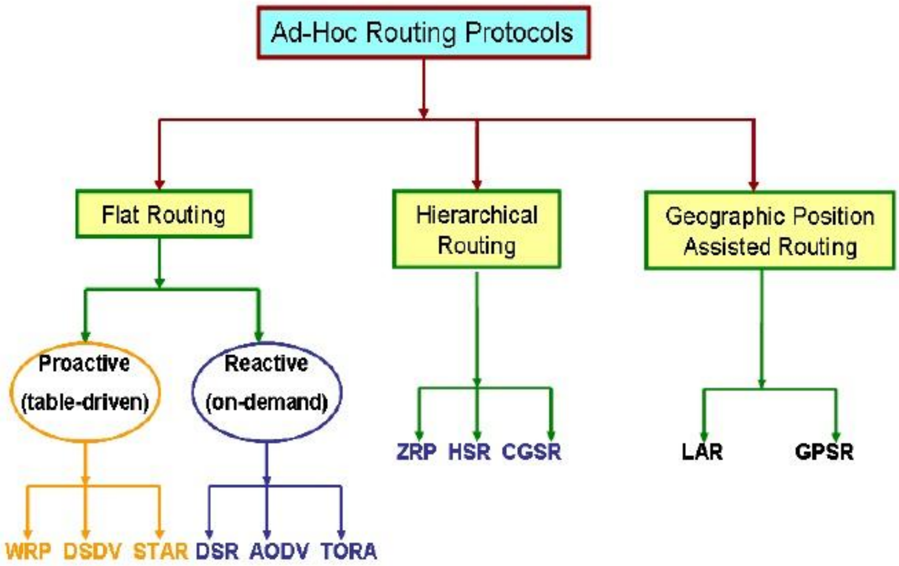

Figure 1.2: Classification of Ad-hoc routing protocols

Next subsections present a general review of these categories of routing protocol. After that we make a brief description of AODV.

1.3.1 Flat Routing Protocols

Flat routing approaches adopt a flat addressing scheme. In a flat routing protocol, all nodes serve the same set of routing functions [7][8]. The flat protocols can be roughly divided into two categories: proactive, and reactive [9].

Next subsections make a general review of the two types of flat routing protocols.

1.3.1.1 Proactive Routing protocols

Proactive routing protocols are also called table-driven protocols. This kind of protocols requires that each node maintains an up-to-date routing table periodically such that a route is ready and available when data packets need to be sent [10]. The proactive routing protocols use link-state routing algorithms which frequently flood the link information about its neighbors [11]. Each node that uses proactive routing protocols maintains one or more tables to store routing information. To adapt to changes in network topology, nodes propagate updates throughout the network to maintain a consistent view of the network. The areas in which different protocols vary are the number of necessary routing-related tables and the methods by which nodes disseminate changes in network structure. While this approach does not require global route discovery broadcasts, there are two main disadvantages [12]. First, even when the network is idle, proactive protocols exhibit a certain amount of overhead for control messages. Second, proactive protocols are relatively slow to adjust to topology changes.

The most popular proactive routing protocols are:

1. Wireless Routing protocol (WRP) [13].
2. Destination-Sequenced Distance-Vector Routing protocol (DSDV) [11].
3. Source Tree Adaptive Routing (STAR) [14].

1.3.1.2 Reactive Routing Protocols

Reactive routing protocols, are also called on-demand. In reactive routing protocols, nodes look for route to destination only on demand. Before a source node sends data to destination node, it first seeks a route in its routing table. If it finds one the communication starts immediately, otherwise the node initiates a route discovery phase. Once a route has been found and established, it is added to the node routing table and maintained until either the destination becomes inaccessible or until the route is no longer used, or expired [15]. On-demand routing protocols reduce routing overhead in high mobility environments by only maintaining actively used routes [16][17]. When a node needs to send data packets to another node and there is no route for this node in routing table then, on-demand routing protocols initiate route discovery. This discovery process is performed via network-wide flooding. But flooding consumes a substantial amount of bandwidth [18]. Reactive protocols can be classified into two categories: source routing and hop-by-hop routing. In Source routing protocols [19][20], each data packet contains the complete path addresses from source to destination. In source routing each intermediate node forwards these packets according to the information in the header of each packet. This means that the intermediate nodes do not need to maintain up-to-date routing information for each active route in order to forward the packet towards the destination. The second type is hop-by-hop routing protocols [21]. In this type of routing protocols each data packet only carries the destination address and the next hop address. Therefore, each intermediate node in the path to the destination uses its routing table to forward each data packet towards the destination. The disadvantage of this strategy [22] is that each intermediate node must store and maintain routing information for each active route and each node requires being aware of their surrounding neighbors through the use of beaconing messages which are also called Hello messages. Compared to the proactive routing protocols for mobile ad hoc networks [23], reactive routing protocols have less control overhead which is a distinct advantage of the reactive routing than proactive routing protocols. Reactive routing protocols have better scalability than proactive routing protocols in mobile ad hoc networks. But, when using reactive routing protocols, source nodes may suffer from long delays for route searching before they can forward data packets.

There are many reactive routing protocols while the most popular protocols are:

1. Dynamic Source Routing Protocol (DSR) [19][24], which is classified as source routing protocol.
2. Ad hoc On-Demand Distance Vector protocol (AODV) [23][25], which is classified as hop-by-hop routing protocol.

1.3.2 Hierarchical Routing Protocols

In this type of protocols, network nodes are organized into a smaller number of clusters; nodes inside a cluster are often disjoint [26]. In this type of routing protocols there are two components routing protocols: first component is an intra-cluster protocol that provides routes between nodes inside the same cluster. Second component is an inter-cluster protocol which operates globally to provide routes between clusters.

Each cluster designates a single cluster-head node to relay inter-cluster traffic. The main disadvantage of this type of protocols is its dependency on cluster-head which becomes traffic hot-spot and results in network congestion and single point of failure.

The most popular types of hierarchal routing protocols are:

1. Zone Routing protocol ZRP [26][27].
2. Hierarchical State Routing (HSR)[23].
3. Cluster-head Gateway Switch Routing (CGSR)[23].

1.3.3 Geographical Position Assisted Routing

The development of Global Positioning System (GPS) makes it possible to provide location information with timing [28]. This location information can be used for directional routing in Ad-hoc systems. Geographical location information can improve routing performance in ad-hoc networks. The use of location information reduces overhead by directing the routing overhead to the location of destination.

The most popular protocols of this type of protocols are:

1. Location Aided Routing Protocol (LAR) [29].
2. Greedy Perimeter Stateless Routing for Wireless Networks (GPSR) [30].

Our research idea in this thesis is to employ location information to improve AODV routing protocol by using directional routing, which leads to reduction in protocol overhead.

1.4 AODV Routing Protocol Overview

The Ad-hoc On-Demand Distance Vector protocol (AODV) is a reactive protocol designed for ad-hoc networks [21]. The main advantages of AODV are its low overhead, quick adaptation to dynamic link conditions and low processing and memory overhead. AODV uses a broadcast route discovery mechanism, and it relies on dynamically established routing table entries at intermediate nodes. The functions performed by AODV protocol include local connectivity management, route discovery, route table management and path maintenance. Local connectivity management may be summarized as follows:

Each node learns about its neighbors by either receiving or sending broadcast packets from or to their neighbors. Receiving the broadcast or HELLO message from a new neighbor or failing to receive HELLO message from a node that was previously in the neighborhood, indicates that the local connectivity has lost.

Path Discovery: The source node initiates path discovery by broadcasting a Route Request (RREQ) message to its neighbors. When a node receives a RREQ, in case it has routing information, it sends the Route Reply message (RREP) back to the destination. Otherwise, it rebroadcasts the RREQ message further to its neighbors. As the RREQ message travels from the source to the destination it automatically sets up the reverse path for all nodes back to the source. As the RREP travels back to the source, each node along the path sets up a forward pointer to the node from which the RREP cames. Each node maintains a monotonically increasing sequence number, which serves as a logical time at that node. Also, every route entry includes a destination sequence number, which indicates the "time" at the destination node when the route was created. The protocol uses sequence numbers to ensure that nodes only update routes with "newer" ones. Doing so, we also ensure loop- freedom for all routes to a destination. All RREQ messages include the originator's sequence number, and its (latest known) destination sequence number. Nodes receiving the RREQ add or update routes to the originator with the originator sequence number, assuming this new number is greater than that of any existing entry. If the node receives an identical RREQ message via another path, the originator sequence numbers would be the same, so in this case, the node would pick the route with the smaller hop count (the shortest path). If a node receiving the RREQ message has a route to the desired destination, then we use sequence numbers to determine whether this route is "fresh enough" to use as a reply to the route request. To do this, we check if this node's destination sequence number is at least as great as the maximum destination sequence number of all nodes through which the RREQ message has passed. If this is the case, then we can roughly guess that this route is not terribly out-of-date, and we send a RREP back to the originator. As with RREQ messages, RREP messages also include destination sequence numbers. Nodes along the route path can update their routing table entries with the latest destination sequence number. Path maintenance is performed in several ways.

Route Maintenance: When any node along an established path moves, so that some of the nodes become unreachable, a Route Error (RERR) message is sent to affected source nodes. Whenever a Node receives RERR it looks at the routing table and removes all the routes that contain the bad nodes. Upon receiving notification indicating a broken link, the source node restarts the path discovery process, if it still needs that route [17]. Figure 1.3 summarizes AODV the node behavior when it receives the main three types of control messages which are (RREQ, RREP, and RERR).

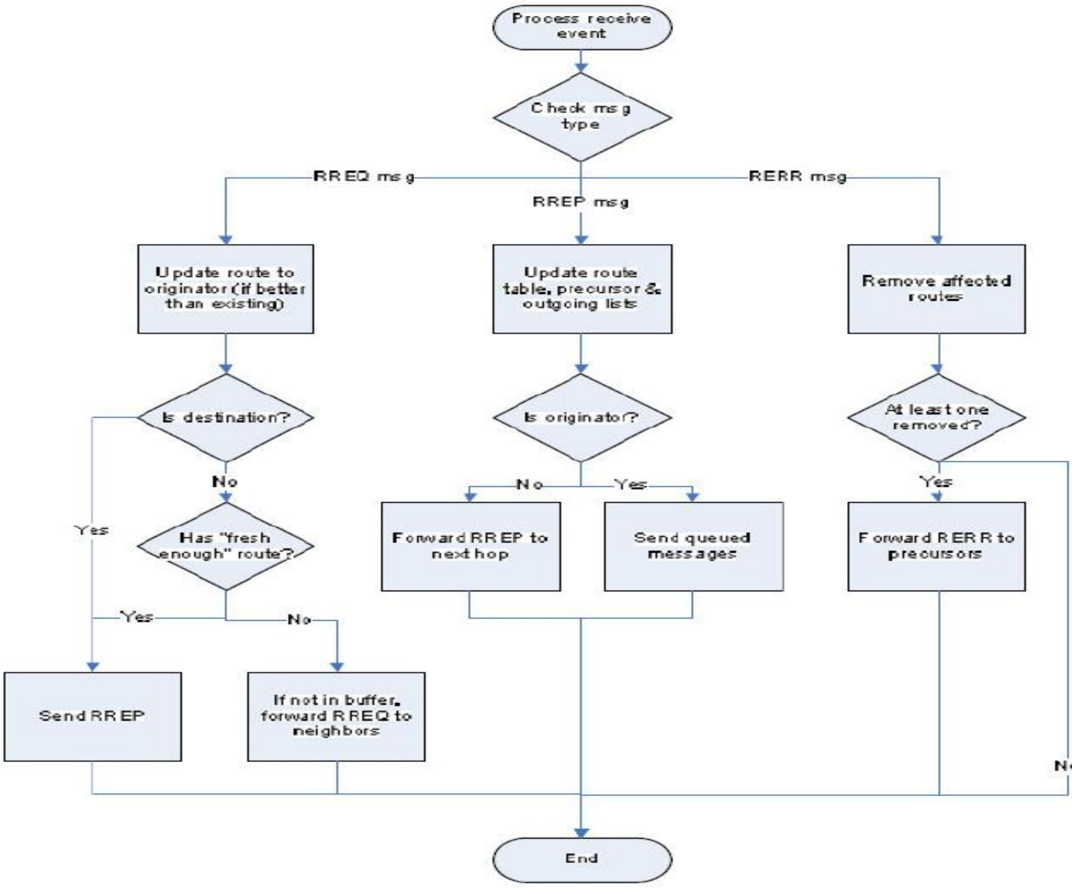

Figure 1.3: AODV flowchart[49]

1.5 Global Positioning System (GPS)

Global Positioning System (GPS) is the most popular commercial solution reliable on the market to get accurate location information. [31]. GPS [32], is composed of 24 satellites that operate in orbit around the earth. Each satellite makes two complete rotations every day. The orbits have been defined to cover the earth, where each region of the earth can see at least four satellites in the sky. By using GPS receiver, mobile devices are able to receive the information being sent by the satellites, and uses this information to estimate its distance to at least four known satellites using a technique called Time of Arrival (ToA), and, then, it computes its position. By using GPS the receiver mobile device is able to know its latitude, longitude, altitude, and speed [33]. GPS provides the most accurate technique for localization of mobile devices. GPS can normally locate a device with errors of about 10 meters [34].

As shown in [34] there are many techniques that can be used for localization like: cellular networks, Wi-Fi, and Bluetooth. While these techniques consume less power than GPS, GPS provides more accuracy in location detection than these techniques.

1.6 Random Mobility Models

The mobility model [35] plays a very important role in determining the protocol performance in mobile ad-hoc networks. Hence, this thesis proposed protocols are done using the random mobility models like Random Waypoint, Random Walk and Random Direction. These models with various parameters reflect the realistic traveling pattern of the mobile nodes. Next subsections describe three mobility models with the traveling pattern of the mobile nodes during the simulation time.

1.6.1 Random Waypoint

The Random Way Point Mobility Model includes pauses between changes in direction and/or speed [36]. A mobile node begins by staying in one location for a certain period of time (i.e. pause). Once this time expires, the mobile node chooses a random destination in the simulation area and a speed that is uniformly distributed between [min-speed, max-speed]. The mobile node then travels toward the newly chosen destination at the selected speed. Upon arrival, the mobile node pauses for a specified period of time, and then it starts the process again. The random waypoint model is a commonly used mobility model in the simulation of ad-hoc networks. It is known that the spatial distribution of network nodes moving according to this model is non uniform.

1.6.2 Random Walk

In this mobility model, a mobile node moves from its current location to a new location by randomly choosing a direction and speed in which to travel [36]. The new speed and direction are both chosen from pre-defined ranges, [min-speed, max-speed] and [0, 2*pi] respectively. Each movement in the Random Walk Mobility Model occurs in either a constant time interval 't' or a constant traveled 'd' distance, at the end of which a new direction and speed are calculated.

1.6.3 Random Direction

A mobile node chooses a random direction in which to travel similar to the Random Walk Mobility Model [37]. The node then travels to the border of the simulation area in that direction. Once the simulation boundary is reached, the node pauses for a specified time, chooses another angular direction (between 0 and 180 degrees) and continues the process.

1.7 Thesis Overview

This section presents a detailed overview about the thesis. First, we present the importance of ad-hoc networks and AODV routing protocol and explain the motivation of this thesis, the objectives to achieve, methodology used in this thesis, the contribution that are added to improve AODV protocol and finally we present the overview of this research.

1.7.1 Thesis Motivation

The wide use of ad-hoc networks even in military or civilian filed makes it a hot research topic. Ad-hoc networks are managed by many routing protocols which are classified into three categories as discussed in section 1.3. Ad-hoc On Demand Distance Vector protocol (AODV) is one of the most popular and efficient routing protocols that are used in ad-hoc networks [1][2]. AODV protocol is classified as a reactive routing protocol. In reactive routing protocols, when a node needs to send data packets to another node and there is no route for this destination node in the routing table, then the routing protocol initiates route discovery. When AODV starts route discovery process, it floods the network with control messages, which leads to reduction in its performance. Another disadvantage of AODV routing protocol is its high delay, where source nodes may suffer from long delays for route searching before they can forward data packets. In this thesis we improve AODV by limiting the routing overhead to within a specified search region, instead of flooding the whole network with control messages. This thesis uses two different search regions. To reduce route discovery delay we use an equation that makes an estimation to TTL of RREQ packets instead of starting search for a route with TTL value which is equal to one.

1.7.2 Thesis Objectives

The aim of this thesis is to improve AODV routing protocol in high mobility ad-hoc networks. Because AODV floods the whole network with control messages, its performance decreases. By using location information of both source and destination, we limit the discovery process to within a specified search region. In this thesis we have two main objectives:

1. First objective is to employ GPS location information of each node to reduce AODV overhead.
2. Second objective is to reduce the route discovery delay by estimates the TTL value of RREQ.

To achieve these goals we modify the original AODV routing protocol to deal with location information and to estimate the TTL of RREQ packets. To measure the performance metrics of our proposed protocols we use JIST/SWANS simulator [38] and two simulation scenarios. The results were compared to the results of the original AODV routing protocol.

1.7.3 Thesis Contribution

This thesis aims to reduce the overhead and delay of AODV routing protocol and to keep the delivery ratio in the same range as that of the original AODV protocol. To achieve these goals the thesis makes the following contributions:

1. Modify RREQ and HELLO messages to allow nodes to propagate thier location information by including it in the RREQ and Hello messages.

2. Reducing route discovery process overhead by limiting the discovery process to within a specified search region instead of flooding control messages to the whole network, where this done by defining two different search regions: one of them is defined as variation of the search region used in LAR protocol and the second search region is an original search region developed by the author of this thesis.
3. Increasing the accuracy of the first search region by adding a tolerance factor to increase the area of the specified search region. This increases the probability of finding the route in this search region.
4. Reducing the delay of AODV by using a new and original equation that estimates TTL of RREQ messages instead of starting with a default TTL value that is equal to one.

1.7.4 Thesis Organization

This thesis is organized as follows: Chapter 1 provides a background of ad-hoc and AODV routing protocol. It contains a brief overview of ad-hoc networks, classification of ad-hoc routing protocols, mobility models, and GPS. Chapter 1 also shows a general review of the original AODV routing protocol. Chapter 1 also includes the motivation of this thesis, research objectives, and thesis contribution. In chapter 2 we present the literature review and previous work. Our proposed work and the techniques we use to improve AODV are presented in Chapter 3. Chapter 4 discusses the results that we obtained from our proposed work. These results were obtained by employing two ad-hoc simulation scenarios. These results were compared to those results obtained from the original AODV. Conclusion and future work is presented in Chapter 5, where conclusion summaries our work, the techniques we used, the results we obtained, and finally presents recommendations for future work.

CHAPTER 2

RELATED LITERATURE REVIEW

2.1 Background

The use of location information to improve the performance of routing protocols is not new. Many research papers use location information to improve routing protocols. In this chapter we present and review the literature which is related to the use of location information to reduce routing protocol overhead and improve its performance.

2.2 GeoAODV

GPS-Enhanced AODV routing protocol (**Geo-AODV**) [39] examines a simple protocol for limiting the number of AODV control messages forwarded though the network during route discovery. GeoAODV takes advantage of the Global Positioning System (GPS) and assumes that each communicating device has GPS access and knows its location. GeoAODV is based on a variation of location aided routing (LAR) called cone-shaped request zone adaptation [40]. By using GPS coordinates, GeoAODV limits the route discovery process to the search region that is likely to contain the path to destination. Only nodes inside of the search region are allowed to rebroadcast RREQ messages during the route discovery process. In GeoAODV each node maintains an additional table, called a geo-table. Each entry in the geo-table contains such information as GPS coordinates, geo-lifetime value, and IP address of the node. The geo-table entries are populated during the route discovery process via information delivered in RREQ and RREP messages. GeoAODV limits the broadcast inside search area by using flooding angle. Upon RREQ message arrival, an intermediate node uses its coordinates and the flooding angle to determine if it belongs to the search region. If an intermediate node determines that it is located inside of the search region then it rebroadcasts the RREQ message. Otherwise the RREQ message is discarded.

2.2.1 Search Region in GeoAODV

As shown in figure 2.1, the search region in GeoAODV is defined by a flooding angle. The value of the flooding angle α, carried in the RREQ message, is a function of destination's geo-lifetime of the destination. For simplicity they define the minimum flooding angle to be 45^{o} and duplicate the flooding angle in instance of failure to find route in this search area.

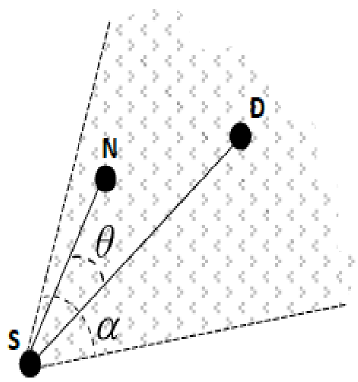

Figure 2.1: Search area of GeoAODV

To determine if an incoming RREQ message should be discarded or rebroadcast further, an intermediate node examines the angle θ formed between the source-destination and source-intermediate node vectors. If the angle θ is within half of the flooding angle then, the intermediate node is in the search region and will rebroadcast RREQ. Otherwise the intermediate node is outside of the search region and will discard the RREQ message.

GeoAODV compares its results with original AODV and the results showed that GeoAODV outperforms AODV.

But you can see that the search region defined in GeoAODV has some limitation, where it may fail in finding nodes near the vertex of the angle because the area near the angle is too small. Another limitation of this area is that the angle of the search region in opened to the end of the network boarders which leads to unnecessary overhead.

2.3 LAR Routing Protocol

Location Aided Routing protocol (LAR) [40] uses location information (which may be out of date, by the time it is used) to reduce the search space for a desired route. This limits the search space which results in fewer route discovery messages. LAR is an on-demand source routing protocol similar to DSR [41]. In LAR, each node obtains its location information from GPS. In LAR, location information is piggybacked on all messages to decrease the overhead of a future route discovery. LAR employs two schemes which use location information to limit the flooding of route discovery process.

2.3.1 LAR Schemes

LAR defines two types of schemes. The first scheme defines two types of zones called expected zone, and request zone. Figure 2.2 shows these two types of zones.

Expected zone is a zone that is expected to contain the destination node. This zone is formed as a circle. To calculate the expected zone, assume that node S knows that node D travels with average speed *v*, then S may assume that the expected zone is the circular region of radius $v(t1 - t0)$, centered at location L. for simplicity and to reduce computation overhead LAR assumes that nodes move with their maximum speed.

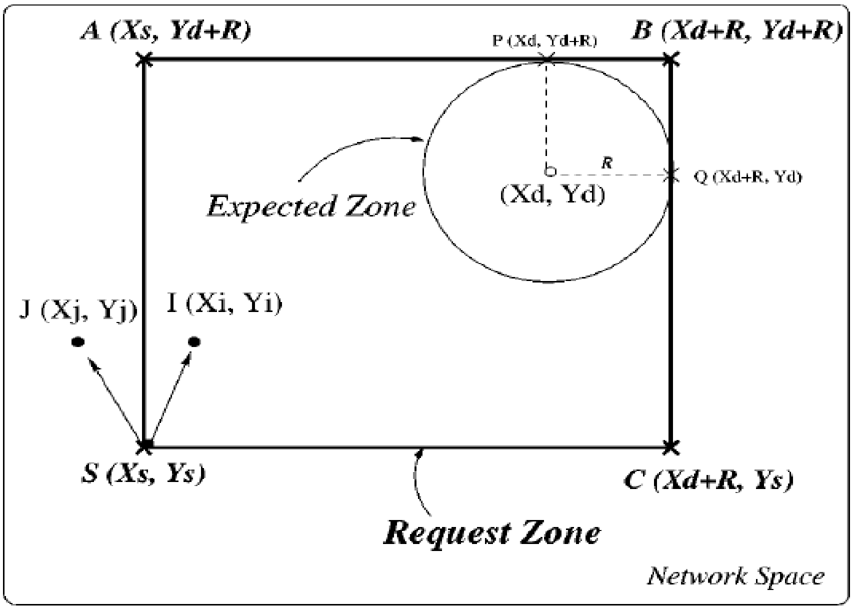

Figure 2.2: LAR zones

The Request Zone is defined to be the smallest rectangle that includes current location of S and the expected zone, such that the sides of the rectangle are parallel to the *X* and *Y* axes. To reduce route discovery overhead, nodes forward a route request only if it belongs to the request zone.

In LAR second scheme, a node forwards the route request only if it is closer to the destination than the source.

LAR defines the request zone to be the smallest rectangular that contains the source and destination, where its sides are parallel to the X and Y axes. But in reality the smallest rectangular is the one that its sides is parallel to the line connects the source and destination.

2.4 Dream Routing Protocol

In Distance Routing Effect Algorithm for Mobility (DREAM) [42][43] there is no route discovery process. Each node in DREAM routing protocol uses the destination location information to forward data messages to the direction of destination instead of initiating route discovery process. In DREAM each node maintains a location table about the position of all nodes in the network and frequently floods a location packet to its neighbors. Each location packet submitted by a node A to other nodes to update their location tables contains A's coordinates, speed and the time of the transmitted location packet. When the source node S wishes to send a message to a destination node D, it looks for its location table and retrieves information about the destination geographical position. Then S sends the message to the all one hop neighbors in the forwarding zone determined by that direction. If no location information is available for D, then S initiates recovery procedure by flooding the network to reach D. When any node A receives the message, it checks if it is the destination. If this is the destination, it sends an acknowledgement to the source node. Otherwise, A repeats the same process by sending the message to all one hop neighbors that are in the direction of D. Each of these nodes repeats the same process, if possible, until D is reached.

2.4.1 Dream Forwarding Zone

In DREAM, when the source node S needs to send a data message to D, it calculates the expected zone which contains D as shown in figure 2.3. This zone is a circle around the destination with radius r equals to $(t_1 - t_0)\ v_{max}$ where t_1 is the current time, t_0 is the timestamp of location information that S has about D, and v_{max} is the speed that D travels with. After calculating the expected zone node S defines its forwarding zone as the region enclosed by an angle whose vertex is *S* and whose sides are tangent to the expected zone calculated for *D* and then sends the packet, destined for *D*, to all its neighbors in the forwarding zone. As results shown DREAM protocol outperform DSR protocol.

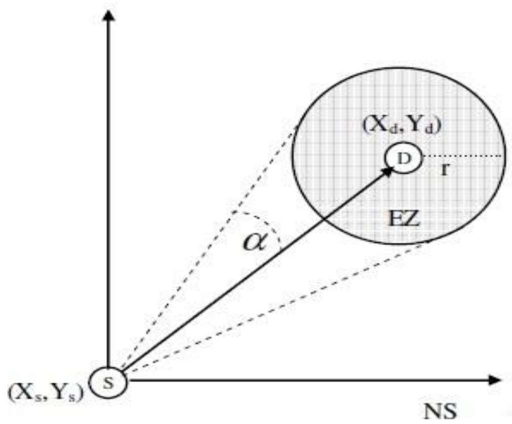

Figure 2.3: DREAM forwarding zone

2.5 GPSR Routing Protocol

Greedy Perimeter Stateless Routing for Wireless Networks (GPSR) [30][44][45] is geographical routing protocol for ad-hoc networks. GPSR uses two types of forwarding: greedy forwarding and perimeter forwarding. In greedy forwarding, packets are marked by their originator with their destinations' locations. Intermediate nodes forward a packet to next hop neighbor that is geographically closest to the destination. Whenever a message needs to be sent, GPSR tries to find a node that is closer to the destination than itself and forwards the message to that node. However, this method fails for topologies that do not have a uniform distribution of nodes or contain voids. Hence, GPSR adapts to this situation by introducing the concept of perimeter routing by utilizing the right-hand graph traversal rule. To exchange node positions, GPSR uses neighborhood beacon that sends a node's identity and its position.

While the previous related work uses location information to reduce routing overhead in mobile ad-hoc networks, there is other related work that uses variations of the previous related work or add new original contribution to the previous related work. In [46], the search area is defined as a triangular with angle α and height $SD+\sigma$. The value of the angle α is duplicated each at search attempt that results in a failure in finding route to destination. They start with small α that is equal to 45^o . The height $SD+\sigma$ is equal to the distance between source and destination plus σ, where σ varies exponentially with the number of search attempts. To decrease routing discovery delay they use an expanding search by setting the TTL value of RREQ packets according to distance between source and destination instead of using the traditional ring search. The results show that their work outperforms the original AODV.

In [47] the authors use the triangular search area like that in [46]. They divide the nodes in the network into two types, traditional nodes and backbone nodes. Backbone nodes are aware of the location of their neighbors. To reduce overhead, they divide the route discovery process into two levels. In the first level (location route) the source node initiates location discovery by asking the backbone about the location of the destination. In the second level (data route), the source node broadcasts the RREQ in the specified triangular search area. The results obtained using this proposed work outperform the results of the original AODV. Comparison between the two LAR schemes was done in [48].

CHAPTER 3

PROPOSED PROTOCOLS AND METHODOLOGY

3.1 Background

In this chapter, we present the proposed protocols and the techniques that we developed in order to reduce routing overhead in AODV routing protocol. We first start by explaining the main reason of the overhead in AODV, next we define and explain the methodologies that we use to reduce routing overhead. In our work, we depend on node location to limit route discovery process to a well-defined small search area instead of the whole network. We define two types of search areas: the first type is a rectangular area that includes source and destination, the second area is defined according to the distance between intermediate nodes and the line connecting the source and destination nodes. Also, we define a new concept to decrease route discovery delay by making an estimation to the TTL value of the RREQ packet.

3.2 Route Discovery Process in AODV

In reactive protocols like AODV, a route is discovered on demand [3]. The main reason of overhead in AODV routing protocol is the flooding that is generated due to the search for a route to destination.

As shown in figure 3.1, when a source node S requests a route to a destination D, it broadcasts a RREQ message if it doesn't have a recorded route already. This broadcast floods the network with RREQ messages. When an intermediate node receives a RREQ, it checks if it has routing information for destination, if it has it sends the Route Reply message (RREP) back to the destination. Otherwise, it rebroadcasts the RREQ message to its neighbors. As the RREQ message travels from the source to the destination, intermediate nodes set up the reverse path to the source. As the RREP packet travels back to the source, each node along the path sets up a forward pointer to the node from which the RREP came and cache the routes for source and destination. Note that if many intermediate nodes have a route to destination they will send back RREP packets, so the source may receive many RREP packets for the same destination. In this case the source will keep only the shortest route path to destination.

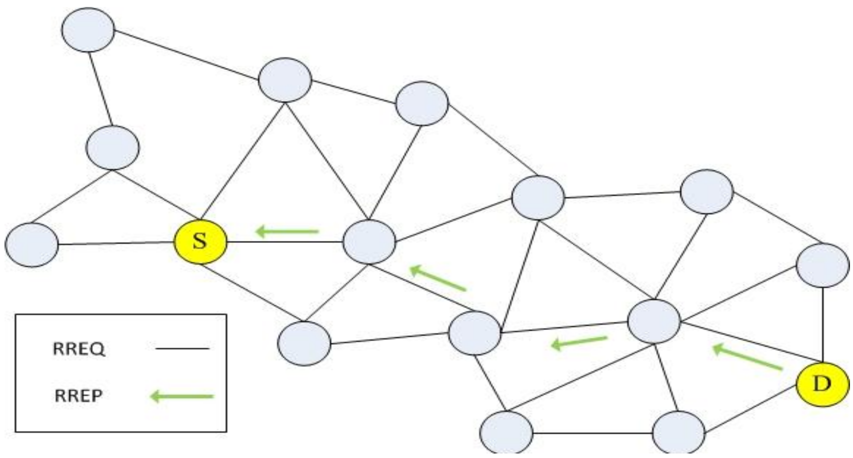

Figure 3.1: Route discovery storm in AODV

This behavior of route discovery makes a storm of RREQ and RREP messages which leads to unnecessary increase of overhead in AODV routing protocol. This overhead decreases the performance of AODV and makes the network flooded with RREQ and RREP especially for dense and high mobility networks. One solution to avoid this storm is ring expanding search [46][49][50]. In ring search the assumption is that the intermediate nodes may have fresh route to destination or the destination is close to the source. In ring search, the source node broadcasts the RREQ messages with a small TTL value; if no response is received it rebroadcast the same RREQ with an incremented TTL and new sequence number; if still no response is received then the node continues to send RREQ messages with an increased TTL and new sequence number; this process continues until the TTL reaches a threshold; when this threshold is crossed then it means that destination doesn't exist within the network and this RREQ is simply dropped. But ring search suffers from the long delay due to sending multiple RREQ messages and waiting for reply and sending new RREQ messages with new larger TTL due to failure of finding the route to destination. Flowcharts in figures 3.2 and 3.3 explain the tasks done by source node and intermediate nodes respectively in AODV.

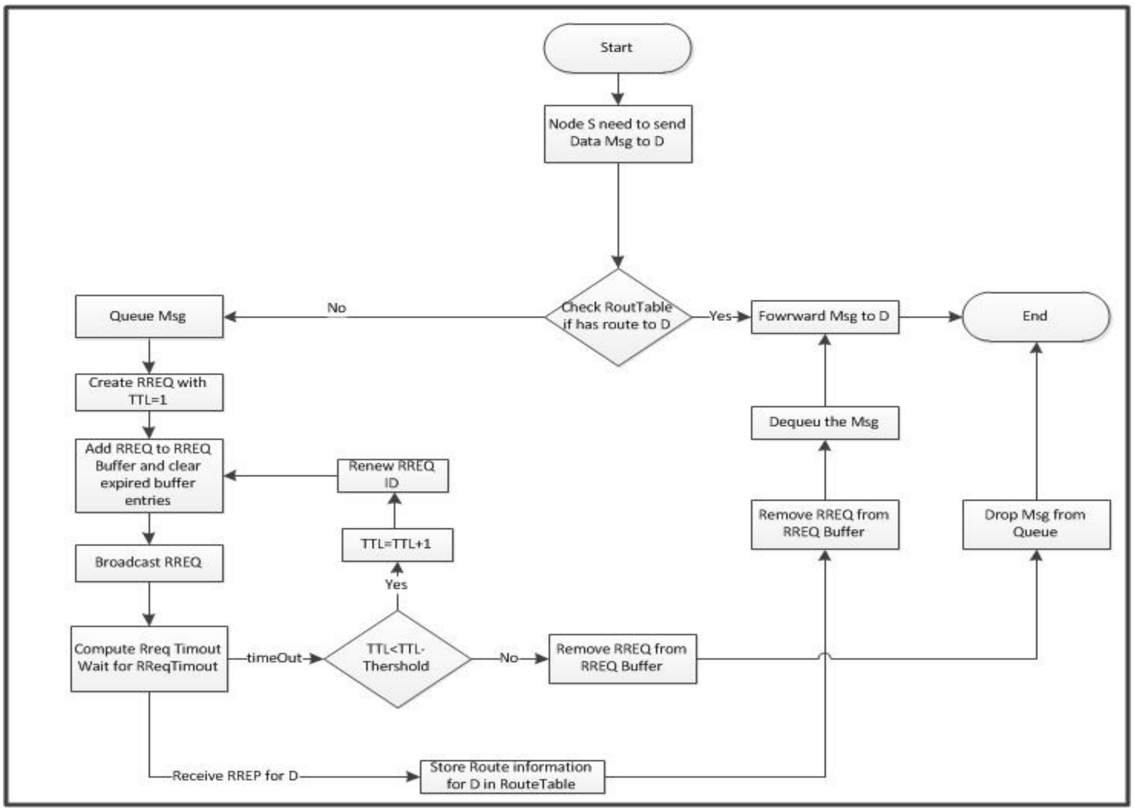

Figure 3.2: Flowchart of route request process at source in AODV

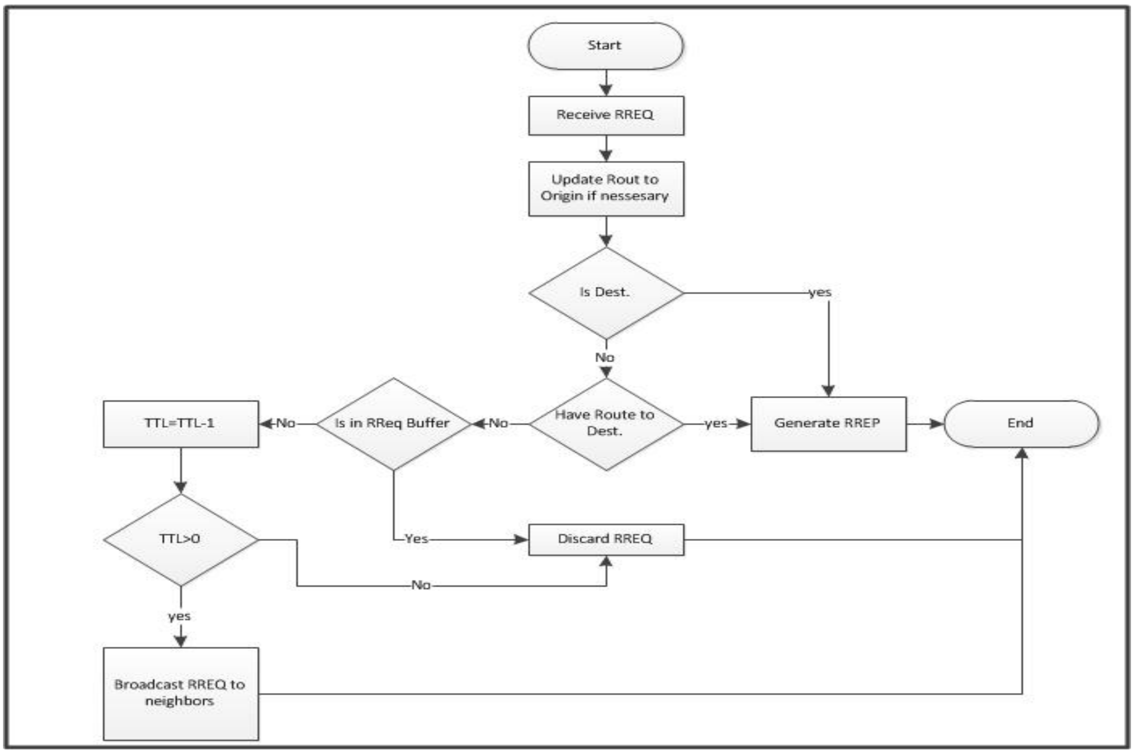

Figure 3.3: Route request process at intermediate node in AODV

3.3 Proposed Protocols

In this section, we present two proposed protocols to reduce routing overhead in AODV protocol. The reduction is done by limiting the route discovery process to within a small search area instead of the whole network. This area is formed according to the location information of source and destination. We assume that each node has a GPS [33] device so each node knows its current location and speed. We propose two protocols to improve AODV protocol. The first one uses an alternative search area to that defined in LAR [29]. This search area has not been proposed before for AODV. This protocol is called AODV-LAR. The second protocol uses a search area that is based on the distance between the intermediate nodes and the line connecting the source and destination. This protocol is called AODV-Line. To reduce route delay we define a new original equation to estimate the TTL value of RREQ message.

3.3.1 AODV-LAR Protocol

The main reason of high overhead of AODV routing protocol is the flooding of control messages in order to make route discovery. When any node needs to send data to a specified destination and it doesn’t have an already discovered route to this destination, it floods the whole network with RREQ messages. Intermediate nodes my respond by many RREP messages. This route discovery process leads to unnecessary routing overhead. If we know the location of destination we can reduce this overhead by restricting the flooding of RREQ messages to within a small area of the network.

In this subsection, we present an enhancement to the original AODV routing protocol by using a variation of LAR scheme [29]. This enhancement protocol is called AODV-LAR. The main idea of this enhancement is to restrict the flooding of RREQ messages to within a rectangular area that contains the source and destination.

Figure 3.4 shows the route search area of AODV-LAR as a rectangle. In AODV when a source node S needs to discover a route to a destination D it floods the working area with RREQ packets and it may receive many RREP messages which leads to high overhead. But in the proposed AODV-LAR protocol, if S knows the location and speed of D at a specified time t_0, it can restrict the flooding to within a restricted area instead of the whole network. This restricted area is shown figure 3.4 as a red rectangle. The sides of the rectangular area are parallel to the line connecting S and D. Note that the length of the rectangular area depends directly on the distance between S and D, where the width of the rectangular area depends on the traveling speed of D and the time of the freshness of the location record of D. From the figure we see that the flooding of RREQ messages is restricted to within the red rectangle. In AODV-LAR protocol the intermediate nodes rebroadcast the RREQ messages if and only if they lie inside the red rectangle.

As a result of the restricted flooding to within a small area of the whole network, the RREP messages are sent back to S just by the nodes inside the red rectangle. By using AODV-LAR we grantee to reduce the overhead caused by the flooding of RREQ packets process in AODV.

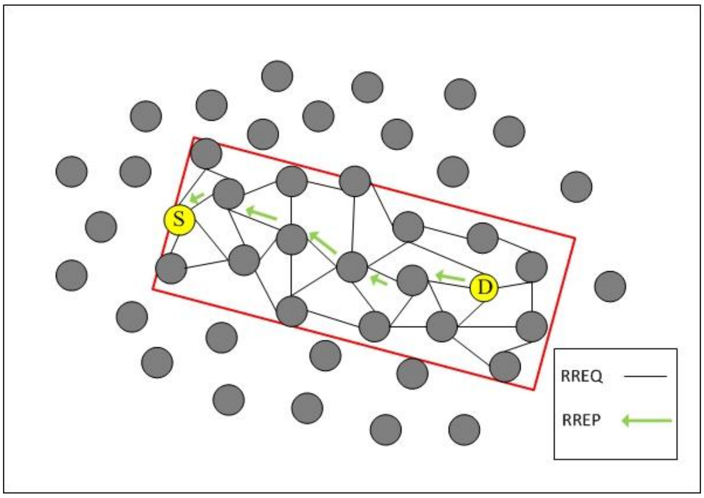

Figure 3.4: Restricted flooding of AODV-LAR

3.3.1.1 AODV-LAR Expected Region

The expected region of the destination node in AODV-LAR is formed as a circle centered at D with radius α. Suppose that the source node knows the location and speed of destination D at some time t_0. But at time t_1 the destination location of D is changed according to its movement. For this reason the source node calculates the expected region of the destination node.

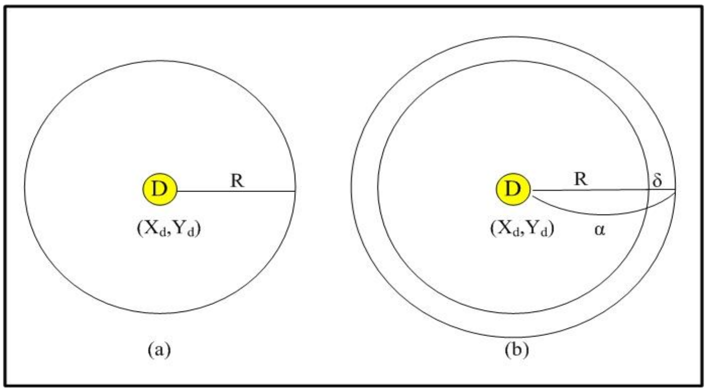

Figure 3.5: (a) LAR expected region, (b) AODV-LAR expected region

The expected region shown is figure 3.5(a) is LAR [29] expected region. The radius of the circle is calculated by equation 3.1.

$$R = (t_1 - t_0)v_{\max} \tag{3.1}$$

Where in equation 3.1:

t_1 is the current time

t_0 is the time of the last known location of D and

v_{max} is the maximum traveling speed of D

Then, the expected region of node D, from the viewpoint of node S at time t_1, is the region that node S expects to contain node D at time t_1.

To add more accuracy and to reduce the overhead, AODV-LAR uses the average node speed instead of maximum node speed. Also we know that the destination node D still moves during the route discovery process, so we add a tolerance factor σ. The expected region of AODV-LAR shown in figure 3.5(b) is a circle centered at D with radius α= (R+ σ) where R is the distance that D travels after (t_1- t_0) time, where t_1 is the current time and t_0 is the time of the last known location of D. Then R is calculated by using the equation 3.2.

$$R = (t_1 - t_0)v_{\text{avg}} \qquad (3.2)$$

Where in equation 3.2: v_{avg} is the average speed of D

To add more accuracy and more reduction of overhead we use v_{avg}, while LAR uses v_{max} which gives larger expected region which leads to more increase in overhead.

The tolerance factor σ is defined as the distance that node D travels until the RREQ message arrives to D. To calculate this tolerance factor we assume that the intermediate nodes that can form the route to D form a straight line. But this straight line may contain infinite number of nodes. For this reason we use the minimum number of hops that can form a straight line route between S and D. Figure 3.6 explains this process. In this figure the transmission range of each node is formed as a circle around that node. Suppose that the transmission range of each node is T. Each node in the figure is inside the coverage area of its previous and next node.

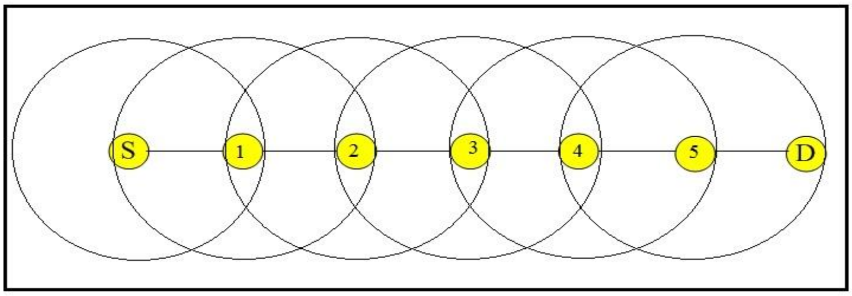

Figure 3.6: Minimum number of hops to form a route

Then the minimum number of hops needed to form a route between S and D is calculated according to equation 3.3.

$$H_{\min} = \frac{\mathrm{D}}{\mathrm{T}} \tag{3.3}$$

Where in equation 3.3: D is the distance between S and D

Assume that the time needed by each node to process the RREQ message is *RREQ_Proc_Time*, then the time needed until RREQ message arrives to D is shown in equation 3.4.

$$t_{\text{tol}} = RREQ\_Proc\_Time * H_{\min} \tag{3.4}$$

Then the tolerance factor σ which is the distance which D travels until RREQ arrives to D is shown in equation 3.5.

$$\sigma = t_{\text{tol}} * v_{\text{avg}} \tag{3.5}$$

From the previous equations we see that the expected region of the destination node in AODV-LAR is a circle with radius α where:

$$\alpha = \sigma + R \tag{3.6}$$

3.3.1.2 AODV-LAR Search Area

To restrict the flooding of route request packets in AODV-LAR, we restrict the flooding to within a small area. This area is always smaller than the whole working area of the network. This AODV-LAR search area is defined as a rectangular area that contains the source node and the expected region of the destination node. The sides of this area are parallel to the line connecting source and destination nodes. The search area of AODV-LAR is shown in figure 3.7. In this figure we see the AODV-LAR search area, where it contains the source node S and the expected range of the destination node D. The sides of this rectangular area are parallel to the line connecting S and D. The length of this rectangular area is (SD+α), where SD is the distance between S and D and α is the radius of the expected region of D defined in equation (3.6). The width of this rectangular area is 2α.

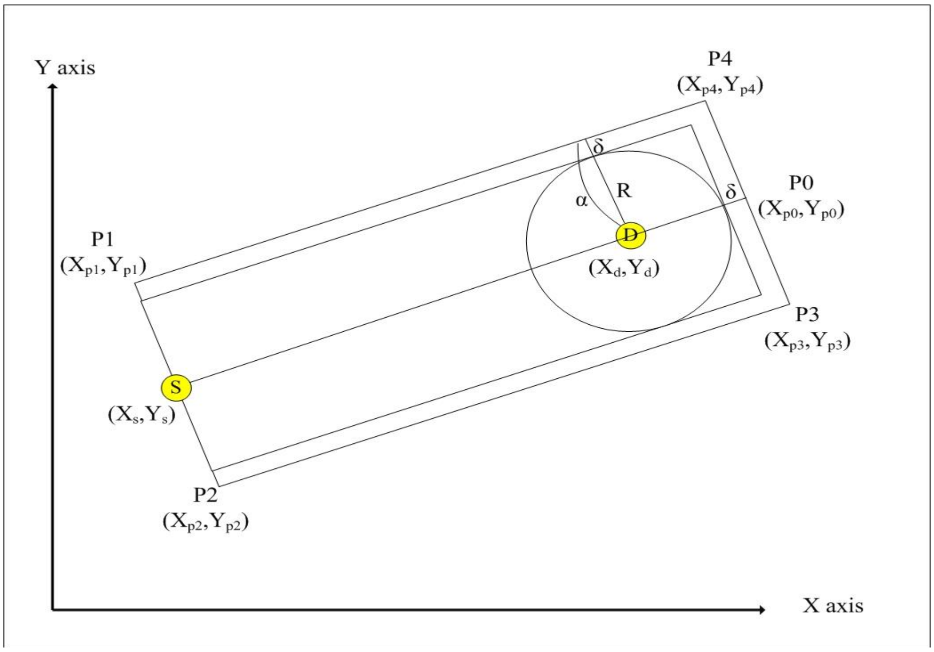

Figure 3.7: AODV-LAR search area

In order to determine whether to rebroadcast RREQ messages, each intermediate node must test if it is inside the rectangular area or not. If the intermediate node lies inside this rectangular area then it rebroadcasts the RREQ message. Otherwise, it does not rebroadcast the RREQ message. This leads to reduction in control overhead. In order for the intermediate node to do this test, each node has to know the corners of this rectangular area. As figure 3.7 shows, the rectangular area is formed by the four corners P1, P2, P3, and P4.

Each point is defined by its coordinates (x, y). We already know the coordinates of S and D. Then by using the coordinates of S and D we have to find the coordinates of the four points P1, P2, P3, and P4 that form the search area. The slope of the line SD is:

$$\mathrm{m} = \frac{Y_\mathrm{s} - Y_\mathrm{d}}{X_\mathrm{s} - X_\mathrm{d}} \qquad (3.7)$$

Note that the line P_1P_2 is orthogonal on line SD. Then, the slope of the line P_1P_2 is:

$$m_0 = -\mathrm{m} \qquad (3.8)$$

But the slope is the ratio of the change in Y over the change in X. Then the coordinates of the point P_2 is (X_s+ λ, Y_s+ λ m_0). Since the distance between S and P_2 is α where α is given by equation 3.9.

$$\alpha = \sqrt{(}\lambda\lambda + \lambda m_0 \ * \lambda m_0 \ ) \qquad (3.9)$$

By rearranging the equation (3.8), we obtain the equation of λ as shown in equation 3.10.

$$\lambda = \frac{\alpha}{\surd(1+m_0 \ *m_0 \ )} \qquad (3.10)$$

Now the value of λ is known, then we compute the coordinates of P_2. By the same steps we find the coordinates of the other corners of the search area. the coordinates of P1, P2, P3, and P4 are listed in equation 3.11.

$$\begin{aligned} P_1 &=(X_s- \lambda, Y_s- \lambda\ m_0) \\ P_2 &=(X_s+ \lambda, Y_s+ \lambda\ m_0) \\ P_3 &=(X_{p0}+ \lambda, Y_{p0}+ \lambda\ m_0) \\ P_4 &=(X_{p0}- \lambda, Y_{p0}- \lambda\ m_0) \end{aligned} \qquad (3.11)$$

The coordinates of P_0 are (X_{p0},Y_{p0}) which are equal to $(X_d- \lambda, Y_d- \lambda\ m)$.

3.3.1.3 Intermediate Node Test

In AODV-LAR, each node that receives the RREQ messages must test if it lies inside the search area or not before it rebroadcasts the RREQ message.

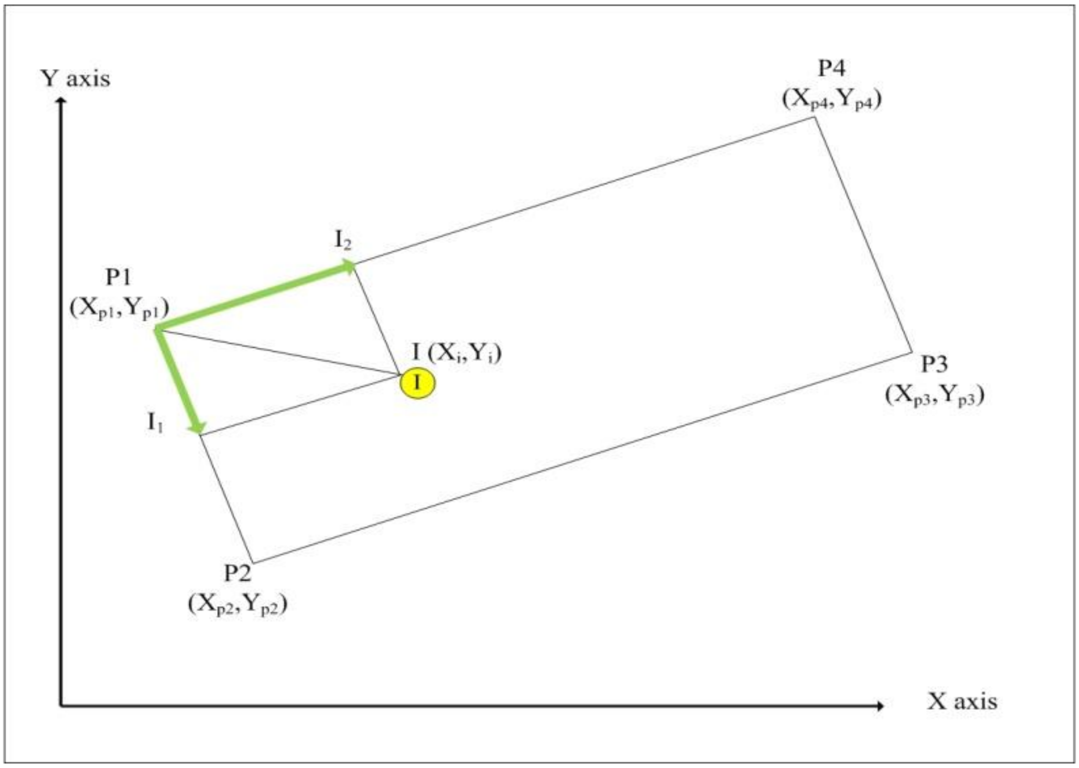

Figure 3.8 AODV-LAR intermediate node test.

Each node knows its coordinates and the coordinates of the four points that form the rectangular search area. For test whether the node is inside the search area, we use dot product [51]. As shown in figure 3.8, the intermediate node “I” lies inside the rectangular area. But how node “I” knows if it lies inside the rectangular area or not?. The green vectors in figure 3.8 are the projection of the vector P_1I on both vectors P_1P_2 and P_1P_4**.** But in reality, this projection is the dot product of P_1I and the two vectors P_1P_2 and P_1P_4. This projection of P_1I onto P_1P_2 and P_1P_4 is the length of the segments P_1I_1 and P_1I_2. Then, if the node "I" lies inside the rectangular area it must satisfy the following conditions:

1. The length of the projection of the vector P_1I on P_1P_2 is less than the length of the vector P_1P_2 and is in the same direction of P_1P_2.
2. The length of the projection of the vector P_1I on P_1P_4 is less than the length of the vector P_1P_4 and is in the same direction of P_1P_4.

We know that the direction of the projection of P_1I is in the same direction as P_1P_2 and P_1P_4. If the result of this projection is greater than zero, then any point satisfies equation 3.12 lies inside the rectangular search area.

$$\begin{gathered} 0 \leq (P_1I \bullet P_1P_2) \leq (P_1P_2 \bullet P_1P_2) \\ 0 \leq (P_1I \bullet P_1P_4) \leq (P_1P_4 \bullet P_1P_4) \end{gathered} \tag{3.12}$$

Where in equation 3.12:

$(P_1P_2 \bullet P_1P_2)$ is the length of the vector P_1P_2.

3.3.1.4 Node Participation in Route Discovery Process

According to the proposed route discovery mechanism in AODV-LAR, there are three types of node participation. Each node inside the working area decides its degree of participation according to its location. Figure 3.9 explains this process.

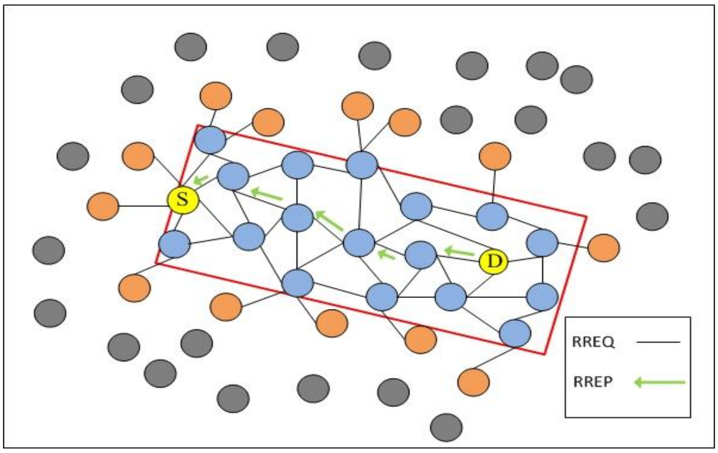

Figure 3.9: Node participation in AODV-LAR route discovery process

According to the figure there are three types of participating nodes as follows:

1. Nodes that can receive and rebroadcast RREQ packets and may reply with RREP packets. These nodes lie inside the rectangular search area and appear in figure 3.9 with blue color.
2. Nodes that can receive RREQ packets and may reply with RREP packets but don’t rebroadcast RREQ packets. These nodes lie outside the search area and are covered by the transmission range of some nodes inside the search area. These nodes appear in figure 3.9 with orange color.
3. Nodes that don’t participate in route discovery process. These nodes appear in the figure with gray color.

3.3.1.5 TTL Estimation

In route discovery process in AODV, the source node floods the network with RREQ messages and may receive many RREP messages which leads to high overhead. The main reason of flooding the whole network with RREQ is to decrease the delay of route discovery process. One solution to avoid this flooding storm is ring search, which is described in section 3.2. In ring search, the assumption is that the intermediate nodes may have fresh route to destination or the destination is close to the source. For this reason the route discovery process in ring search starts with small TTL which is usually equal to 1. If route discovery fails, the source initiates a new route discovery process with new RREQ and larger TTL. To make tradeoff between the flooding search and ring search we need to make an optimal estimation of TTL. This estimation decreases the overhead caused by search flooding process and decreases the delay caused by ring search. The estimation of TTL depends on the location of source and destination. As described in section 3.3.1.1, we see that the minimum hop count that can form a route between the source and destination is given by equation (3.3).

Then we estimate the starting initial TTL value to be equal to the minimum hop count where:

$$TTL = H_{\min} = \lfloor \frac{\mathrm{D}}{\mathrm{T}} \rfloor$$

But we know that the intermediate nodes may have fresh route to destination which may lead to unnecessary overhead. For this reason we estimate the starting TTL value to be the half of minimum hop count, i.e.:

$$TTL_{\text{start}} = \left\lfloor \frac{\mathrm{D}}{2\mathrm{T}} \right\rfloor \tag{3.13}$$

3.3.1.6 Location Management in AODV-LAR

We assume that each node in the network has a GPS device, where GPS receivers are thin, light and not expensive [47]. These receivers can be easily embedded in nodes to determine their coordinates (x, y) and their speed. GPS also provides the nodes with time. We use GPS because of its accuracy, where GPS provides the most accurate technique for localization of mobile devices [34]. Another reason of using GPS is that GPS provides nodes with time, so no time synchronization is needed between nodes.

Nodes distribute their location by adding their location information to RREQ and Hello messages. Each node in the network manages a location table to store location information of other nodes inside the network.

3.3.1.6.1 Modification of RREQ and Hello Messages in AODV-LAR

In AODV-LAR protocol, nodes distribute their location information by adding the location information to RREQ and Hello Messages. To add location information in RREQ and Hello messages, we need to modify the format of these messages. The location information contains three fields which are:

1. Source location
2. Source average speed
3. Time stamp

But we also need to add the corners of the search area to the RREQ messages to restrict flooding to within this rectangular search area which is defined by its four corners. By adding the corners of the search area we explicitly define the search area. Another solution is to implicitly define the search area by just adding the location information of destination inside RREQ message and let each intermediate node compute the corners of the search area. But this solution leads to more consumption in node resources and increases the delay. So we decide to explicitly define the search area by adding its corners to the RREQ message.

Note that the felids of source location and the four corners of the search area consist of the X and Y coordinates**.**

3.3.1.6.2 Location Table Management in AODV-LAR

Each node in AODV-LAR manages a location table. The location table is used to store the location information of the nodes inside the network. Each entry of this table consists of location information of one node in the network. As shown in figure 3.10, The location table entry consists of four fields: Node Address, Node Location, Source Average Speed, and Time Stamp.

Node Address	Node Location	Source Avg.Speed	Time Stamp

Figure 3.10: Location table entry in AODV-LAR

When a node receives a RREQ or HELLO message, it modifies or adds an entry to its location table. The time stamp of the location entry refers to freshness of that entry. If the location table of the node that receives the RREQ or HELLO message doesn’t have a location entry of the node that originates the

RREQ or HELLO messages, then it simply adds the entry to its table. When the location table of the node that receives the RREQ or HELLO message has a location entry of the node that originates the RREQ or HELLO messages, then, the reshness of the location information determines whether it needs to update the entry or not.

3.3.1.7 AODV-LAR Route Discovery Process

In this subsection, we summarize all the events of the discovery process in AODV-LAR. New modifications were added to the original AODV. This leads to changes in the events of the route discovery process. To understand these modifications see figure 3.11 and figure 3.12. As shown in figure 3.11, when the source S has data to send to destination D, it first checks if it has a route to D in its routing table. If so, it directly forwards the message to D. If it does not have a route to D, it initiates a route discovery process. S first checks if it has the location information of D. If it has the location information of D, then S computes the search area corners and TTL estimation. Then S creates a new RREQ and adds the search area, estimated TTL, and its location information to that RREQ packet, then it broadcasts the RREQ to the defined search area. If S doesn't have information location of D then the route discovery process uses ring search by setting TTL to 1 and incrementing TTL by 1 for each failure in finding a route to D. During ring search, if S receives location information of D, it computes the search area and the estimated TTL and adds them to the next RREQ packet to restrict the search to within the rectangular search area. The intermediate node behavior is shown in figure 3.12 which is similar to the behavior in original AODV expect that the intermediate node in AODV-LAR updates its location table by updating the location information of S, and doesn’t broadcast RREQ packets if it lies outside the defined search area. If the RREQ packet doesn’t define a restricted search area, then any node can broadcast RREQ packet if it is not expired. The expiration of RREQ packet is defined by its TTL. If TTL is greater than zero, then nodes can broadcast the RREQ packet to its neighbors.

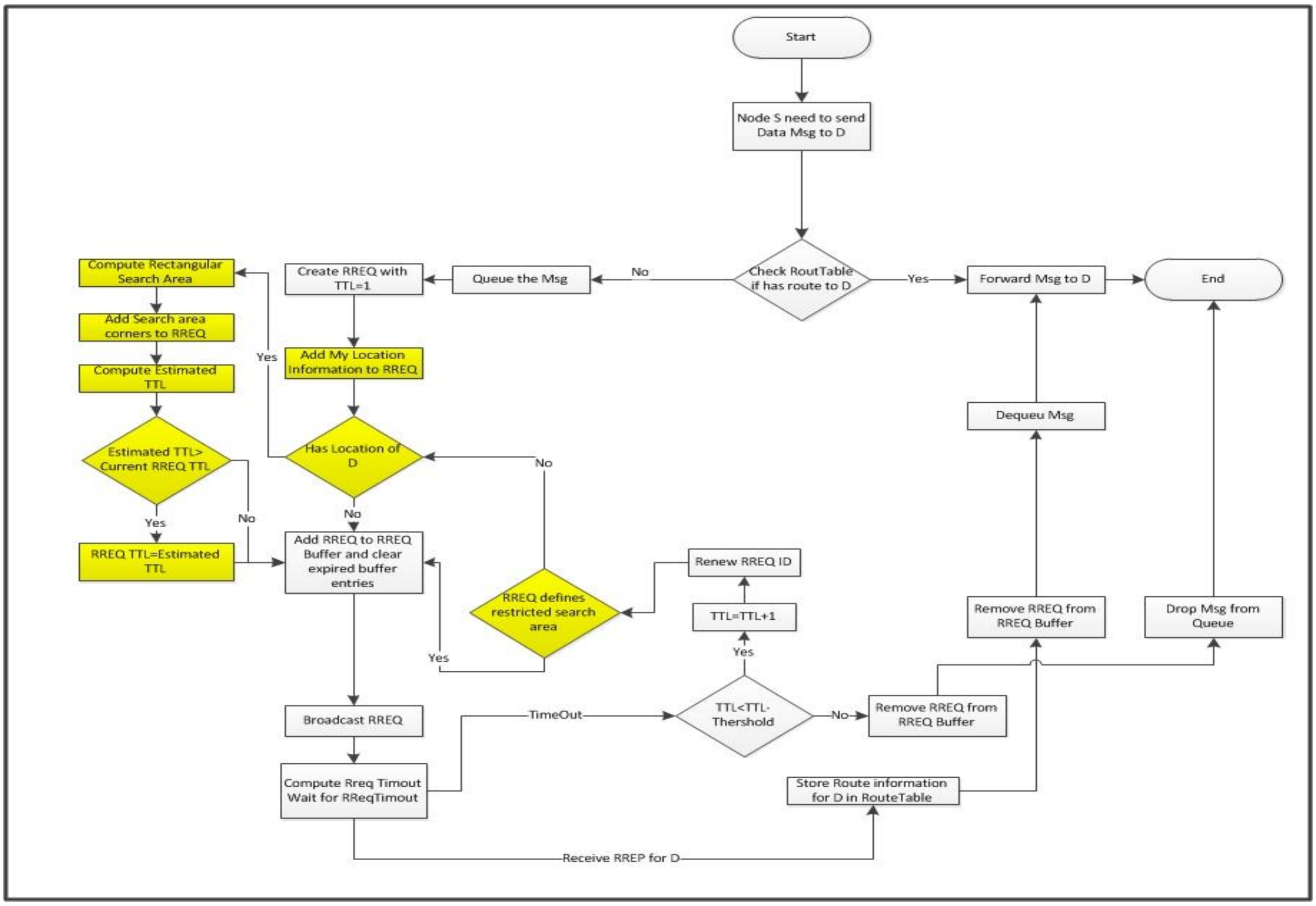

Figure 3.11: Route request process at source node in AODV-LAR

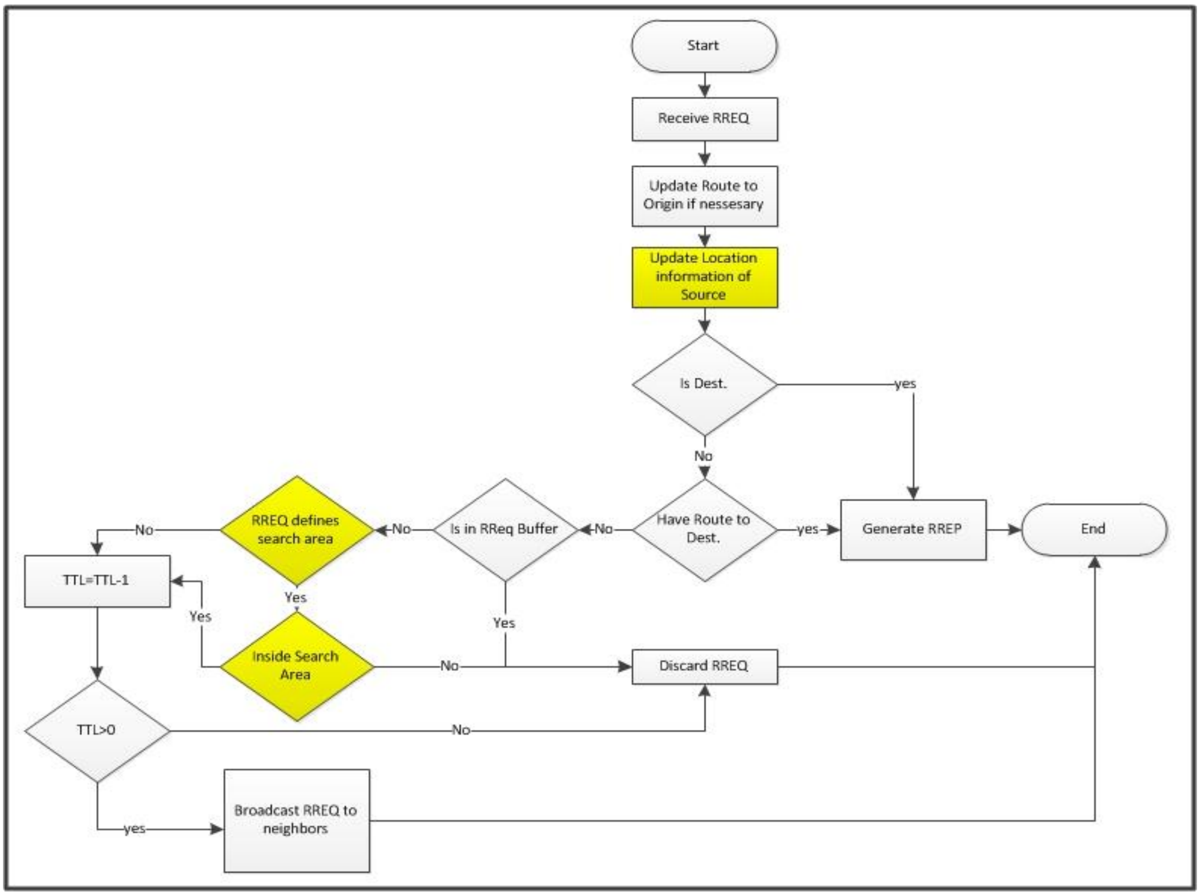

Figure 3.12: Route request process at an intermediate node in AODV-LAR

3.3.2 AODV-Line

In this subsection we present a new improvement to the original AODV routing protocol by restricting flooding of the RREQ packets to decrease the routing overhead. This improved protocol is called AODV-Line. The main idea of this modification is to restrict the flooding to be just near the line that connects the source and destination. As figure 3.13 shows, we see the whole working area inside a black rectangular area. In AODV, when a source node S needs to discover a route to a destination D, it floods the working area with RREQ packets and may receive many RREP packets which leads to high control overhead. But in AODV-Line, if S knows the location of D it can restrict the flooding to be near the line that connects source and destination. To restrict flooding, each node decides to rebroadcast RREQ packets according to its distance from the line that connects S and D and the distance between itself and the destination node. As a result of restricted flooding, RREP packets are sent back to S just by the nodes that are located within a specified distance from the line that connects S and D or by the nodes that are covered by those nodes. As figure 3.13 shows, the blue nodes satisfy the distance condition and the orange nodes are covered by the blue ones. Only the blue nodes can rebroadcast the RREQ messages while the blue and orange nodes can reply with RREP messages.

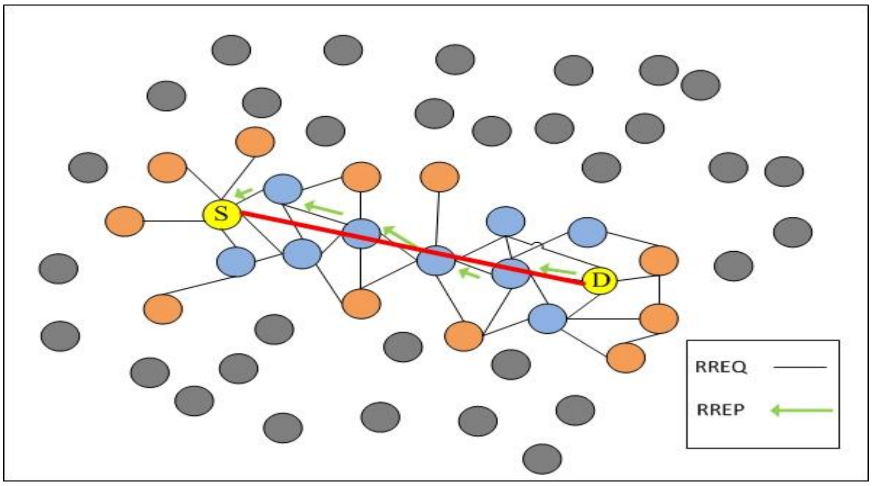

Figure 3.13: Restricted flooding of AODV-Line

3.3.2.1 AODV-Line Search Area

To restrict the flooding of route request process in AODV-Line, we restrict the flooding to be within a small area. This area is always smaller than the working area of the whole network. AODV-Line search area is defined by a specified distance from the line connecting the source and destination. The search area of AODV-Line is shown in figure 3.14. Each node that has a distance from the line that connects S and D which is less than $\boldsymbol{W}$ can rebroadcast the RREQ packet. We need to know the appropriate value of $\boldsymbol{W}$.

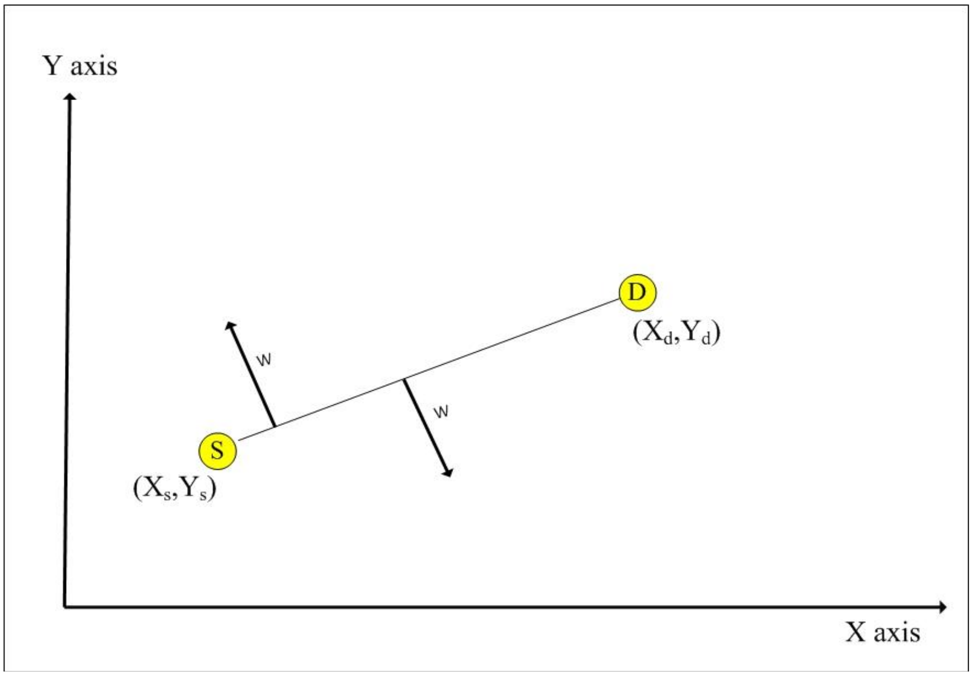

Figure 3.14: AODV-Line search area

In AODV-Line the value of $\boldsymbol{W}$ must be large enough to contain enough number of nodes to form a route to D. For this reason we assume that the route is formed by nodes that lie at a straight line between S and D. Then the minimum number of nodes required to form this route is defined as shown in figure 3.6. and equation 3.3 where:

$$H_{\min} = \frac{\mathrm{D}}{\mathrm{T}} \tag{3.14}$$

where D is the distance between S and D and T is the node transmission range. Suppose that the node density inside the working area is σ and nodes are uniformly distributed, then we need ***W*** that forms a rectangular area that contains the minimum number of nodes that can form a straight line route between S and D.

The area of this rectangular area ***A*** is defined as in equation 3.15.

$$A = 2WD \tag{3.15}$$

According to our assumption that nodes are uniformly distributed inside the working area, then the number of nodes inside ***A*** can be found according to equation 3.16.

$$H_{\mathrm{num}} = A\sigma = 2WD\sigma \tag{3.16}$$

But we need to find at least H_{min} nodes inside A then:

$$H_{\mathrm{min}} = \frac{\mathrm{D}}{\mathrm{T}} = 2WD\sigma \tag{3.17}$$

By rearranging equation 3.17 we can define ***W*** as shown in equation 3.18.

$$W = \frac{1}{2\mathrm{T}\sigma} \tag{3.18}$$

From equation (3.18) we see that ***W*** doesn't depend on the distance between S and D but ***W*** is a function of node density and node transmission range.

3.3.2.3 Intermediate Node Test in AODV-Line Protocol

In AODV-Line each node that receives the RREQ message must test its distance from the line that connects source and destination locations and its distance from the destination node before it decides to rebroadcast RREQ message or not. If the node lies at a distance less than the specified distance in RREQ and its distance from destination is less than the distance between source and destination, it rebroadcasts the RREQ message. Each node knows its coordinates and the coordinates of source and destination. Then each intermediate node can find the equation of the line connecting source and destination.

The general form of the liner equation is as shown in equation 3.19.

$$aX+bY+C=0 \tag{3.19}$$

As shown in figure 3.15., we know the coordinates of source node S and destination node D. Then by using these coordinates we need to find the equation of the line SD.

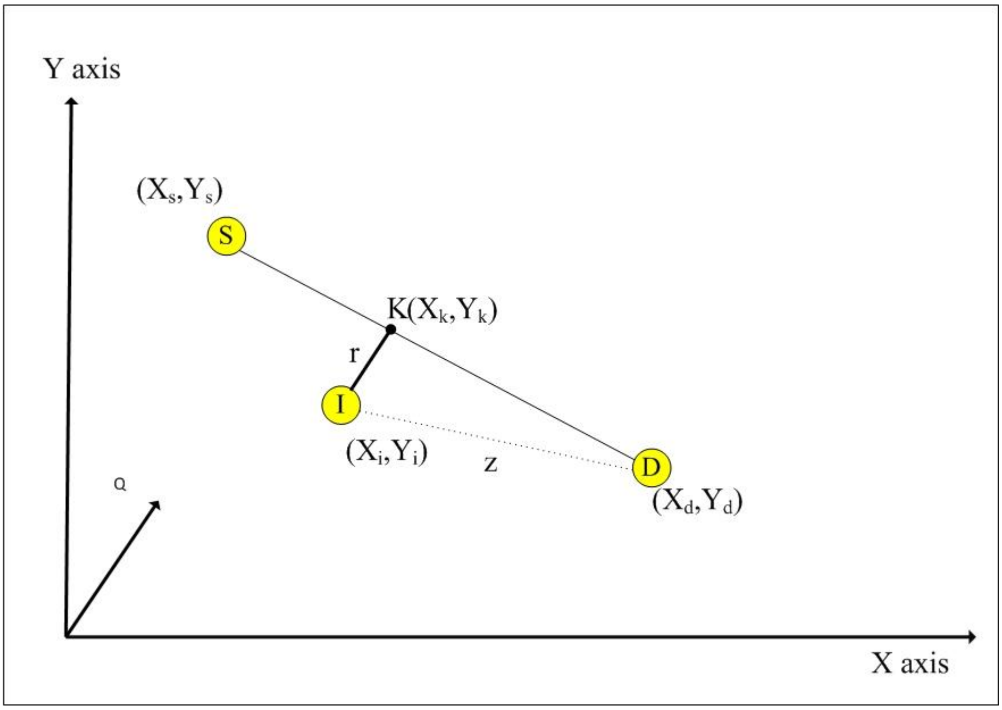

Figure 3.15: Intermediate node test in AODV-Line.

The slope of the line SD is as shown in equation 3.20.

$$m = \frac{Y_s - Y_d}{X_s - X_d} \tag{3.20}$$

Then the slope of the line SD is:

$$(Y\text{-}Y_s)= m(X\text{-}Xs) \qquad (3.21)$$

By rearranging equation 3.21 we obtain the general form of the equation of SD, as shown in equation 3.22.

$$\begin{gathered} aX+bY+C=0\text{ , where} \\ a=m, \\ b=-1 \\ c= -(m.X_s\text{-}Y_s) \end{gathered} \qquad (3.22)$$

After the intermediate nodes find the equation of line SD, then they measure their distance from the line SD. The point K at the line SD at figure 3.15 is the intersection of the vector that passes through the intermediate node "I" and perpendicular to the line SD. The length of the vector "IK" is the shortest distance between node "I" and the line SD. But we need to find the equation that calculates this distance. For this reason we write the equation of the line SD in a normalized form as shown in equation 3.23.

$$\frac{a}{\sqrt(a^2+b^2)}X+\frac{b}{\sqrt(a^2+b^2)}Y+\frac{a}{\sqrt(a^2+b^2)}c=0 \qquad (3.23)$$

Then the unity vector Q $(\frac{a}{\sqrt{a^2+b^2}}, \frac{b}{\sqrt{a^2+b^2}})$ shown in figure 3.15 is normal to the line SD. The vector Q is parallel to the vector "IK". Suppose that the length of the vector "IK" is ***r*** then:

$$IK=r.Q \qquad (3.24)$$

Then

$$K\text{-}I=r.Q \tag{3.25}$$

By multiplying both sides of equation 3.25 by *Q* then:

$$K.Q\text{-}I.Q=r.QQ$$

By substituting the values of *K*, *I*, and *Q* we get equation 3.26.

$$\frac{a}{\sqrt{(a^2+b^2)}}X_{\mathrm{k}}+\frac{b}{\sqrt{(a^2+b^2)}}Y_{\mathrm{k}}-\frac{a}{\sqrt{(a^2+b^2)}}X_{\mathrm{i}}-\frac{b}{\sqrt{(a^2+b^2)}}Y_{\mathrm{i}}=r \tag{3.26}$$

We know that the point **K** lies at the line SD. Then according to equation (3.23) we can replace the first two terms by $\frac{-a}{\sqrt{(a^2+b^2)}}c$ to get equation 3.27.

$$-\frac{c}{\sqrt{(a^2+b^2)}}-\frac{a}{\sqrt{(a^2+b^2)}}X_{\mathrm{i}}-\frac{b}{\sqrt{(a^2+b^2)}}Y_{\mathrm{i}}=r \tag{3.27}$$

Finally, the distance ***r*** from the intermediate node "*I"* and the line SD can be given directly by equation 3.28.

$$r=\left|\frac{c+aX_{\mathrm{i}}+bY_{\mathrm{i}}}{\sqrt{a^2+b^2}}\right| \tag{3.28}$$

Nodes that lie behind the source node S must be prevented from participation in route discovery process, because this leads to unnecessary routing overhead. The cause of this prevention is to restrict the route discovery process to only nodes in the direction of destination. So each node must measure its distance to destination, if this distance is larger than the distance between source and destination, the intermediate node will not broadcast the RREQ messages. Then in AODV-Line each node can rebroadcast the RREQ if and only if the intermediate node satisfies the following conditions:

1. The distance between the intermediate node and the line SD is less than or equal to the defined restricted flooding parameter ***W*** in RREQ.
2. The distance between the intermediate node and the destination is less than the distance between source and destination.

3.3.2.4 Node Participation in Route Discovery Process

According to our route discovery mechanism in AODV-Line there are three types of node participation. The degree of node participation is defined by the distance of the intermediate node from the line connecting the source and destination and the distance between the intermediate node and the destination is less than the distance between source and destination. Figure 3.16 explains the node participation in route discovery process in AODV-Line.

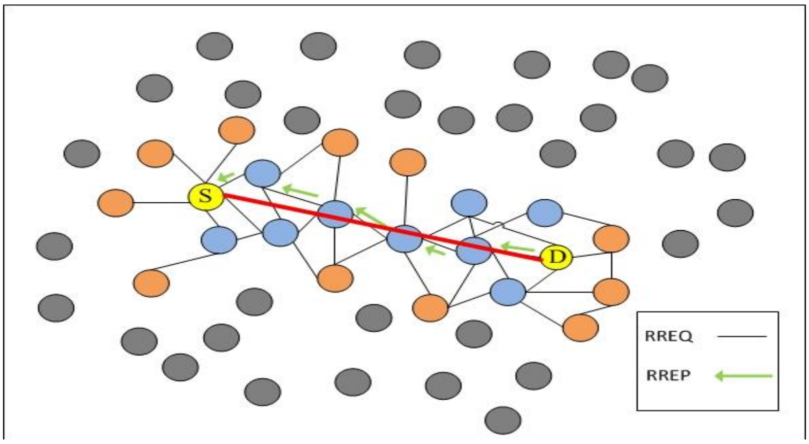

Figure 3.16: Node participation in AODV-Line route discovery process

According to Figure 3.16, there are three types of node participations which are as follows:

1. Nodes that can receive and rebroadcast RREQ and may reply with RREP. The distance of these nodes from the line connecting source and

destination is less than the specified restricted flooding parameter in RREQ, and the distance between these nodes and the destination is less than the distance between source and destination. These nodes appear in figure 3.16 with blue color.

2. Nodes that can receive RREQ and may reply with RREP but don't rebroadcast RREQ. These nodes have a distance from the line that is larger than the specified restricted flooding parameter or the distance between these nodes and the destination is larger than the distance between source and destination the. These nodes appear in figure 3.16 with orange color.
3. Nodes that don't participate in route discovery process. These nodes appear in figure 3.16 with gray color.

3.3.2.5 Location Management in AODV-Line Protocol

In AODV-Line, nodes distribute their location by adding the location information to RREQ messages and Hello messages. The location information in AODV-Line consists of node location and the timestamp of this location. In addition to its location information, source node adds the location information of the destination node to RREQ message to allow the intermediate nodes to test the restricted flooding conditions. Unlike AODV-LAR, the addition of destination node location leads to faster nodes location convergence. Each node in the network manages a location table to store location information of other nodes inside the network.

3.3.2.5.1 Modification of RREQ and Hello Messages in AODV-Line Protocol

In AODV-Line protocol, nodes distribute their location information by adding the location information to RREQ and Hello Messages. Nodes in AODV-Line add their location information and destination location information to RREQ messages, while they just add their location information in HELLO messages. So we need to modify the format of these messages. The location information contains two fields which are:

1. Node location
2. Time stamp

Note that the location information needed in AODV-Line is less than that needed in AODV-LAR. The reason is that in AODV-Line we don't need to know the speed of destination. Unlike AODV-LAR, the search area in AODV-Line is defined implicitly by just adding the location information of the destination node, and intermediate nodes use the information location of both source and destination to test their participation degree in route discovery process.

3.3.2.5.2 Location Table Management

Each node in AODV-Line manages a location table. The location table is used to store the location information of the nodes of the network. Each entry of this table consists of location information of one node in the network. As figure

3.17 shows, the location table entry consists of three fields: Node Address, Node Location, and Time Stamp.

Node Address	Node Location	Time Stamp

Figure 3.17: Location table entry in AODV-Line protocol

Unlike AODV-LAR, RREQ messages in AODV-Line not just contain the location information of the source but also the location information of the destination. Then when a node receives a RREQ message, it modifies or adds two entries in the location table: one for the source and the second for the destination. The time stamp of the location entry refers to freshness of that entry. If the location table of the node that receives the RREQ or HELLO message doesn't have a location entry of the location information in the received RREQ or HELLO message, then it simply adds the entry to its table. When the location table of the node that receives the RREQ or HELLO message has a location entry for the location information in the received RREQ or HELLO message, then freshness of the location information determines whether it needs to update the entry or not.

3.3.2.6 AODV-Line Route Discovery Process

In this subsection we summarize all the events of the route discovery process in AODV-Line. The enhancements which are added to the original AODV lead to changes in the events of the route discovery process. Figures 3.18

and 3.19 show these enhancements. As shown in figure 3.18, when the source S has data to send to destination D, it first checks if it has a route to D in its routing table. If so it directly forwards the message to D. If it hasn’t a route to D, it initiates a route discovery process. The source node S first checks if it has location information of D. If it has location information of D, then S creates new RREQ message and adds the location information of D and the defined restricted search area parameter $\boldsymbol{W}$ to RREQ message and broadcast the RREQ message to its neighbors. If the source node S doesn’t have the location information of D, it will behave like original AODV by using ring search flooding and starts with TTL equals one and increases the value of TTL according to failure in finding route to D. But during ring search, if S receives location information of D, then S adds the location information and the restricted flooding parameter $\boldsymbol{W}$ to the next RREQ packet. The intermediate node behavior shown in figure 3.19. is similar to the behavior in original AODV expect that the intermediate node updates its location table by updates the location information of S and may updates the location information of D, and doesn’t broadcast RREQ packet if its distance from the line formed between S and D is larger than restricted search parameter $\boldsymbol{W}$ or its distance from D is larger than the length of SD line. If the RREQ packet doesn’t has a defined search area, then any node can broadcast RREQ packet if it not expired. The expiration of RREQ is defined by its TTL. If the TTL is greater than zero nodes can broadcast RREQ to its neighbors.

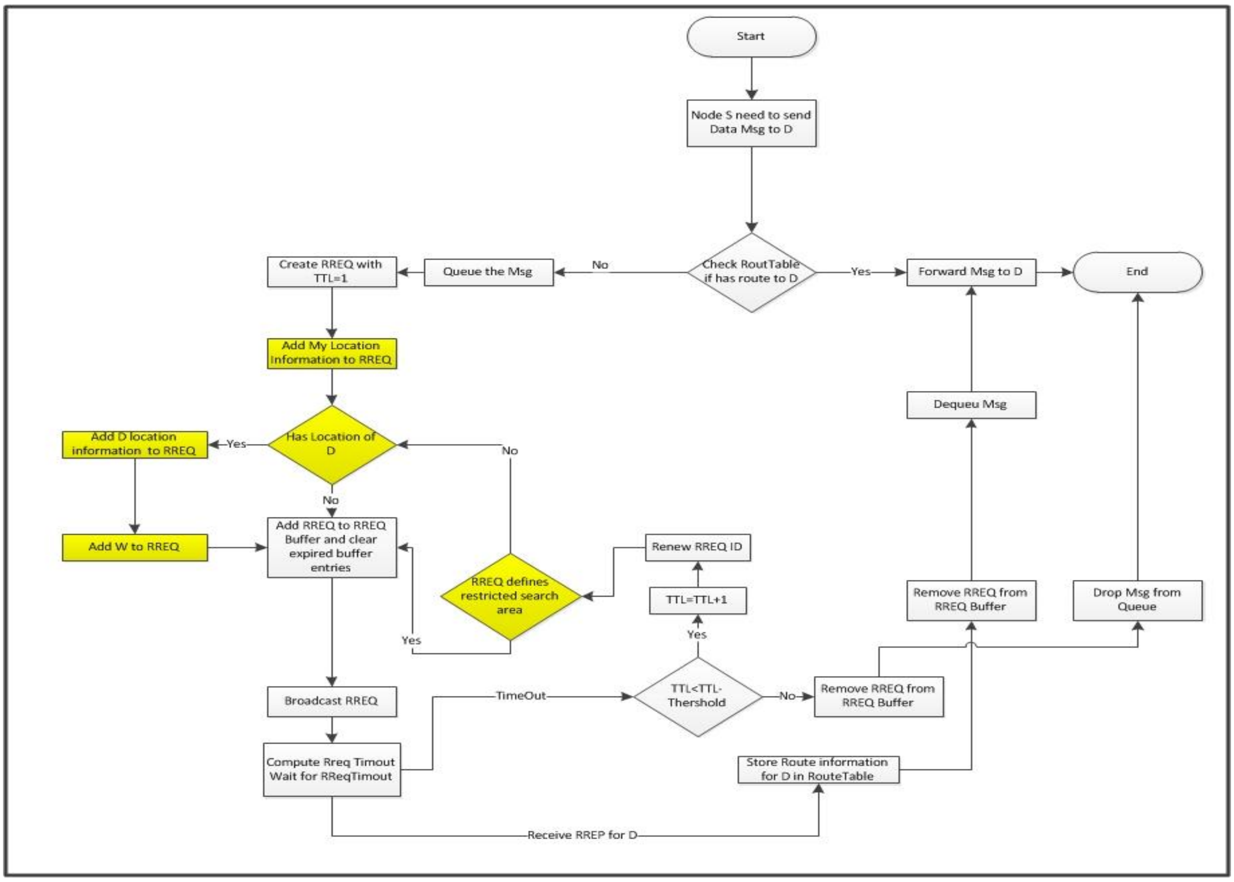

Figure 3.18: Route request process at source node in AODV-Line

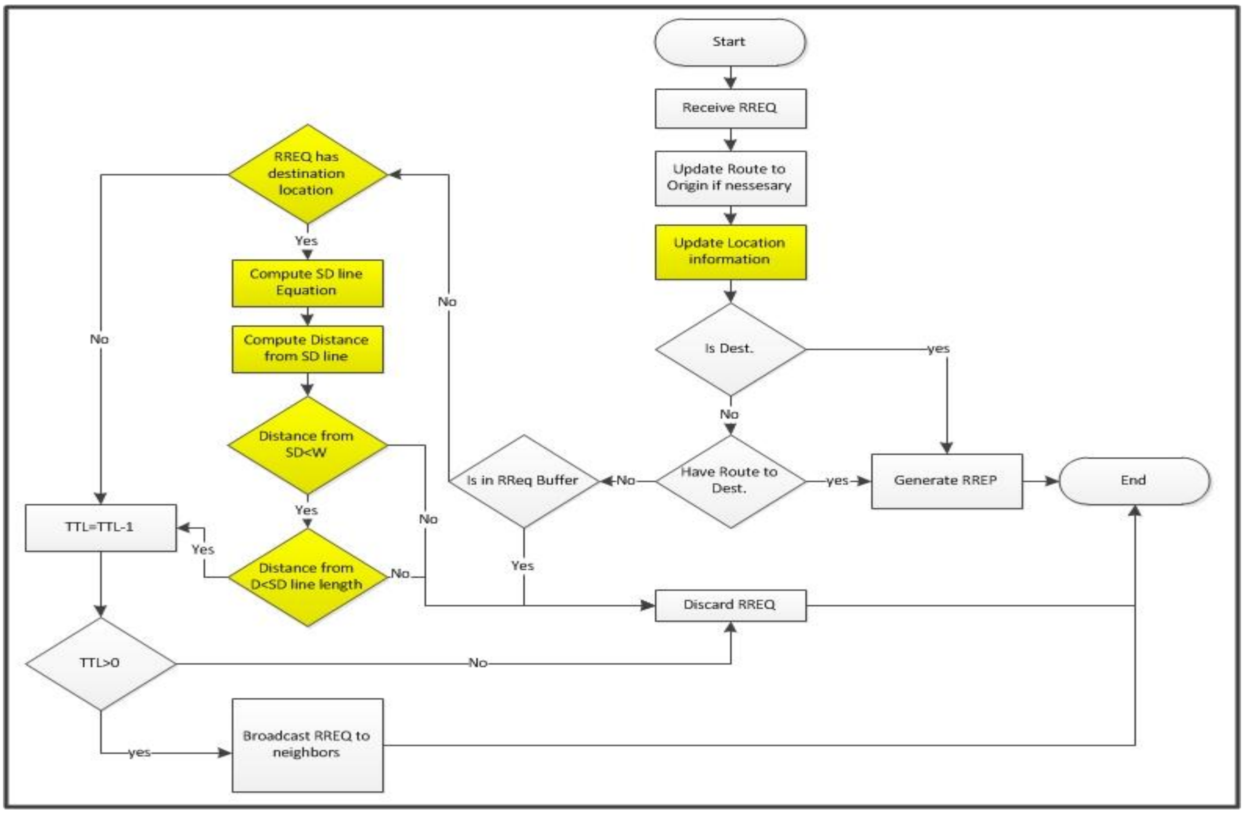

Figure 3.19: Route request process at intermediate node in AODV-Line

3.3.3 AODV-LAR Versus AODV-Line

We presented above two routing protocols which are AODV-LAR and AODV-Line. The main difference between these two protocols is in their search area definition. While AODV-LAR defines a rectangular search area, AODV-Line defines search area according to the distance between intermediate node and the line connecting source and destination. In AODV-LAR the size of the rectangular search area depends on the average speed of the destination and the freshness of location information, while the restricted search parameter $\boldsymbol{W}$ of search area in AODV-line depends on node density in the working area and the nodes transmission range. AODV-LAR defines the search area explicitly by adding the four corners of the search area to the RREQ message, while AODV-Line defines the search area implicitly by adding the location information of the destination to the RREQ message and each intermediate node calculates the line equation between source and destination. AODV-Line doesn't need the node speed, so the location information of AODV-Line entry is less than those of AODV-LAR. The location table convergence in AODV-Line is faster than the convergence of location table in AODV-LAR because the RREQ messages in AODV-Line include both location information of source and destination, while RREQ messages of AODV-Line just include the location information of source node.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Background

In this chapter we test the performance of the two proposed protocols. We choose the popular network simulator Java In Simulation Time for Scalable Wireless Ad hoc Networks (JiST/SWAN)[38], as the simulator of the proposed protocols. We implement and simulate the two proposed routing protocols by using JiST/SWAN simulator. To test the validity of the proposed protocols, we use two different simulation scenarios. In the first scenario we measure the performance of AODV-LAR and AODV-Line with varying number of nodes and compare the results of both proposed protocols with the performance of AODV. In the second scenario we measure the performance of AODV-LAR and AODV-Line with constant number of nodes and varying node mobility model. To justify the effectiveness of the proposed routing protocols we use popular performance metrics used in the literature to measure the performance of routing protocols.

4.2 Performance Metrics

There are many performance metrics to test the validity and performance of routing protocols. Some of these metrics are popular in research area. We use the following popular performance metrics to validate the two proposed routing protocols.

1. **Routing Overhead**

The routing overhead is caused by the control packets transmitted in the network during simulation. The overhead of AODV-LAR, AODV-Line and AODV is simply the sum of all control packets transmitted during simulation time. These control packets are RREQ, RREP, RERR, and HELLO packets.

2. **Number of RREQ Transmitted**

In route discovery process in AODV the source node floods the network with RREQ packets, while we use restricted flooding in our proposed protocols. So, to justify our work we need to measure the number of RREQ packets flooded in the network in AODV-LAR, AODV-Line and AODV.

3. **Route Discovery Delay**

The route discovery delay is the time needed to find a route to destination. This time starts when a source initiates route discovery request process until it finds a route to destination.

4. **Packet Delivery Ratio (PDR)**

PDR is the ratio of the number of data packets received by the destination from the source to the number of data packets generated by the source.

5. **Normalized Routing Load (NRL)**

   Normalized routing load is defined as the number of routing packets transmitted per data packet delivered at the destination.

6. **Hop Count**

   Hop counts is the number of hops needed to reach destination. The best route is the one which has a l hop count.

4.3 Simulation Setup and Results

In this section we show the two simulation scenarios and the results obtained using each scenario**.** In these scenarios we measure and compare the performance metrics of the original AODV, AODV-LAR and AODV-Line protocols.

4.3.1 First Scenario

In this scenario we measure the performance metrics of the original AODV, AODV-LAR and AODV-Line and compare the obtained results. We need to justify the feasibility of both proposed protocols AODV-LAR and AODV-Line in varying network size.

4.3.1.1 First Scenario Simulation Setup

The simulation parameters for the first scenario are summarized in table 4.1. The simulation area is 1000m X 1000m. In this scenario we test the AODV, AODV-LAR, and AODV-Line with varying number of nodes. We use the Random Way Point mobility model which is one of the most popular mobility models**.** In this mobility model each node chooses a random destination in the simulation area and a speed that is uniformly distributed within the range [2, 10] and starts moving until it reaches this destination and stops for 30 seconds (pause time), then starts the moving process again. The simulation time is 9000 seconds and the nodes sending rate is 1pkt/ min. For simplicity we choose static values of the restricted search area parameter ***W*** in AODV-Line. The values of ***W*** can be calculated according to equation (3.18). Also for simplicity, we run the simulation by just 3 values of ***W***, where the appropriate ***W*** value for 100 nodes is 20 m, for 60 nodes appropriate ***W*** value is 33.3 m, and for 20 nodes appropriate ***W*** value is 100 m. Transmission range of each node is 250 m. The route request time per TTL is 150 ms, where the source node waits for this time until it receives route reply. If the source doesn’t receive route reply in this TTL time, it generates new route request by new incremented TTL. The results were averaged over ten simulation runs.

Table 4.1: First scenario simulation setup

Simulation Area	1000m X 1000m
Number of nodes	20,40,60,80, and 100
Mobility model	Random Way Point
Nodes speed	2-10 m/s
Pause time	30 seconds
Send Rate	1 pkt/min
Node transmission range	250 m
W values	20, 33.3, and 100 m
Simulation time	9000 seconds
Waiting time per TTL	150 ms per TTL

4.3.1.2 First Scenario Results

Now we present the results of the first scenario. We used the defined performance metrics in the previous section**.**

4.3.1.2.1 Routing Overhead

The routing overhead of AODV-LAR and AODV-Line is less than original AODV as shown in figure 4.1. This overhead is the sum of all control packets transmitted through the Ad-hoc network. The reason of reduction in overhead is the restriction of flooding in AODV-LAR and AODV-Line to a smaller area than that in AODV. As the figure shows, the two proposed protocols outperform the original AODV. The figure also shows that the overhead of the AODV-Line decreases as the restriction flooding parameter ***W*** decreases. The reason is that the smaller ***W*** leads to smaller flooding area.

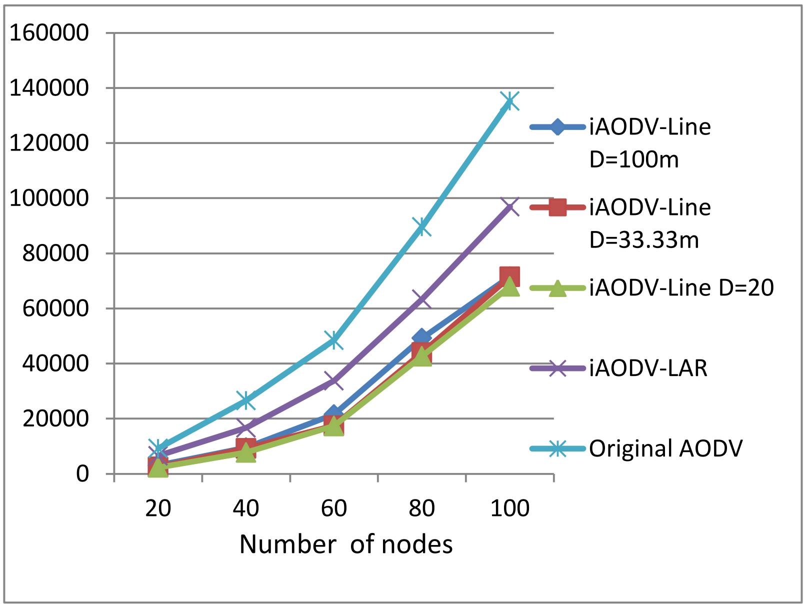

Figure 4.1: Routing overhead in the first scenario

The reduction of overhead proves that our two proposed protocols have higher performance than AODV protocol, where they save bandwidth and network resources as the overhead is decreased.

4.3.1.2.2 Number of Transmitted RREQ Packets

The restriction of flooding area in AODV-LAR and AODV-Line leads to less number of RREQ packets flooded inside the network as shown in figure 4.2. The reason for this is that in the two proposed protocols the flooding of RREQ packets is restricted to within smaller area than AODV while AODV floods the whole network with RREQ packets.

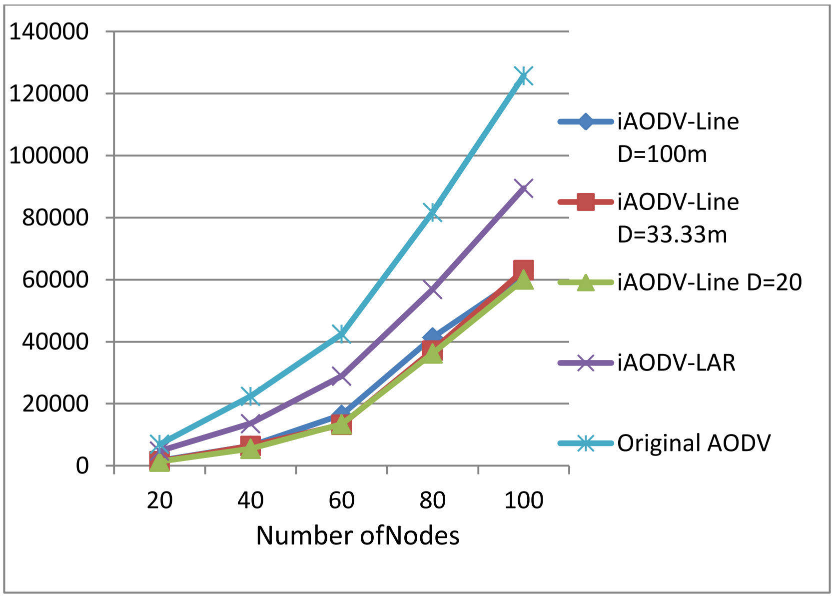

Figure 4.2: Number of RREQ packets transmitted in the first scenario

This reduction of RREQ packets flooded inside the network directly affects the overhead, where it leads to less overhead inside the network.

4.3.1.2.3 Route Discovery Delay

As shown in figure 4.3 we see that the route discovery delay in both AODV-LAR and AODV-Line is less than the route discovery delay in the original AODV. This reduction in delay leads to faster data transmission. The main reason of the reduction of delay in AODV-LAR is the use of estimated TTL to estimate TTL_{start} value instead of starting with TTL that is equal to one.

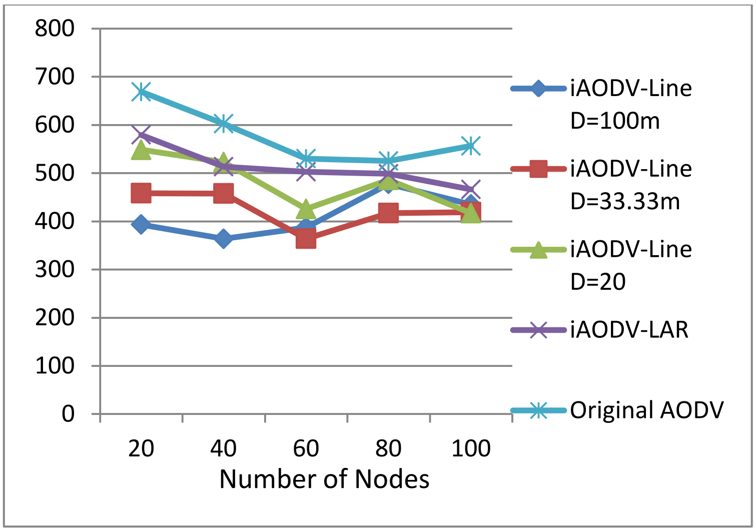

Figure 4.3: Route discovery delay in the first scenario

Note that the delay in AODV-Line is less than delay in both AODV-LAR and AODV. The main reason of this reduction in delay is the high speed convergence of location table in AODV-Line where RREQ packets include locations of both source and destination. Another reason is that the overhead of AODV-Line is less than the overhead of AODV-LAR, where this overhead consumes a high processing time and leads to more delay. Note that the best delay values in AODV-LAR are obtained by the best appropriate values of ***W***. For example, the appropriate ***W*** value for 20 nodes is 100 and with this value we obtain the best delay. The decrease of ***W*** value to 20 m leads to insufficient node density inside the search area which leads to failure to finding a route, and for this reason the delay increased. The best delay obtained when the network size is 60 nodes comes with ***W*** value is equal to 33.3m which is the appropriate value for the network size. When we increase the ***W*** value to 100 m the delay is increased because the overhead is increased which leads to high processing time. When the ***W*** value is decreased to 20 m, the delay is also increased because there is no sufficient number of nodes inside the search area which leads to failure in finding the route and this increases the delay.

4.3.1.2.4 Packet Delivery Ratio (PDR)

As shown in figure 4.4 the PDR of AODV, AODV-LAR, and AODV-Line is comparable. From the figure we see that the delivery ratio is increased as the number of nodes is increased until it reaches 60 nodes.

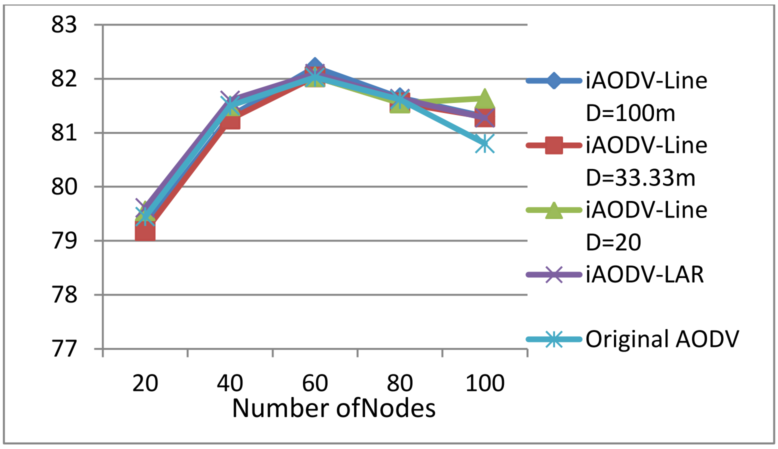

Figure 4.4: Packet Delivery Ratio (PDF) in the first scenario

The reason is that with low dense networks, some nodes are isolated and the source can not find a route to destination which leads to failure in delivering the data packets to destination.

But when the number of nodes is more than 60 nodes we see that the delivery ratio is decreased. The main reason is the high overhead which is increased as the number of nodes is increased which leads to the drop of data packets from the node buffers.

4.3.1.2.5 Normalized Routing Load (NRL)

Figure 4.5 shows that our proposed protocols outperform AODV whn using the NRL performance metric. The best result is obtained when we use AODV-Line with the restriction search parameter ***W is*** equal to 20m.

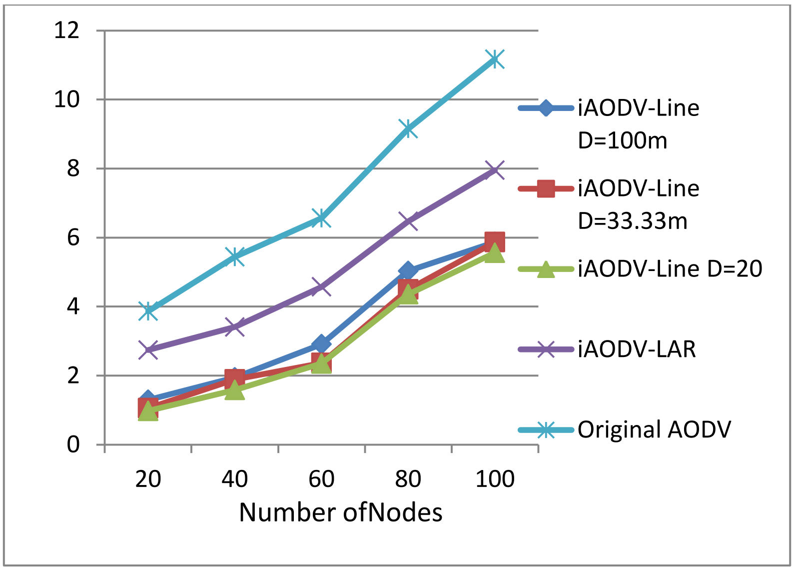

Figure 4.5: Normalized Routing Load (NRL) in the first scenario

The reason is that this value of ***W*** leads to the smallest search area which adds more reduction in overhead. This NRL reduction saves the mobile node resources. From the figure we can say that our proposed protocols outperform the original AODV.

4.3.1.2.6 Hop Count

The hop count observed by AODV-Line and AODV-LAR is better than the hop count observed by the original AODV. The main reason is that the smallest hop count is always closer to the line segment connecting the source and destination [58]. In AODV-Line and AODV-LAR the search for a route is closer to the line connecting the source and destination which leads to smaller hop count. The Smaller hop count decreases the packet delivery delay where the data packets traverse less number of hops to reach the destination which improves the routing protocol performance.

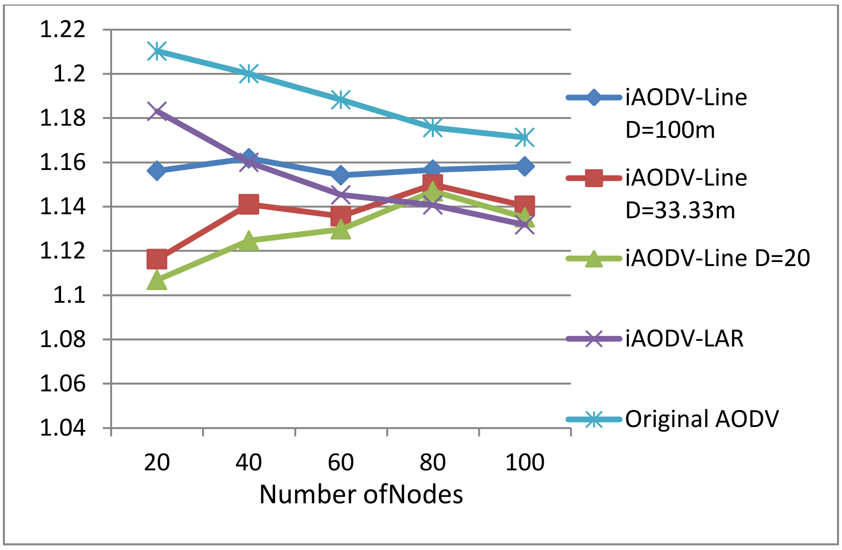

Figure 4.6: Hop count in the first scenario

Note that in the most cases, the minimum hop count comes with AODV-Line with the restriction parameter ***W*** is equal to 20 m, because of its closest distance to the line connecting the source and destination. But when the density of the network increases, the AODV-LAR hop count is better than that of ADOV-Line. The reason for that is that the rectangular search area width is adapted to node speed and is not static like the restriction parameter ***W*** in AODV-Line. As shown in the figure we see that our proposed protocols outperform the original AODV.

4.3.2 Second Scenario

In this scenario we measure the performance metrics of the original AODV, AODV-LAR and AODV-Line and compare the obtained results. We need to justify the feasibility of both proposed protocols AODV-LAR and AODV-Line in case of high mobility speeds.

4.3.2.1 Second Scenario Simulation Setup

The simulation parameters for the second scenario are summarized in table 4.2. The simulation area is 1000m X 1000m. In this scenario we test AODV, AODV-LAR, and AODV-Line with varying node speeds.

Table 4.2: Second scenario simulation setup

Simulation Area	1000m X 1000m
Number of nodes	40
Mobility Model	Random Way Point
Nodes speed	10, 20, 30, 40, and 50
Pause time	0 seconds
Sending rate	1 packet/minute
Node Transmission Range	250 m
W values	50 m
Simulation time	9000 seconds
Waiting time per TTL	150 ms per TTL

We use the Random Way Point mobility model which is one of the most popular mobility models [20]. The simulation time is 9000 seconds and the nodes sending rate is 1 packet/minute. For simplicity we choose static values of the restricted search area parameter ***W*** in AODV-Line. The value of ***W*** can be calculated according to equation (3.18) and it is equal to 50 m. Transmission range of each node is 250 m. The route request time per TTL is 150 ms. The results were averaged over ten simulation runs.

4.3.2.2 Second Scenario Results

Now we present the results of the second scenario. We use the defined performance metrics in the previous section**.**

4.3.2.2.1 Routing Overhead

` The routing overhead in AODV is increased as shown in figure 4.7. The increase in routing overhead is due to the increase of mobility speed which leads to high link breakage according to high mobility degree of nodes.

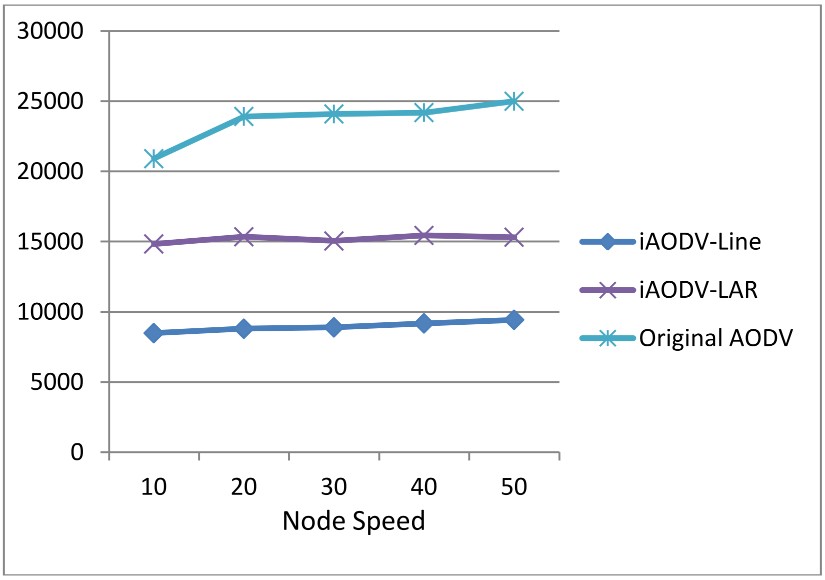

Figure 4.7: Routing Overhead in the second scenario

But the overhead in AODV-LAR and AODV-Line stay in the same range. As shown in the figure, the overhead of the two proposed protocols is less than the overhead of the original AODV. The reason of the reduction of the overhead is the restricted flooding used in the proposed protocols. AODV-Line overhead is less than the overhead obtained by using AODV-LAR. The reason is that in LAR the restricted search area in AODV-LAR depends on node speed to define the search area and doesn't take into account the node density in the network, and this area is always larger than that of AODV-Line. The larger the earch area contains higher number of nodes which leads to higher overhead.

4.3.2.2.2 Number of Transmitted RREQ Packets

The number of RREQ packets flooded in the network of AODV-LAR and AODV-Line is less that of the original AODV as shown in figure 4.8. The main reason for this is the restricted flooding in AODV-LAR and AODV-Line which leads to less number of RREQ packets flooded inside the network.

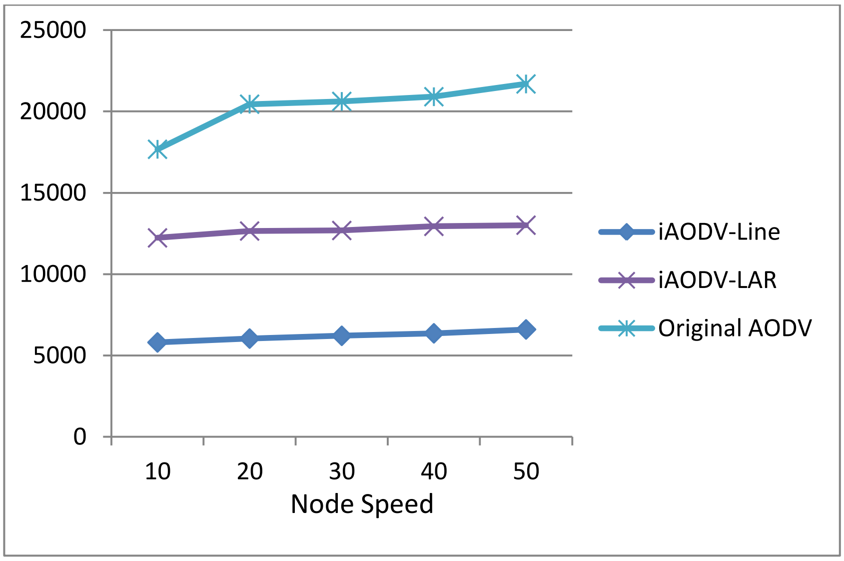

Figure 4.8: Number of RREQ packets transmitted in the second scenario

The reason for the decrease in the number of flooded RREQ packets is that in the two proposed protocols the flooding of RREQ packets is restricted to inside a smaller area while AODV floods the whole network with RREQ packets. This proves the effectiveness of the two proposed protocols in decreasing the overhead of the original AODV. This reduction saves the nodes and network resources. Hence, the two proposed protocols outperform the original AODV.

4.3.2.2.3 Route Discovery Delay

The best route discovery delay is obtained by using AODV-Line protocol as shown in figure 4.9. The delay decreases when we use AODV-Line because its overhead is low, where the overhead consumes the computation resources and leads to high processing delay of control packets.

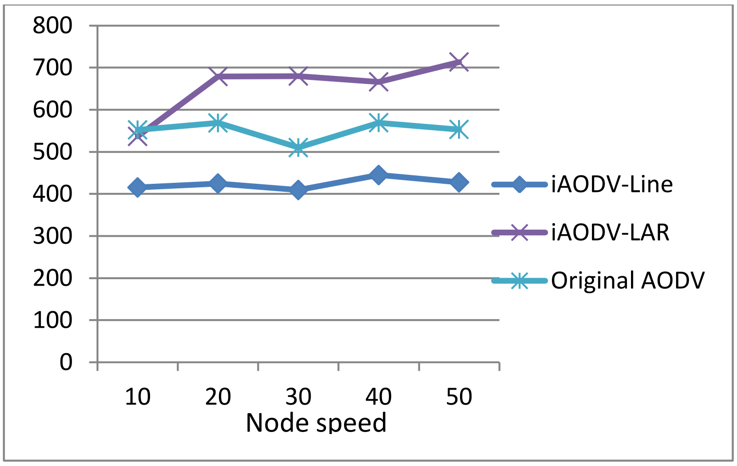

Figure 4.9: Route discovery delay in the second scenario

But when we use AODV-LAR we see that the delay increases as the speed increases. While in low speed, the delay of AODV-LAR is better than the delay of AODV. The delay of AODV-LAR in the figure is not better than the delay of AODV in high mobility speeds. The reason of that is that with high mobility speed the rectangular search area size is increased. TTL estimation duplicates the flooding of RREQ in instance to decrease the delay. But we may find a route using near intermediate nodes. But this estimation leads to high overhead also in high speeds. Then the increase of the overhead comes from the larger search region caused by high mobility speed and the TTL estimation that leads to increased overhead. This increased overhead leads to high processing delay and this increases the route discovery delay of AODV-LAR. AODV-Line performance doesn't depend on node speed, but depends on node density with fixed search area which decreases the overhead and leads to more reduction in delay. Then the TTL estimation technique is sufficient for low node speeds and insufficient with high node speeds.

4.3.2.2.4 Packet Delivery Ratio (PDR)

The results of the packet delivery ratio (PDR) for the proposed protocols and the original AODV are comparable as shown in figure 4.10. This proves the validity of the two proposed protocols. Note that when the node speed increases the packet delivery ratio decreases. The reason is that the high link breakage which is caused by high mobility speeds.

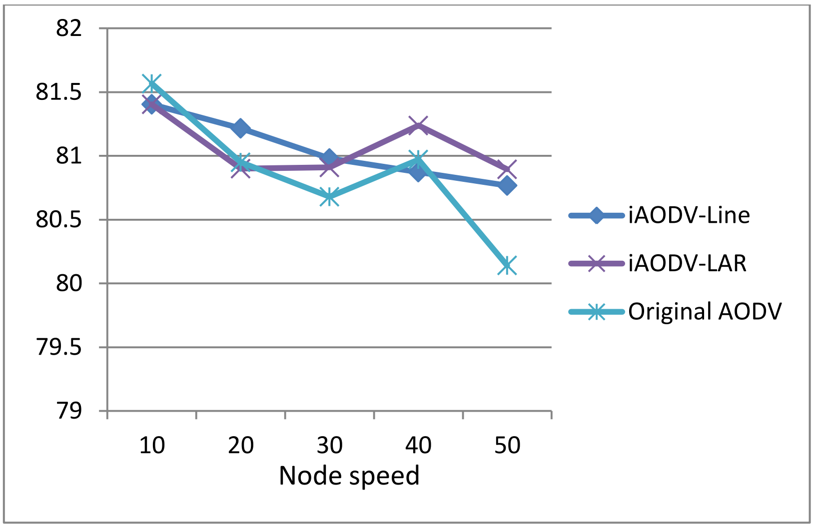

Figure 4.10: Packet Delivery Ratio (PDR) in the second scenario

4.3.2.2.5 Normalized Routing Load (NRL)

The normalized routing load of the two proposed protocols is better than that of the original AODV as shown in figure 4.11. The lowest routing load is obtained when we use AODV-Line and AODV-LAR, because they have the lowest overhead values and their PDF is comparable to the original AODV.

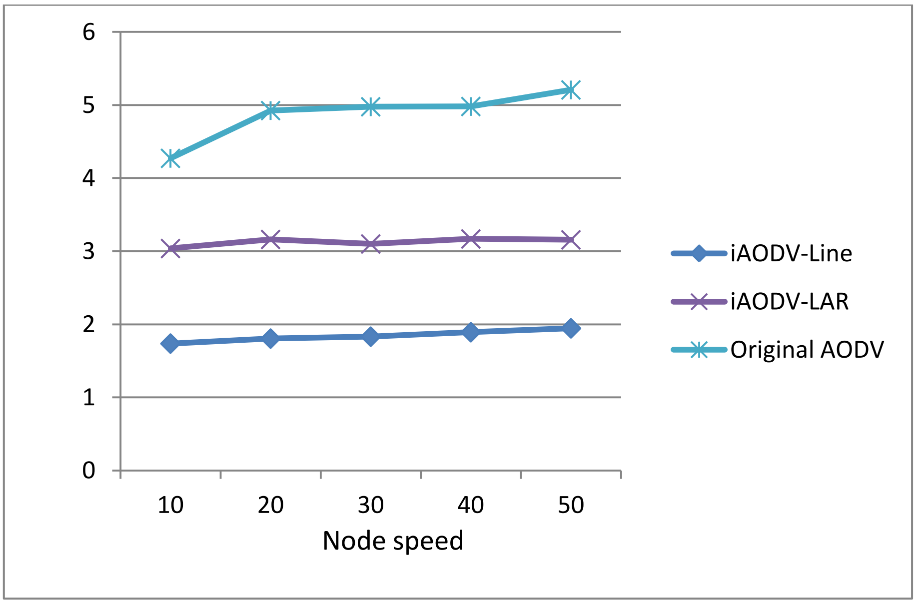

Figure 4.11: Normalized Routing Load (NRL) in the second scenario

This decrease in NRL proves the validity of the proposed protocols. The reduction in NRL leads to reduction in consuming nodes resources like computation resources, memory resources and power.

4.3.2.2.6 Hop Count

The average hop count of AODV-Line and AODV-LAR is less than that of the original AODV as shown in figure 4.12. The main reason is that the shortest path is always found near the line connecting the source and destination [58]. In the AODV-LAR and AODV-Line the search for a route is always near the line connecting the source and destination which leads to a smaller number of hop count. In AODV, the search is done over the whole network which leads to high values of hop count.

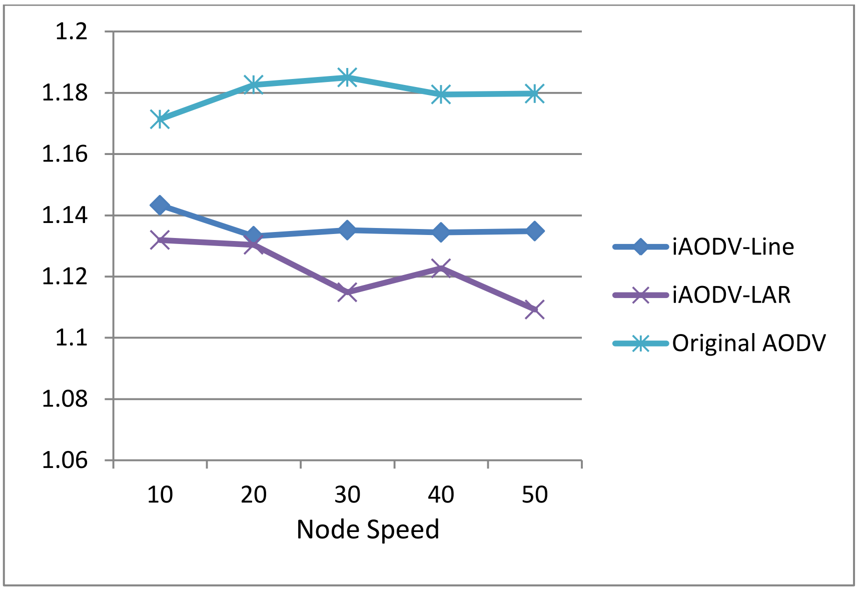

Figure 4.12: Hop counts in the second scenario

As shown in the figure we can say that the proposed protocols outperform the original AODV.

Finally we can say that the results show that the proposed protocols, AODV-LAR and AODV-Line outperform the original AODV. The proposed protocols decrease the overhead of AODV. When using AODV-LAR we obtain 25% reduction of overhead of AODV. The use of AODV-Line leads to 50% reduction of AODV overhead. Also, the proposed protocols reduce the delay of the original AODV. The PDF of the proposed protocols is comparable with that of the original AODV.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis we proposed two protocols to reduce the overhead of AODV. The proposed protocols use location information obtained by GPS to reduce the routing overhead of AODV. The first protocol called AODV-LAR uses location information to restrict the flooding of route discovery process to within a small rectangular search area. AODV-LAR also uses a TTL estimation equation to reduce the delay and overhead. The second proposed protocol called AODV-Line uses location information to restrict flooding near the line connecting source and destination nodes. The simulation results show that AODV-LAR and AODV-Line outperform AODV where both proposed protocols reduce the overhead and the delay of AODV. The results also show that the TTL estimation equation used in AODV-LAR is sufficient at low mobility speed, while it adds more overhead and delay at high mobility speeds.

5.2 Future Work

Many improvements can be done to add more performance to AODV-LAR and AODV-Line. One suggestion is to make centralized location system, where each node stores its location and queries for other node locations from this system. Another suggestion is to modify AODV-LAR and AODV-Line to increase the packet delivery ratio (PDF). Performance comparison between our proposed protocols and other location aided routing protocols can be done.

REFERENCES

[1] M. Geetha , and R. Umarani, "An Overview of Multi Point Relay AODV in Mobile Ad hoc Network," Proceedings of the International Joint Journal Conference on Engineering and Technology,2011, pp.71-76.

[2] B. S. Kawish, B. Aslam, and S. A. Khan," Reducing the Overhead Cost in Fixed & Low Mobility AODV Based MANETs," Proceedings of the International Multiconference on Computer Science and Information Technology,2006, pp. 569 – 578.

[3] B. S. Kawish, B. Aslam, and S. A. Khan, "Reduction of Overheads with Dynamic Caching in Fixed AODV based MANETs," World Academy of Science, Engineering and Technology , 2006, pp 60-65.

[4] M. Kumar and R.S .Rajesh," A Survey of Mobile Ad Hoc Reactive Routing Protocols in Two Different Mobility Models,", International Journal of Engineering and Technology Apr. 2009,Vol. 1, No. 1.

[5] J. Broch, D. A. Maltz, D. B. Johnson Y. Hu and J. Jetcheva, "A Performance Comparison of Multihop Wireless Ad Hoc Network Routing Protocols", ACM MOBICOM , 1998, Dallas, Texas. pp 25-30.

[6] Y. Hassan, M. Abd El-Aziz, and A. Abd El-Radi," Performance Evaluation of Mobility Speed over MANET Routing Protocols." International Journal of Network Security, Nov. 2010,Vol.11, No.3, PP.128-138.

[7] B. Liang, and Z. J. Haas," Hybrid Routing in Ad Hoc Networks with a Dynamic Virtual Backbone," IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, Jun. 2006, VOL. 5, NO. 6.

[8] V. N. Talooki, and J. Rodriguez," Quality of Service for Flat Routing Protocols in Mobile Ad hoc Networks," Mobimedia, 2009, 7-9 Sep., London, UK.

[9] B. Hod," Cooperative and Reliable Packet-Forwarding On Top of AODV," master thesis, School of Engineering and Computer Science ,The Hebrew University of Jerusalem,2005.

[10] C. A. Dhote, M .A. Pund, and R.S. Mangrulkar," Hybrid Routing Protocol with Broadcast Reply for Mobile Ad hoc Network," International Journal of Computer Applications, 2010, Vol.1–No.10, pp108-113.

[11] C. P. P. Bhagwat.," Highly Dynamic Destination Sequenced Distance Vector DSDV Routing for Mobile Computers," Proceeding of ACM SIGCOM, September 1994, pp. 234 – 244.

[12] S. Murthy and J. J. Garcia-Luna-Aceves, "An Efficient Routing Protocol for Wireless Networks," ACM Mobile Networks and App. J., Special Issue on Routing in Mobile Communication Networks, Oct. 1996, pp. 183–97.

[13] J.J. Garcia-Luna-Aceves, M. Spohn, "Source-Tree Adaptive Routing in Wireless Networks", Proceedings of the 7th Annual IEEE international conference on Network Protocols, Toronto, Canada, 1999, 31Oct.- 3Nov.

[14] U. Lee," A Proactive Routing Protocol for Multi-Channel Wireless Ad-hoc Networks, " PhD thesis, Virginia Polytechnic Institute and State University, 2006.

[15] R. Astya, and S.C. Sharma, "Traffic Load based Performance Analysis of DSR & STAR Routing Protocol," International Journal of Advanced Computer Science and Applications, Oct. 2010, Vol. 1, No. 4, pp58-62.

[16] E. Royer and C.-K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," IEEE Personal Communications, Apr. 1999. vol. 6, no. 2, pp. 46–55.

[17] J. Broch, D. Maltz, D. Johnson, Y.-C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," in 4th Annual International Conference on Mobile Computing and Networking (MobiCom), 1998.

[18] P. Sholander, A. Yankopolus, and P. Coccoli," EXPERIMENTAL COMPARISON OF HYBRID AND PROACTIVE MANET ROUTING PROTOCOLS," IEEE,MILCOM, 2002, , 7-10 Oct , vol.1, pp. 513 – 518.

[19] D. Johnson, D. Maltz, Y. Hu, "The Dynamic Source Routing Protocol (DSR), " rfc4728, http://www.ietf.org/rfc/rfc4728.txt,2007.

[20] C. Toh," A novel distributed routing protocol to support ad-hoc mobile computing," IEEE 15th Annual International Phoenix Conf., 1996, pp. 480–486.

[21] S. Das, C. Perkins, E. Royer, "Ad hoc on demand distance vector (AODV) routing, "draft-ietf manetaodv-11.txt, work in progress, 2002.

[22] M. Abolhasan , T. Wysocki , and E. Dutkiewicz," A review of routing protocols for mobile ad hoc networks" Elsevier B.V,2004, Ad Hoc Networks 2 ,pp 1-22.

[23] C. Liu, and J. Kaiser," A Survey of Mobile Ad Hoc network Routing Protocols," University of Ulm, Tech.Report Series, 2003.

[24] C. Perkins, E. Belding-Royer, and S. Das," Ad hoc On-Demand Distance Vector (AODV) Routing", rfc3561, http://www.ietf.org/rfc/rfc3561.txt, July 2003.

[25] A. K. Gupta , Dr. H. Sadawarti, and Dr. A. K. Verma," Performance analysis of AODV, DSR & TORA Routing Protocols," IACSIT International Journal of Engineering and Technology , Apr. 2010, Vol.2, No.2,pp.226-231.

[26] Z. J. Haas, and M. R. Pearlman," The Zone Routing Protocol (ZRP) for Ad Hoc Networks," draft-ietf-manet-zone-zrp-03.txt, 2000.

[27] M. R. Pearlman, and Z. J. Haas, “Determining the Optimal Configuration for the Zone Routing Protocol, “IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, AUGUST 1999,VOL. 17, NO. 8,pp. 1395-1414 .

[28] M. Sujoy,” Ad Hoc mobile Wirless Networks.” Techscribe – IEEE National Student Paper Presentation Contest, 2004.

[29] Y. Ko, and N. H. Vaidya, “Location-Aided Routing (LAR) in mobile ad hoc networks,” Wireless Networks . 2000, pp. 307-321.

[30] B. Karp, and H. T. Kung. “GPSR: Greedy Perimeter Stateless Routing for Wireless Networks,” Proc. of ACM/IEEE International Conference on Mobile Computing and Networking , Aug. 2000.

[31] R. Francescantonio,” Cooperative Mobile Positioning and Tracking in Hybrid WiMAX/WLAN Networks,” Master thesis, Aalborg University, 2007.

[32] A. Boukerche, H.A.B.F. Oliveira, E. F. Nakamura, and A. A.F. Loureiro, “Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems,” Computer Communications, 30 July 2008, Vol.31, Issue 12, pp.2838-2849.

[33] URL: “http://en.wikipedia.org/wiki/Global_Positioning_System,” 2011.

[34] S. Han, T. Li , C. Qian, D. Leith, A. K. Mok, and S. S. Lam, “HartFi: an energy-efficient localization system,” Proceedings of the 2nd ACM SIGCOMM workshop on Green networking, ACM , 2011.

[35] S. R. Das, R. Castaneda, J. Yan, and R. Sengupta, “Comparative Performance Evaluation of Routing Protocols for Mobile Ad Hoc Networks”, 7th International Conference on Computer Communication and networks, Oct. 1998, pp. 153-161.

[36] J. Broch, D. A. Maltz, D. Johnson, Y.-C. Hu, and J. Jetcheva, “A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols”. In Proceedings of the 4th Annual ACM/IEEE International Conference on Mobile Computing and Networking, Oct. 1998, pp. 85–97.

[37] M.K. Kumar, and R.S. Rajesh,” Performance Analysis of MANET Routing Protocols in Different Mobility Models” International Journal of Computer Science and Network Security, Feb. 2009, VOL.9 No.2.

[38] URL: “http://jist.ece.cornell.edu/”, Jul. 2009.

[39] H. Asenov, and V. Hnatyshin,” GPS-Enhanced AODV routing,” In Proceedings of the International Conference on Wireless Networks (ICWN’09), Las Vegas, NV, USA, July 2009.

[40] Y. Ko and N. H. Vaidya, “Location-aided routing (LAR) in mobile ad hoc networks,” Wireless Networks, 6(4),Jul. 2000, pp. 307-321.

[41] S. Nanda, and R.S. Gray, “Multipath location aided routing in 2D and 3D,” Wireless Communications and Networking Conference, 2006, 3-6 Apr., IEEE Volume 1, pp. 311 – 317.

[42] S. Basagni, I. Chlamtac, V.R. Syrotiuk, and B.A. Woodward, “A Distance Routing Effect Algorithm for Mobility (DREAM)”, MOBICOM'9, 1999.

[43] M. Bakhouya, J. Gaber, and M. Wack,” Performance Evaluation of DREAM Protocol for Inter-vehicle Communication,” Wireless Vitae IEEE press, 2009, pp. 289-293.

[44] L. Nithyanandan, G. Sivarajesh, and P. Dananjayan,” Modified GPSR Protocol for Wireless Sensor Networks,” International Journal of Computer and Electrical Engineering, Vol. 2, No. 2, April, 2010, pp. 324-328.

[45] P.Pranitha, G.Swamy, and M. Aakunuri,” A Review on Enhanced GPSR protocol For Wireless Sensor Networks,” Computer Engineering and Intelligent Systems ,2011, Vol 2, No.4.

[46] D. Espes, and Z. Mammeri. “Adaptive expanding search methods to improve AODV Protocol,” IEEE, Mobile and Wireless Communications Summit 16th IST, July 2007, pp. 1-5.

[47] D. Espes , and C. Teyssie ,” Approach for Reducing Control Packets in AODV-based MANETs,” Conference on Universal Multiservice Networks. IEEE,2007, pp. 93-104.

[48] M.A. Zayene, and N. Tabbane, “Performance evaluation of Location-Aided Routing protocols in ad hoc networks,” IEEE, Global Information Infrastructure Symposium, 2009, pp. 1-6.

[49] Clifton Lin,”AODV routing implementation for scalable wireless Ad-hoc network simulation (SWANS)”, Available at: "http://jist.ece.cornell.edu/docs/040421-swansaodv.pdf", June 2010.

[50] A. Akram, and M. Shafqat,” Battery and Frequency Optimized AODV for Wireless Mesh Networks,” Canadian Journal on Multimedia and Wireless Networks, Apr. 2010, Vol. 1, No. 3, pp. 31-37.

[51] URL:” http://en.wikipedia.org/wiki/Dot_product,” 2012.

[52] URL:” http://en.wikipedia.org/wiki/Linear_equation”,2012.

[53] C Kim, E.Talipov, and B.Ahn, “A Reverse AODV (R-AODV) Routing Protocol in ad hoc MobileNetworks”, IFIP International Conference on Embedded and Ubiquitous Computing, Aug 2006, pp.522-531.

[54] A.M. Ortiz, , F. Royo, T. Olivares, , and L. Orozco-Barbosa," Intelligent route discovery for ZigBee mesh networks," : World of Wireless, Mobile and Multimedia Networks (WoWMoM), IEEE, Aug 2011, pp. 1-6.

[55] H. Nishat , V. Krishna K , D.S. Rao, and S. Ahmed," Performance Evaluation of On Demand Routing Protocols AODV and Modified AODV (R-AODV) in MANETS," International Journal of Distributed and Parallel Systems (IJDPS) Vol.2, No.1, January 2011, pp. 94-101.

[56] P. S. Bharadwaj, S. Rashmi, and B.S. Shylaja, "Performance Evaluation of MANET Based Routing Protocols for VANETs in Urban Scenarios," International Conference on Network and Electronics Engineering (IPCSIT) , Singapore, 2011, vol.11 , pp. 164-169.

[57] A. Kowshika , C. Maheswari , and. S. Karthik," AN EFFICIENT PACKET FORWARDING IN MANET WITH AODV USING RANDOM WAY POINT MOBILITY MODEL," Journal of Mathematics and Technology, 2010, No. 3, pp. 75-80.

[58] Y. Ganjali, and A. Keshavarzian," Load Balancing in Ad Hoc Networks: Single-path Routing vs. Multi-path Routing," IEEE INFOCOM, 2004, 7-11 March 2004 , Vol. 2,pp. 1120 – 1125.