วิธีจัดเส้นทางพหุวิถีโดยอาศัยตำแหน่งสำหรับโครงข่ายแอดฮอก

นาย ฮา เยวียง ตรุง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมไฟฟ้า ภาควิชาวิศวกรรมไฟฟ้า
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2548

ISBN 974-17-4810-8

MULTIPATH LOCATION-AIDED ROUTING METHOD FOR AD HOC NETWORKS

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A Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master Program of Engineering in Electrical Engineering
Department of Electrical Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2005
ISBN 974-17-4810-8

Thesis Title MULTIPATH LOCATION-AIDED ROUTING METHOD FOR AD HOC NETWORKS

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Field of Study Electrical Engineering

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ฮา เยวียง ตรุง : วิธีจัดเส้นทางพหุวิถีโดยอาศัยตำแหน่งสำหรับโครงข่ายแอดฮอก (MULTIPATH LOCATION-AIDED ROUTING METHOD FOR AD HOC NETWORKS) อ. ที่ปรึกษา : รศ. ดร.วาทิต เบญจพลกุล, 60 หน้า. ISBN 974-17-4810-8

โครงข่ายแอดฮอกเป็นโครงข่ายที่ประกอบด้วยโนดเคลื่อนที่ไร้สาย ซึ่งรูปร่างของโครงข่ายเปลี่ยนแปลงอยู่ตลอดเวลา โครงสร้างของโครงข่ายแอดฮอกไม่ได้ใช้การบริหารแบบรวมศูนย์ (centralized administration) หรือใช้โครงสร้างของโครงข่ายที่มีใช้กันอยู่ทั่วไป การประยุกต์ใช้งานโครงข่ายแอดฮอกหลัก ๆ ได้แก่ การบรรเทาสาธารณภัย การทหาร การประชุม และการตรวจวัดสภาวะแวดล้อม รูปแบบการจัดเส้นทางสำหรับโครงข่ายแอดฮอกมีการเสนอมาหลายวิธีและอัลกอริทึมจัดเส้นทางหลายวิธีในปัจจุบันใช้ข้อมูลตำแหน่งของโนดสำหรับการตัดสินใจจัดเส้นทางของโนดแต่ละโนด วิทยานิพนธ์นี้เสนอการใช้ข้อมูลตำแหน่งของโนดในการจัดเส้นทางสำหรับโครงข่ายแอดฮอกที่มีประสิทธิภาพและเชื่อถือได้ ในวิทยานิพนธ์นี้จะมีการอธิบายอัลกอริทึมจัดเส้นทางโดยอาศัยตำแหน่งและเสนอวิธี Multipath Location-Aided Routing (MLAR) แทนวิธี Location-Aided Routing (LAR) วิทยานิพนธ์นี้จำลองแบบโดยใช้ ns-2 เพื่อศึกษาสมรรถนะและคุณสมบัติอื่น ๆ ของวิธี MLAR และเปรียบเทียบวิธี MLAR กับวิธี Ad Hoc On-Demand Distant Vector (AODV), วิธี Ad Hoc On-Demand Multipath Distant Vector (AOMDV) และวิธี LAR โดยกำหนดให้การเคลื่อนที่ของโนดแต่ละโนดเป็นแบบสุ่ม ภายใต้ขอบเขตการเคลื่อนที่และรูปแบบการสื่อสารที่เหมือนกัน ผลการจำลองแบบแสดงให้เห็นว่าวิธี MLAR มีประสิทธิภาพสูงกว่าวิธี LAR และวิธี AODV สำหรับรูปแบบการเคลื่อนที่ส่วนใหญ่ วิธี AOMDV สามารถส่งแพ็กเกตได้มากกว่าวิธี MLAR แต่ทำให้จำนวนครั้งที่เกิด flooding ของแพ็กเกตควบคุมมากขึ้น ส่งผลให้วิธี AOMDV ใช้แบนด์วิดท์มากกว่าวิธี MLAR.

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ปีการศึกษา 2548	

4670657521: MAJOR ELECTRICAL ENGINEERING
KEY WORD: AD HOC NETWORKS / AD HOC ROUTING / MULTIPATH ROUTING / DSR / AODV / LAR.

HA DUYEN TRUNG: MULTIPATH LOCATION-AIDED ROUTING METHOD FOR AD HOC NETWORKS. THESIS ADVISOR: ASSOC. PROF. WATIT BENJAPOLAKUL, D.ENG, 60 pp. ISBN 974-17-4810-8.

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. There are a number of routing schemes that have been proposed and several of these have been already extensively simulated or implemented as well. The primary applications of such networks have been in disaster relief operations, military use, conferencing, and environment sensing. There are many routing algorithms at present that use position information to make routing decisions at each node. Our goal is to utilize position information to provide more reliable as well as efficient routing for ad hoc network. We hence describe extensions to location-aided routing algorithm. We proposed replacing Location-Aided Routing (LAR) with multipath LAR (MLAR). We have implemented MLAR through simulation using ns-2 and study its efficiency, and other properties. We use random waypoint mobility and compare MLAR approach versus Ad Hoc On-Demand Distant Vector (AODV), Ad Hoc On-Demand Multipath Distant Vector (AOMDV) and LAR methods for a range of movement and communication models. Our simulation results demonstrate the performance benefits of MLAR over LAR and AODV in most movement scenarios. AOMDV delivers more packets than MLAR consistently, but does more frequent flooding of control packets and thus higher bandwidth usage than MLAR.

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Academic year 2005

ACKNOWLEDGEMENTS

With the help and support from various organizations and people, I could complete my study. Thus, I would like to express my appreciation and grateful thanks to:

The JICA Project for AUN/SEED-Net (ASEAN University Network / Southeast Asia Engineering Education Development Network) for providing me the scholarship to study at Chulalongkorn University.

The International School of Engineering (ISE), Chulalongkorn University for giving me the chance to have the scholarship to study at Chulalongkorn University.

I would like to express my deep gratitude to Associate Professor Dr. Watit Benjapolakul, my advisor and my teacher, for his continuous supports, kindly helps, and recommendations throughout my time as his graduate student at Chulalongkorn University. Without his aids, encouragement, suggestion, and supervision, this thesis could not have made possible.

Also, I would like to send my great gratitude to all professors of the Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University, for their guides and helps during the time I have studied at Chulalongkorn University. My special thanks are sent to Associate Professor Dr. Somchai Jittapunkul, Assistant Professor Dr. Chaodit Aswakul, Dr. Chaiyachet Saivichit for their valuable comments and academic suggestions on my research work.

My appreciation goes to my friends for their enthusiasm and all what they have done for me during my study in Thailand.

Last but not least, my special thanks go to all members of my family for what they have done for me when I have studied far from home. Without their help I could not be able to complete my study.

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LIST OF ABBREVIATION

ABR	Associativity Based Routing
AODV	Ad Hoc On-Demand Distance Vector Routing
AOMDV	Ad Hoc On-Demand Multipath Distance Vector Routing
CBR	Constant Bite Rate
DCF	Distributed Coordination Function
DPF	Packet Delivery Fraction
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
DSRP	Dynamic Source Routing Protocol
EMI	Electro-Magnatic Internet
FSR	Fisheye State Routing
GLS	Geographic Location Service
GPS	The Global Positioning System
GSR	Global State Routing
HSR	Hierarchical State Routing
IETF	Internet Engineering Task Force
LAR	Location Aided Routing
MAC	Medium Access Control
MANETs	Mobile Ad Hoc Netwotks
MDSR	Multipath Dynamic Source Routing
MLAR	Multipath Location Aided Routing
MN	Mobile Node
NS	Network Simulator
RERR	Route Error Message
RREP	Route Reply Message
RREQ	Route Request Message
SSR	Signal Stability Routing
TCL	Tool Command Language
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

CHAPTER I

INTRODUCTION

1.1 Overview and Motivation

A mobile ad-hoc network (often referred to as MANET) is the one consisting of a collection of mobile nodes (MNs) sharing a wireless channel without any centralized control or established communication backbone. Ad hoc networks have no fixed routers; all nodes are capable of movement and can be connected dynamically in an arbitrary manner. Usually, these nodes act as both end systems and routers at the same time. Nodes of these networks, which function as routers, discover and maintain routes to other nodes in the network. The topology of the ad hoc network depends on the transmission power of the nodes and the location of the MNs, which may change with time. A working group namely "MANET" has been formed by the Internet Engineering Task Force (IETF) to study the related issues and stimulated research in MANET [1].

A fundamental problem in ad hoc networking is how to deliver data packets among MNs efficiently without predetermined topology or centralized control, which is the main objective of ad hoc routing protocols. Since mobile ad hoc networks change their topology frequently, routing in such networks is a challenging task. So far, much work has been done on routing in ad hoc networks. The current work can be divided into three categories: proactive protocols, reactive protocols and position-based routing protocols.

Proactive routing protocol includes: Destination Sequenced Distance Vector (DSDV) [2], Global State Routing (GSR) [3], Fisheye State Routing (FSR) [4], Hierarchical State Routing (HSR) [5, 6] etc. They attempt to maintain a correct view of the network topology add the time and build routes from each node to every other node before they are needed, hence they are also called table-driven protocols. Any changes in topology are propagated through the network, so that all nodes know of the changes in topology. Thereby, proactive protocols maintain routing information about the available paths in the network even if these paths are not currently used. The major drawback of these approaches is that the maintenance of unused paths may occupy an important part of the available bandwidth if the topology of the network changes frequently [7].

Reactive routing protocols includes: Ad hoc On-demand Distance Vector Routing (AODV) [8, 9], Dynamic Source Routing Protocol (DSRP) [10], Associativity Based Routing (ABR) [11], and Signal Stability Routing (SSR) [12] etc. Reactive routing protocols maintain only the routes that are currently in use, thereby trying to maintain low control overhead, reducing the load on the network when only a small subset of all available routes is in use at any time. However, they still have some inherent limitations. First, since routes are only maintained while in use, it is usually required to perform a route discovery before packets can be exchanged between communication peers. This leads to a delay for the first packet to be transmitted. Second, even though route maintenance for reactive algorithms is restricted to the routes currently in use, it may still generate an important amount of network traffic when the topology of the network changes frequently. Finally, packets to the destination are likely to be lost if the route to the destination changes.

Position-based routing algorithms in ad hoc network reduce some of the limitations of proactive and reactive routing in ad hoc network by using additional information (location information) from the Global Positioning System (GPS)[1]. The requirement is information about the physical position of the participating nodes be available [13, 14, 15, 16, 17]. The routing decision at each node is then based on the destination’s position contained in the packet and the position of the forwarding node’s neighbors. Position-based routing thus does not require the establishment or maintenance of routes. The nodes have neither to store routing tables nor to transmit messages to keep routing tables up-to-date. So far, several work has been done on Position-based routing in ad hoc

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[1] We will use the terms position and location interchangeably.

networks, such as Location Aided Routing protocol (LAR) [18] and so on [19 - 23].

Following the description above, the key challenge in mobile ad hoc networks is to be able to route with low overheads even in dynamic conditions of node mobility, limited channel bandwidth and limited battery power of nodes. Overhead here is defined in terms of the routing protocol control messages which consume both channel bandwidth as well as the battery power of nodes for communication/processing. Several performance studies [7, 18] of ad hoc networks have shown that on-demand protocols earn lower routing overheads compared with proactive counterparts, and position based routing protocols are lower than on-demand reactive routing.

Most existing ad hoc routing protocols build and utilize only one single route for each pair of source and destination nodes. Due to node mobility, node failures, and the dynamic characteristics of the radio channel, links in a route may become temporarily unavailable, making the route invalid. The overhead of finding alternative routes may be high and extra delay in packet delivery may be introduced. Multipath routing addresses this problem by providing more than one route to a destination node. Source and intermediate nodes can use these routes as primary and backup routes.

High route discovery latency together with frequency route discovery attempts in dynamic networks can affect the performance adversely. Multipath protocols try to alleviate these problems by computing multiple paths in a single route discovery attempt. Multiple paths could be formed at both traffic sources as well as at intermediate nodes. New route discovery is needed only when all paths fail. This reduces both route discovery latency and routing overheads. Multiple paths can also be used to balance load by forwarding data packets on multiple paths at the same time [24], though we will not investigate this aspect in our work.

Our work motivates to provide the improvement of multiple paths location-aided routing method over unipath location-aided routing in terms of packet delivery, end to end delay through simulation using

Network Simulator (ns). We thus propose a method by replacing LAR with multipath LAR (MLAR) to improve performance of overall routing metrics. Location information can be used to reduce propagation of control packets, to perform controlled flooding, to maintain routes in mobility conditions and to make simplified packet forwarding decisions. We will also compare the performance of the MLAR with LAR in terms of packet delivery fraction (pdf), average end to end delay, and control overhead in most scenarios. We will also implement the performance difference between AODV and AOMDV to see how AOMDV does better than AODV in a factor of two of wide range of movement and communication models.

1.2 Scopes and Goals

The research proposal aims to achieve the following primary goals:

1. Implement the unipath and multipath routing methods for MANETs in network simulator (ns-2).
2. Evaluate the performances of a well-studied-non-position routing protocol known as Ad hoc On-demand Distance Vector (AODV) and location information based routing protocol known as Location-Aided Routing (LAR) in terms of routing overhead, packet delivery fraction, and average end-to-end delay via a simulation on a uniform platform.
3. Investigate to develop a multiple path routing method as an extension to LAR. We refer to this method as Multipath Location-Aided Routing (MLAR) method.

1.3 Expected Benefits

1. To study well-studied routing protocols used in Mobile Ad Hoc Networks and their performance evaluation with ns-2.
2. To study the unipath, multipath methods and their performance evaluation.

3. To use the multipath routing method via the proposed method to reduce both route discovery latency and routing overheads.

1.4 Thesis Organization

This chapter provides an introduction to the reader about the general domain this thesis pertains to, namely, wireless mobile ad hoc networking. This thesis is organized as follows. In Chapter II we describe the literature review of Mobile Ad Hoc Networks (MANETs). Chapter III describes our proposed multipath location-aided routing method as an extension to LAR for Ad Hoc Networks based on simulation. Chapter IV describes the implementation information of multipath location routing in Network Simulator. The performance evaluation and comparison between four methods are interpreted in Chapter V. Finally, Chapter VI concludes our work and the future works.

CHAPTER II

LITERATURE REVIEW OF MOBILE AD HOC NETWORKS

This chapter provides the literature review of mobile ad hoc network. Unipath routing in MANETs is describes in section 2.1. Section 2.2 will describe the multipath routing in MANETs. Comparison of unipath and multipath routing is describes in section 2.3.

2.1 Mobile Ad Hoc Networks

In MANETs, communication between nodes is done through the wireless medium. Because nodes are mobile and may join or leave the network, MANETs have a dynamic topology. Nodes that are in transmission range of each other are called neighbors. Neighbors can communicate directly to each other. However, when a node needs to send data to another non-neighboring node, the data are routed through a sequence of multiple hops, with intermediate nodes acting as routers. An example ad hoc network is depicted in Figure 2.1.

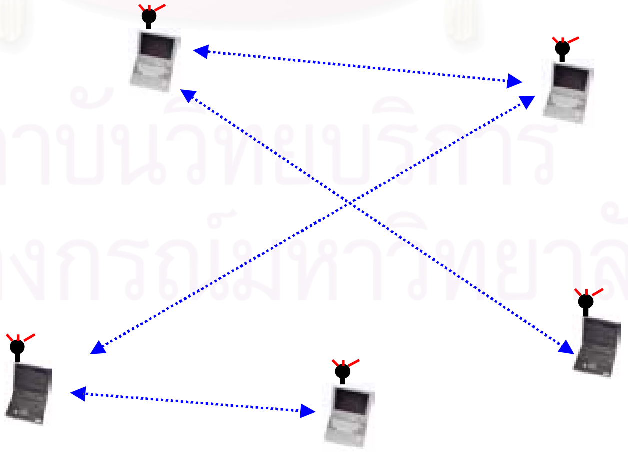

Figure 2.1: An example ad hoc network.

Figure 2.1 shows an example ad hoc network, two nodes that are in transmission range of each other are connected by a dot line

There are numerous issues to consider when deploying MANETs. The following are some of the main issues.

1. **Unpredictable environment:** Ad hoc networks may be deployed in unknown terrains, hazardous conditions, and even hostile environments where tampering or the actual destruction of a node may be imminent. Depending on the environment, node failures may occur frequently.
2. **Unreliability of wireless medium:** Communication through the wireless medium is unreliable and subject to errors. Also, due to varying environmental conditions such as high levels of electro-magnetic interference (EMI) or bad weather, the quality of the wireless link may be unpredictable. Furthermore, in some applications, nodes may be resource-constrained and thus would not be able to support transport protocols necessary to ensure reliable communication on a loss link. Thus, link quality may fluctuate in a MANET.
3. **Resource-constrained nodes:** Nodes in a MANET are typically battery powered as well as limited in storage and processing capabilities. Moreover, they may be situated in areas where it is not possible to re-charge and thus have limited lifetimes. Because of these limitations, they must have algorithms which are energy-efficient as well as operating with limited processing and memory resources. The available bandwidth of the wireless medium may also be limited because nodes may not be able to sacrifice the energy consumed by operating at full link speed.
4. **Dynamic topology:** The topology in an ad hoc network may change constantly due to the mobility of nodes. As nodes move in and out of range of each other, some links break while some links between nodes are created.

As a result of these issues, MANETs face with numerous types of faults including,

1. **Transmission errors:** The unreliability of the wireless medium and the unpredictability of the environment may lead to transmitted packets being distorted and thus received in error.
2. **Node failures:** Nodes may fail at any time due to different types of hazardous conditions in the environment. They may also drop out of the network either voluntarily or when their energy supply is depleted.
3. **Link failures:** Nodes failures as well as changing environmental conditions (e.g., increased levels of EMI) may cause links between nodes to break.
4. **Route breakages:** When the network topology changes due to node/link failures and/or node/link additions to the network, routes become out-of-date and thus incorrect. Depending upon the network transport protocol, packets forwarded through stale routes may either eventually be dropped or be delayed; packets may take a circuitous route before eventually arriving at the destination node.
5. **Congested nodes or links:** Due to the topology of the network and the nature of the routing protocol, certain nodes or links may become over utilized, i.e., congested. This will lead to either larger delays or packet loss.

Routing protocols for MANETs must deal with these issues to be effective. In the remainder of this section, we present an overview of some of the key unipath routing protocols for MANETs.

2.2 Unipath Ad Hoc Routing

Routing protocols are used to find and maintain routes between source and destination MNs. Three main classes of ad hoc routing protocols are summarily represented earlier: table-based (proactive), on-demand (reactive) and position-based protocols. In table-based protocols, each MN must periodically exchange message with routing information to keep routing table up-to-date. Therefore, routes between MNs are computed and stored, even when they are not needed. Table-based protocols may be impractical, especially for large, highly mobile networks. Because of the dynamic nature of ad hoc networks, a considerable number of routing message may have to be exchanged in order to keep routing information accurate or up-to-date.

In on-demand protocols, MNs only compute routes when they are needed. Therefore, on-demand protocols are more scalable to dynamic, large networks. When an MN needs a route to another MN, it initiates a route discovery process to find a route. On-demand protocols consists of the following two main phases.

1. Route discovery is the process of finding a route between two nodes (see Figure 2.2).
2. Route maintenance is the process of repairing a broken route or finding a new route in the presence of a route failure (see Figure 2.3).

Most currently proposed routing protocols for ad hoc networks are unipath routing protocols. In unipath routing, only a single route is used between a source and destination MN. Two of the most widely used protocols are the Dynamic Source Routing (DSR) [10] and the Ad hoc On-demand Distance Vector (AODV) [8, 9] protocols. DSR and AODV are both well-studied on-demand protocols. Since the multipath routing protocols discussed later are an extension of one of these two protocols, the following subsection gives a brief overview of DSR and AODV.

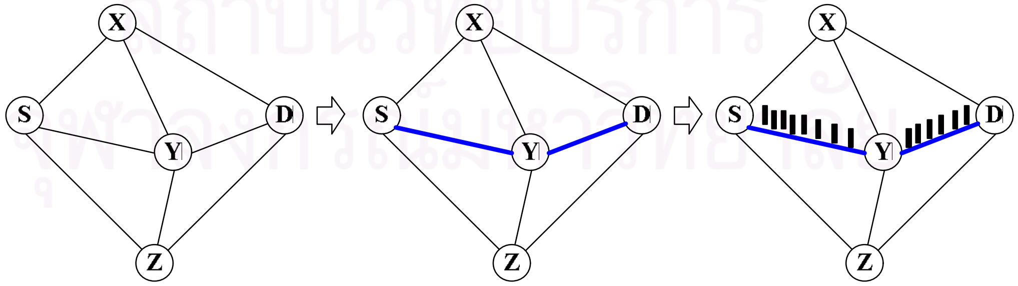

Figure 2.2: An example of route discovery in an ad hoc network.

Figure 2.2 shows an example of route discovery in an ad hoc network; node S sends data to node D, it must first discover a route to D going though node Y, and set up the route. Once the route is established, S can begin sending data to D along the route.

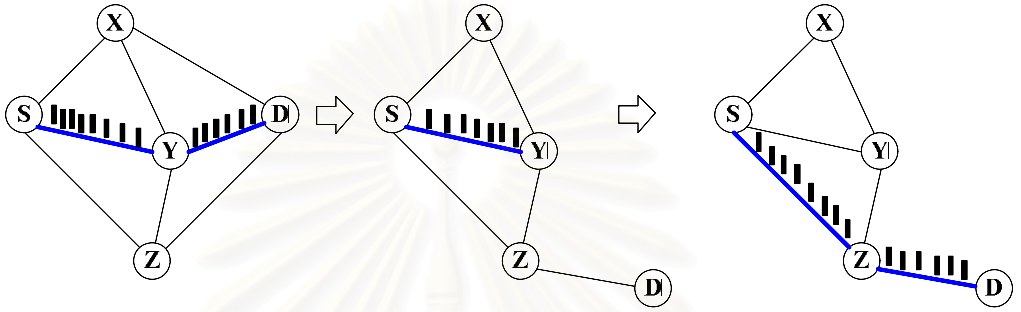

Figure 2.3: An example of route maintenance in an ad hoc network.

Figure 2.3 illustrates an example of route maintenance in an ad hoc network; node S sends data along an established route to node D through node Y. When D moves out of range of Y, this route breaks. S finds a new route to node D through node Z, and thus can begin sending data to D again.

2.2.1 Dynamic Source Routing

Dynamic source routing (DSR) [10] is an on-demand routing protocols for ad hoc networks. Like any source routing protocol, in DSR the source includes the full route in the packets' header. The intermediate nodes use this to forward packets towards the destination and maintain a route cache containing routes to other MNs.

Route discovery. If the source does not have a route to the destination in its route cache, it broadcasts a route request (RREQ) message specifying the destination node for which the route is requested. The RREQ message includes a route record which specifies the sequence of nodes traversed by the message. When the destination receives the RREQ, it sends back a route reply message (RREP). If the destination has a route to the source in its route cache, then it can send a route response (RREP) message along this route. Otherwise, the RREP message can be sent along the reverse route back to the source. Intermediate nodes may also use their route cache to reply to RREQs. If an intermediate node has a route to the destination in its cache, then it can append the route to the route record in the RREQ, and send an RREP back to the source containing this route. This can help limit flooding of the RREQ. However, if the cached route is out-of-date, it can result in the source receiving stale routes.

Route maintenance. When a node detects a broken link while trying to forward a packet to the next hop, it sends a route error (RERR) message back to the source containing the link in error. When an RERR message is received, all routes containing the link in error are deleted at that node.

2.2.2 Ad Hoc On-Demand Distance Vector Routing

Ad hoc on-demand distance vector (AODV) routing [8, 9] is an on-demand routing protocol for ad hoc networks. However, as opposed to DSR, which uses source routing, AODV uses hop-by-hop routing by maintaining routing table entries at intermediate nodes.

Route Discovery. The route discovery process is initiated when a source needs a route to a destination and it does not have a route in its routing table. To initiate route discovery, the source floods the network with an RREQ packet specifying the destination for which the route is requested. When a node receives an RREQ packet, it checks to see whether it is the destination or whether it has a route to the destination. If either case is true, the node generates an RREP packet, which is sent back to the source along the reverse path. Each node along the reverse path sets up a forward pointer to the node it received the RREP from. This sets up a forward path from the source to the destination. If the node is not the destination and does not have a route to the destination, it rebroadcasts the RREQ packet. At intermediate nodes duplicate RREQ packets are discarded. When the source node receives the first RREP, it can begin sending data to the destination.

To determine the relative degree out-of-datedness of routes, each entry in the node routing table and all RREQ and RREP packets are tagged with a destination sequence number. A large destination sequence number indicates a more current (or more recent) route. Upon receiving an RREQ or RREP packet, a node updates its routing information to set up the reverse or forward path, respectively, only if the route contained in the RREQ or RREP packet is more current than its own route.

Route Maintenance. When a node detects a broken link while attempting to forward a packet to the next hop, it generates an RERR packet that is sent to all sources using the broken link. The RERR packet erases all routes using the link along the way. If a source receives an RERR packet and a route to the destination is still required, it initiates a new route discovery process. Routes are also deleted from the routing table if they are unused for a certain amount of time.

In position-based routing protocols, the route discovery at each node based on the destination’s position contained in the packet and the position of the forwarding node’s neighbors. Position-based routing thus does not require the establishment or maintenance of routes. The MNs have neither to store routing tables nor to transmit message to keep routing table up-to-date. So far, some proposed work has been studied on unipath routing protocols, such as Location-Aided Routing (LAR) [18] and so on [19-23]. The following subsection presents a review of LAR.

2.2.3 Location-Aided Routing

2.2.3.1 Protocol Overview

LAR [18] is an on-demand source routing protocol, like DSR. The main difference between LAR and DSR is that LAR sends location information in all packets to (hopefully) decrease the overhead of a future route discovery in wireless ad hoc networks. In DSR, if the neighbors of S do not have a route to D, S floods the entire ad hoc network with a route request packet to D. LAR uses location information for MNs to flood a route request packet for D in a *request zone* instead of in the entire ad hoc network. This request zone is defined by location information on D.

In Figure 2.4; source node S determines its neighbors within the request zone by using the location of S and the *expected zone* for destination node D. The expected zone is a circular area determined by the most recent location information on D, (X_D, Y_D), the time of this location information, (t_0), the average velocity of D, (V_{avg}), and the current time, (t_1). This information creates a circle with radius $R = V_{avg} * (t_1 - t_0)$ centered at (X_D, Y_D). The request zone is a rectangle whose corners are S, A, B, and C, current location of node S is denoted as (X_S, Y_S).

If a neighbor of S determines it is within the request zone, it forwards the route request packet further. Another MN that is not a neighbor of S determines it is within the request zone or not by using the location of the neighbor that sent the MN the route request packet and the expected zone for D based on the most recent available information. Thus the request zone and the expected zone adapt during transmission. For instance, in Figure 2.4, if node $N(X_{next}, Y_{next})$ receives the route request from another node, node N forwards the request to its neighbors, because N determines that it is within the rectangular request zone. However, when node O(X_O, Y_O) receives the route request zone, node O discards the request, as node O is not within the request zone.

When node D receives the route request message, it replies by sending a route reply message. However, in case of LAR, node D includes its current location and current time in the route reply message. When node S receives this route reply message (ending its route discovery), it records the location of node D. Node S can use this information to determine the request zone for a future route discovery. (It is also possible for D to include its current speed into the route reply message).

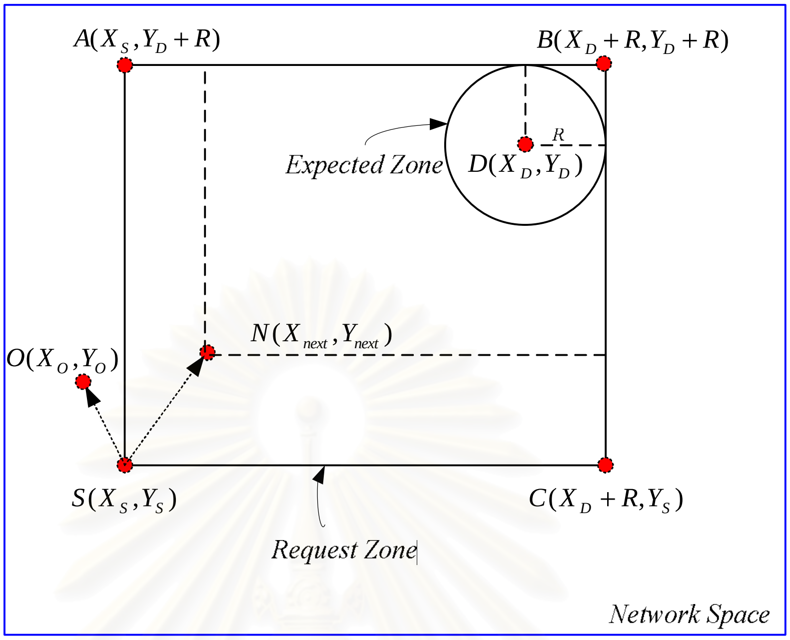

Figure 2.4: Expected and request zones in LAR (Adapted from [18]).

Size of the Request Zone: Note that the size of the rectangular request zone above is proportional to (i) average speed of movement V_{avg}, and (ii) time elapsed since the last known location of the destination was recorded. In our implementation, the sender comes to know location of the destination only at the end of a route discovery. At low speeds, route discoveries occur after long intervals, because routes break less frequently (thus, $t_1 - t_0$ is large). So, although factor (i) above is small, factor (ii) becomes large at low speed as well, for similar reasons, a large request zone may be observed. So, in general, a smaller request zone may occur at speeds that are neither too small, nor too large. For low speeds, it is possible to reduce the size of the request zone by piggybacking the location information on other packets.

Error in Location Estimate: In the above, we assume that each node knows *its own* location accurately. However, in reality there may be some error in the estimated location. Let *e* denote the maximum error in the coordinates estimated by a node. Thus, if a node N believes that it is at location (*Xn, Yn*), then the actual location of node N may be anywhere in the circle of radius *e* centered at (*Xn, Yn*).

We will refer to *e* as location error factor. In the above LAR scheme, we assume that node S obtained the location (*Xd, Yd*) of node D at time t_0, from node D (perhaps in the route reply message during the previous route discovery). Thus, node S does not know the actual location of node at time t_0 – the actual location is somewhere in the circle of radius *e* centered at (*Xd, Yd*).

To take the location error *e* into account, modifying LAR so that the expected zone is now a circle of radius $R = e + V_{avg} * (t_1 - t_0)$ [18]. The request zone may now be bigger, as it must include the larger request zone. Apart from this, no other change is needed in the algorithm. As the request zone size increases with *e*, the routing overhead may be larger for large *e*.

LAR includes a two stage route discovery method. In the first stage, the route request packet is forwarded according to LAR scheme. If a route reply packet is not received within the route request timeout period, then a second route request packet is flooded through the entire nodes in ad hoc network. If a route reply packet is not received again within the route request timeout period (30s), then D is considered unreachable and packets are dropped.

2.2.3.2 Implementation Decisions

The variations and optimizations (except the alternative definitions of the request zone) have been proposed in [18]. These optimizations include adaptation of the request zone based on more recent location information, propagation of location and speed information in every packet transmitted, and local search for route repair. Two of these three optimizations will be considered. We do not include the local search optimizations (see [18]).

a) Adaptation of the Request Zone:

Accuracy of *request zone* (i.e., probability of finding a route to the destination) can be improved by adapting the *request zone*, initially determined by the source node S, with up-to-date location information for node D, which can be acquired at some intermediate MNs. Let us consider the case that node S starts search of a destination node D within a *request zone* at time t_1, which is based on location information about D learned by S at time t_0. Let us assume that the route request includes the timestamp t_0, because the location of node D at time t_0 is used to determine the *request zone*. Also, location of node S and the time t_1 when the request is originated are also included. Now suppose that some intermediate node N within *request zone* receives the route request at time t_2, where $t_1 < t_2$. More recent location information for D may potentially be known by node N (as compared to node S), and the *expected zone* based on that information may be different from previous *request zone*. Therefore, *request zone* initially determined at a source node may be adapted at node N.

b) Propagation of Location and Speed Information:

Initially, in ad hoc network environments, a MN may not know the physical location (either current or old) of other MNs. However, as time progress, each node can get location information from many hosts either as a result of its own *route discovery* or as a result of message forwarding for another node’s route discovery. For instance, if node S includes its current location in the *route reply* message, then each node receiving these messages can know the locations of nodes S and D, respectively. In general, location information may be propagated by piggybacking it on any packet. Similarly, a node may propagate to other nodes its average speed (over a recent interval of time) information. In our simulations, we assume that average speed is constant and known to all MNs. In practice, the average speed could be time-variant.

2.3 Multipath Ad Hoc Routing

Many multipath routing protocols have been proposed in literature. Standard routing protocols in ad hoc wireless networks, such as AODV and DSR, are mainly intended to discover a single route between a source and destination node. Multipath routing, consisting of finding multiple source and destination node pairs, can be used to compensate for the dynamic and unpredictable nature of ad hoc networks.

2.3.1 Background

Multipath routing has been explored in several different contexts. Traditional circuit switched telephone networks used a type of multipath routing called alternate path routing. In alternate path routing, each source node and destination node has a set of paths (or multipaths) which consists of a primary path and one or more alternate paths. Alternate path routing was proposed in order to decrease the call blocking probability and increase overall network utilization.

In alternate path routing, the shortest path between exchanges is typically one hop across the backbone network; the network core consists of a fully connected set of switches. When the shortest path for a particular source destination pair becomes unavailable (due to either link failure or full capacity), rather than blocking a connection, an alternate path, which is typically two hops is used. Well-known alternate path routing scheme such as Dynamic Alternative Routing is proposed and evaluated in [25].

Alternate or multipath routing has also been addressed in data networks which are intended to support connection-oriented networks. However, in packet-oriented networks, like Internet, multipath routing could be used to alleviate congestion by routing packets from highly utilized links to links which are less highly utilized. The drawback of this approach is that the cost of storing extra routes for each router usually precludes the use of multipath routing.

The use of multipath routing for ad hoc networks is currently not new and has been studied by many authors as extensions to existing protocols as well as for entire new ones. There are several ways to use the multiple paths. If multipath routes are stored in the caching but only one path is used for transmission at a time, other paths are kept as backup paths in case the used one is broken; multipath routing is generally called alternate path routing - the multipaths are not used simultaneously, where as if more than one path is used at the same time it is referred to as simultaneous or disjoint multipath routing, which disperses the data traffic along different paths. The dispersity routing can be divided into redundant and non-redundant routing. In [26], I. Stojmenovic showed via simulation that, while multipath routing may increase routing overhead while finding multiple routes, they have the potential for selections in network traffic load balancing, if data are sent simultaneously along multiple paths. In simulation studies on Ad hoc On-demand Multipath Distance Vector Routing (AOMDV) [27], where data are sent via just a single path at a time, the authors stated that multipath variant of AODV [8, 9] have improved the packet delivery ratios for CBR (Constant Bit Rate)/UDP (User Datagram Protocol) traffic by up to 40% and significantly reduced the packet delivery latency, often more than a factor of a wide range of movement and communication models. They also stated that routing overhead in this method was improved by 30% since less route discovery phases ware required against AODV. However, they do note that at higher mobility the performance difference between AODV and AOMDV is much lower. In this thesis, we will find AOMDV does better than AODV in terms of delivery ratio fraction in most scenarios at a cost of increased flooding. The AODV and AOMDV protocols are explained in more detail in this thesis.

The Dynamic Source Routing (DSR) [10] protocol includes the optimization of using an alternate cached path when a path fails as an optimization, but it is not explored. Some other authors have proposed multiple paths DSR and alternate path DSR protocols and evaluate their performance via simulation. Thus we are curious to study how well a position based algorithm for routes of multiple paths of LAR using a multipath route caching strategy will be against other states of non-position based algorithms AODV (unipath) and AOMDV (multiple paths), as well as the position based algorithm LAR (unipath).

2.3.2 Applications

The primary use of multipath routing is to provide backup routes on the source and intermediate nodes. Nasipuri and Castaneda [28] show that multipath routing can increase the lifetime of routes and reduce the frequency of route queries for on-demand routing protocols. By reducing the chance of route disruption, multipath routing effectively increases the packet delivery fraction.

As mentioned before, multipaths can also provide load balancing, and improve link utilization in ad hoc networks. Load balancing can be achieved by spreading the traffic along multiple routes. The MDSR extension distributes load among multiple paths based on the measurement of round-trip time. Simulation results show that packet delivery fraction and end-to-end delay are significantly improved [28].

From a fault tolerance perspective, multipath routing can provide route resilience. While routing redundant packets is not the only way to utilize multiple paths, it demonstrates how multipath routing can provide fault tolerance in the presence of route failures.

Because MNs in the network communicate through the wireless medium, radio interference must be taken into account. Transmissions from a node along one path may interfere with transmissions from a node along another path, thereby limiting the achievable throughput. However, results show that using multipath routing in ad hoc networks of high density results in better throughput than using unipath routing [29].

2.3.3 Multipath Routing Components

Multipath routing consists of two components: route discovery, route maintenance. We discuss route discovery and route maintenance components in the following subsections.

2.3.3.1 Route Discovery and Maintenance

Route discovery and route maintenance consists of finding multiple routes between a source and destination node. Multipath routing protocols can attempt to find node disjoint, link disjoint, or non-disjoint routes. Node disjoint routes have no nodes or links in common. Link disjoint routes have no links in common, but may have nodes in common. Non-disjoint routes can have nodes and links in common.

Node-disjoint paths are also link-disjoint. Braided paths relax requirement for nodes disjointness, which means that alternate paths in a braid are partially overlaid with the primary path, i.e., they are not completely disjoint. As illustrated in Figure 2.5, A-B-C-D-E-I and A-F-G-H-I are node-disjoint paths, and A-F-G-H-I and A-F-J-K-L-I are braided paths

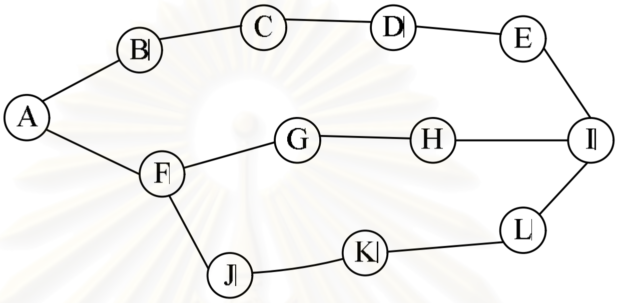

Figure 2.5: Disjoint and braided multiple paths.

Disjoint routes offer certain advantages over non-disjoint routes. For instance, non-disjoint routes may have lower aggregate resources than disjoint routes, because non-disjoint routes share links or nodes. In principle, node disjoint routes offer the most aggregate resources, because neither links nor nodes are shared between the paths. Disjoint routes also provide higher fault-tolerance. When using non-disjoint routes, a single link or node failure will only cause a single route to fail. However, with link disjoint routes, a node failure can cause multiple routes that share that node to fail.

The main advantage of non-disjoint routes is that they can be more easily discovered. Because there are no restrictions that require the routes to be node or link disjoint. Node-disjoint routes are the least abundant and hardest to find due to node-disjointedness is a stricter requirement than link-disjointedness. Given the trade-offs between using node disjoint versus non-disjoint routes, link disjoint routes offer a good compromise between the two. In the following of studies, we will review some of the proposed multipath protocols for finding node disjoint, link disjoint routes and using link disjoint to discover multiple paths of LAR in our proposed work section.

In proactive routing protocols, each node has a complete view of the network topology and all possible paths to a destination can be constructed using modified link state or distance vector algorithm. On-demand protocols, however, avoid periodic broadcast of full topology information to reduce routing overhead. When a route to a destination is required a route request is flooded to the network until an up-to-date route to the destination is found. To avoid unnecessary route request broadcast, intermediate nodes usually drop duplicate route requests. Another important optimization for on-demand protocols is the use of route caches on intermediate nodes. However, such optimization techniques reduce the chance of discovering multiple paths.

After a source begins sending data along multiple routes, some or all of the routes may break due to node mobility and / or link and mobile node failures. As in unipath routing, route maintenance must be performed in the presence of route failures. In multipath routing, route discovery can be triggered each time one of the routes fails or only after all the routes fail.

2.3.3.2 AOMDV

Ad hoc On-demand Multipath Distance Vector (AOMDV) [27] is an extension to the AODV protocol for computing multiple loop-free and link-disjoint paths. To keep track of multiple routes, the routing entries for each destination contain a list of the next-hops along with the corresponding hop counts. All the next hops have the same sequence number. For each destination, a node maintains the advertised hop count, which is defined as the maximum hop count for all the paths. This is the hop count used for sending route advertisements of the destination. Each duplicate route advertisement received by a node defines an alternate path to the destination. To ensure loop freedom, a node only accepts an alternate path to the destination if it has a less hop count than the advertised hop count for that destination. Because the maximum hop count is used, the advertised hop count therefore does not change for the same sequence number. When a route advertisement is received for a destination with a greater sequence number, the next-hop list and advertised hop count are reinitialized.

AOMDV can be used to find node-disjoint or link-disjoint routes. To find node-disjoint routes, each node does not immediately reject duplicate RREQs. Each RREQ arriving via a different neighbor of the source defines a node-disjoint path. This is because nodes cannot broadcast duplicate RREQs, so any two RREQs arriving at an intermediate node via a different neighbor of the source could not have traversed the same node. In an attempt to get multiple link-disjoint routes, the destination replies to duplicate RREQs, the destination only replies to RREQs arriving via unique neighbors. After the first hop, the RREPs follow the reverse paths, which are node-disjoint and thus link-disjoint. The trajectories of each RREP may intersect at an intermediate node, but each takes a different reverse path to the source to ensure link-disjointness.

2.4 Comparison of Unipath and Multipath Routing

The main advantage of DSR and AODV is its simplicity. In DSR, while nodes do maintain route caches, they do not need to maintain routing tables with forwarding information, as in AODV. However, with both DSR and AODV as we know, they are based on variations of flooding, more overhead is incurred in routing data packets, since the entire route must be specified in the packet header. LAR [18] presents the limitation of search for a route to the request zone, determined based on expected location of the destination node at the time of route discovery. Simulation results indicate using location information results in significantly shorter routing overhead, as compared with an algorithm that does not use location information.

The multipath extensions to AODV and LAR inherit advantages and disadvantages from their parent protocols. The primary advantage of AOMDV is that it allows intermediate nodes to reply to RREQs, while still selecting disjoint paths. However, it also has more messages overhead during route discovery due to increased flooding. Additionally, in the multipath protocols, the destination replies to multiple RREQs, which results in longer overhead.

The primary disadvantages of multipath routing protocols compared with unipath protocols are complexity and overhead, but provides better performance in term of route discovery latency. In the case of multipath extensions to AODV, maintaining multiple routes to a destination results in larger routing tables at intermediate nodes. Multipath routing can result in packet reordering. In this research, a method of multipath routing extension to LAR, MLAR, is proposed in the next chapter.

CHAPTER III

THE PROPOSED MULTIPATH LOCATION – AIDED ROUTING METHOD

In this chapter, we will describe the proposed multiple paths location-aided routing method as extension to LAR to provide better performance in terms of packet delivery and routing discovery latency.

In order to create the multiple path variant of LAR (refer to as MLAR), we start with the code base for LAR to work with network simulator ns-2. LAR is basically an on-demand *source routing* algorithm like DSR. That is, the sender knows the completed hop-by-hop route to the destination. These routes are stored in a *route cache*. The data packets carry the source route in the packet header.

The advantage of LAR is location awareness and LAR tries to find routes with minimal flooding using the information available about the source and destination positions. Multiple path of LAR is created which aggressively uses route caching of alternate paths between the source and destination but does not use simultaneous multiple paths between the source and destination which can lead to out-of-order packet delivery problems (packet reordering). The data packets are transmitted along one path, other paths are kept as backup paths in case the used one is broken.

For MLAR we simply cached the two most recently received routes. The reasoning for this was that in cases of high movement of nodes, the most recently received route is more likely to be more successful. In the original LAR code we received, the most recently received route was always used. Thus in LAR the path used in the most recently received route reply would be the path used for the next data packet to be sent. Of the two routes in the MLAR cache, the shorter one was selected as the primary route if it was the newer route. If both were entered in the cache at approximately the same time (the interval between two successively received paths to the same destination was less than a low threshold value), the shorter route was initially preferred. The reason why we select the most recently received path even if it was longer is simple: the most recently received path is likely to be the path most likely to succeed since mobility could cause paths to break, even if the older path in routing cache was one or two hops shorter or has a shorter record round trip delay time for the route request and reply cycle. The procedure is shown in Figure 3.1.

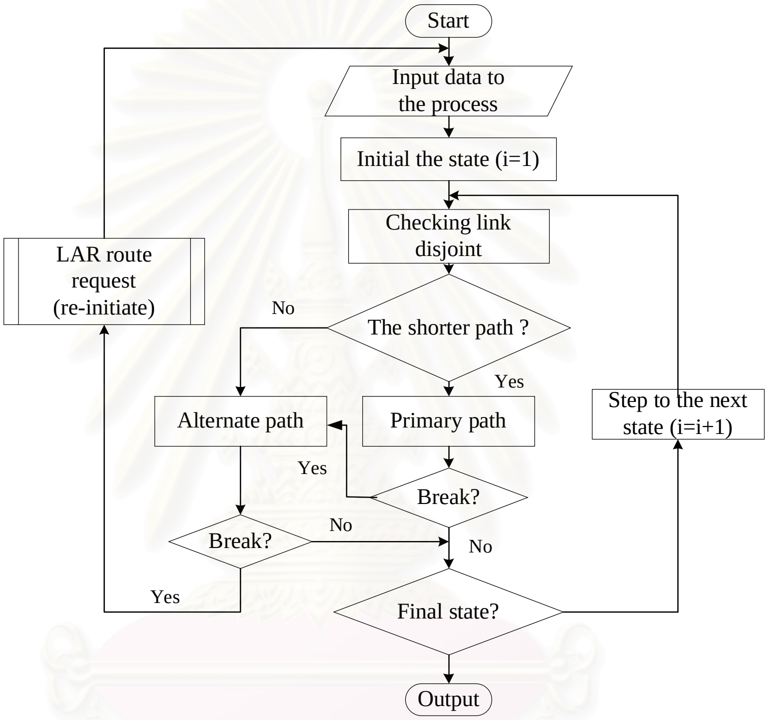

Figure 3.1: Flowchart of multipath LAR.

Routing methods in both LAR and MLAR never expire even though they are not used for extended time periods, except that a route transmission error is detected. Given that the packet header contains the entire source route. If a node detects a broken link, it tries to retransmit the data packet using an alternate path from it own cache by updating the packet header. In case alternate path is also broken, it sends a route error packet to the source to let it know of the broken link for future transmissions.

Some other works like AOMDV and multipath DSR (MDSR) make sure that the paths stored are "*link disjoint*" and have no common hop between them, or *“node disjoint”* and thus have no common nodes in their paths. MDSR lets the destination check the route request packets (RREQs) it has received and the paths within them before sending route request replies (RREPs) back to the source with the most disjoint paths. AOMDV described earlier does this by deciding in a distributed method at each MN along the route if the path is link disjoint or node disjoint. Whereas other approaches like MDSR let the destination examine the route request (RREQs) it has received and the paths within them before sending route replies (RREPs) back to the source with the most disjoint paths. We thus modified our approach to work in multiple paths of LAR (MLAR) to allow an MN to accept a second route to a destination if and only if it was link disjoint with the first cached path. This can be done by examining the same link in both paths, i.e., if the path in both routes consists of the same two MNs in the same order, the nodes are not considered. This is done at all MNs whenever a routing table entry is updated, on any data or control packet receiving since in LAR and MLAR the entire source route is available in every packet.

In simulation, if the source route path in a data packet fails, the second path is tried in the transmission. In LAR the packet would have been put into a queue at the node before the transmission failure and eventually dropped after a time out if a new route to the destination was not discovered before the timeout. An *error packet* would also be sent back to the source to let it know the broken path so that it can initiate a now *route request* and *reply cycle*. A path fails whenever the MAC layer reports back a transmission failure in reaching the next hop after a certain threshold number of resending attempts.

In MLAR, if the second path also fails in the same manner from the source, a new route request cycle is initiated. If the second failure in MLAR is at an intermediate node, the node sends an error packet to the source by the reverse route or broadcast an error message back to the source so the source and all nodes that used that old path can invalidate their caches at least beyond the breakpoint where the failure occurred.

The risk here is if the second path which is attempted to use is stale path, then we will keep trying to use it until we get first error packet or unless the first hop transmission from the source is unsuccessful. This risk can partly be minimized by having routes expire after a reasonable or adaptive value of a timeout period as suggested by [27] and several other authors as an optimization for DSR. We have not implemented this optimization for this study. However, we find MLAR perform consistently better than LAR in terms of delivery fraction, similar to the performance of AOMDV outperforms AODV by exploiting the disjointedness in the alternate paths and avoiding reinitiating request and reply cycles.

For simplicity, we will not consider using three or more cached routes for our initial study while most studies show that the gains in caching three routes are very low compared to those in caching two routes. Four or more paths generally present unimportant improvements in highly mobile scenarios [26].

To evaluate our method, we intend to perform multiple paths of LAR as an extension to LAR (refer to as MLAR) method. Network simulator (ns-2) is a discrete-event simulator used to provide flexible platform for the evaluation and comparison of network routing algorithms. Four routing methods have been simulated – AODV, AOMDV, LAR and MLAR. We intend to study several cases by varying the number of connection (sessions), moving speed to see the performance difference among them.

CHAPTER IV

IMPLEMENTATION INFORMATION

This chapter provides the implementation information of simulations in the network simulator (ns). It begins with the basic assumption in section 4.1. Section 4.2 describes the simulation information. The next section describes the route error handling. Finally, Section 4.4 provides geographic location information in ad hoc networks.

4.1 Basic Assumptions

It is generally practicable to implement most wireless ad hoc networking protocols for use in real world. Testing in this case is quite hard with real hardware, thus the preferred alternative is to implement the modeled system in a detailed simulator and then plug in various ad hoc protocols in different wide range of scenarios to measure their performance for various models of movement and communication. Simulation is not without its drawbacks obviously as even a single real world factor, such as the weather, humidity, real-world traffic model, human behavior, radio interference from other devices, physical obstacles, or material properties, might not be modeled perfectly and thus could produce entirely different performance characteristics from the MNs discovered during actual use. Some basic assumptions in our simulations are:

- Assume all MNs have information about their own physical positions and other MNs going to communicate with, from a GPS receiver at each MN[2].
- Assume each MN knows its current location *precisely* (i.e., no error), the MNs are moving in a two-dimensional plane.

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[2] Currently, the implementation and applications of GPS receiver are not concerned and assuming an ideal scenario, refer to [13, 14, 15, 16, and 17] for more information.

- Assume all MNs and their radio ranges are approximately equal and symmetric.
- Assume a free space propagation model for radio transmission (omni directional antenna).
- All the wireless links between the MNs are bidirectional.
- Most link failures occur due to mobility or confliction, skip occurring by turning MNs off.

These assumptions will be an important topic for future work, but they are appropriate for our initial comparison.

4.2 Simulation Information

We decided to use a simulator for our performance study because a practical implementation of an ad hoc network was obviously not feasible. We chose the popular network simulator ns-2 [30] as the simulator primarily to implement methods because it is widespread use in the academic community and the comprehensive manuals and tutorials that are freely available. It is possible to simulate a mobile multi-hop ad hoc wireless network in ns-2 using simulated 802.11 MAC layer. We selected ns-2 so that we could compare our approach with the other protocols on a single common and pre-validated platform for our simulations. Ns-2 version 2.28 was the most recent version of the network simulator at the time of this work; it has been started and served as a common platform for all the protocols that we wished to compare.

With permissions, we were able to use contributed code from several other authors for study. We received a copy of the AODV code based on the installation of ns-2 version 2.28. We received a compatible version of AOMDV from Mahesh K. Marina. We did not modify the AODV and AOMDV code or any their timeout values or parameters, which authors selected during their own evaluations. We received a copy of LAR code for a much earlier version of ns-2 from Tracy Camp and her project team at the Toilers group at the Colorado School of Mines. We modified their code to work with our version of ns-2 and to duplicate their performance results.

4.3 Route Error Handling

In MLAR, when a node discovers a link failure, it tries to retransmit the data using an alternate path from its own route cache by updating the packet header with the new alternate path. In either case, it sends a route error packet to the source along the reverse source route to let it know the broken link for future use. Implementation in ns-2 includes the location error factor *e* as noted in section 2.2.3.1; however, following the results presented in [18], we set the error factor to zero in all our simulations.

In order to do intermediate route repair, an intermediate route, looks into its cache and tries to find an alternate path to the destination and use it. In LAR, chances are that the path stored at the intermediate node is likely to be the same as the path in the source route in the header. Having two or more paths saved in MLAR, on the other hand provides an alternative for salvaging the packet. However, if the alternate path selected is stale and no longer available, an error packet will be ultimately generated.

On receiving an error packet which is generally flooded (route errors are only flooded when unicast route back to the source fails at any point) to ensure delivery to the source, the source can try an alternate path if it has one or try and seek a new route via a route request cycle. Link disjoint and node disjoint paths ensure that routes fail independently of each other in most cases.

The route error packet contains the addresses of the hosts at both ends of the hop in error and when it is traversing back, all routes in the route caches of all intermediate nodes containing the failed link will be removed from the caches and a new route discovery is initiated by the source if the route is still needed.

4.4 Geographic Location Information

A lot of geographic routing protocols assume the presence of Geographic Location Service (GLS) that allow each to know the position of every other node. There have been a few attempts to implement such services, but most have very high overheads since information needs to be propagated throughout the network for always single significant movement. Some simulations make use of global knowledge of positions through hooks in the simulator code and state that they assume they know the exact position of destination MNs through an assumed perfect GLS that works as a separate mechanism (called a location service) to provide location information on nodes in the ad hoc network.

Our approach for LAR and MLAR use previous knowledge of the position of a node if available. If location information is needed, a node will ask for it. If not, it floods route discovery packets in an incremental and scoped manner until the destination is found (if the network is connected and it is reachable) or until the timer expires.

CHAPTER V

PERFORMANCE EVALUATION

This chapter is organized as follows. In section 5.1, we describe the testing methodology of simulation. In section 5.2, we show the simulation results of the performance of all four routing methods under metrics versus movement in various communication scenarios. The general observations of our proposed routing method from the simulation for metrics such as packet delivery fraction, end to end delay, control packet overheads are also carried out in this section.

5.1 Methodology

5.1.1 Simulation Environment

We make use of ns-2 [30], which has support for simulating a multihop wireless ad hoc environment completed with physical, data link, and medium access control (MAC) layer models on ns-2. The Distributed Coordination Function (DCF) of IEEE 802.11 for wireless LANs is used as the MAC layer protocols. The radio model uses characteristics similar to a commercial radio interface, Lucent's WaveLAN. WaveLAN is modeled as a shared media radio with a nominal bit-rate of 2 Mbps and a nominal radio range of 250 meters.

The protocols maintain a *send buffer* of 64 packets. It contains all data packets waiting for a route, such as packets for which route discovery has started, but no reply has arrived yet. To prevent buffering of packets indefinitely, packets are dropped if they wait in the send buffer for more than 30 s. All packets (both data and routing) sent by the routing layer are queued at the *interface queue* until the MAC layer can transmit them. The interface queue has a maximum size of 50 packets and is maintained as a priority queue with two priorities each served in FIFO order. Routing packets get higher priority than data packets.

The overall goal of our tests was to measure the ability of the routing methods to react to network topology change while continuing to successfully deliver data packets to their destinations. To measure this ability, our basic methodology was to apply to a simulated network a variety of workloads, in effect, testing with each data packet originated by some sender whether the routing protocol can at that time route to the destination of that packet. We were not attempting to measure the methods' performance on a particular workload taken from real life, but rather to measure the performance under a range of conditions.

Our evaluations are based on the simulation of 50 wireless nodes forming an ad hoc network, moving about over a square (670m x 670m) flat space for 300 seconds of simulated time. We choose a square space in order to allow nodes to move more freely with equal node density. The physical radio characteristics of each MN's network interface, such as antenna gain, transmit power, and receiver sensitivity, were chosen to approximate the Lucent WaveLAN Direct Sequence Spread Spectrum radio.

Along with ns-2, we made use of two scenario-generator script utilities available under ~ns/indep-utils/cmu-scen-gen namely `setdest` and the tcl script `cbrgen.tcl`. `setdest` was used to generate the movement of the MNs and `cbrgen.tcl` was used to generate the communication patterns.

In order to enable direct, fair comparisons among the routing methods, it was critical to challenge the methods with identical loads and environmental conditions. Each run of the simulator accepts as input a *scenario file* that describes the exact motion of each MN and the exact sequence of packets originated by each MN, together with the exact time at which each change in motion or packet origination is to occur. We pre-generated 75 different scenario files with varying movement patterns and communication patterns, and then run all routing methods against each of these scenario files. Since each method was challenged in an identical fashion, we can directly compare the performance results of the four methods.

The simulation Tool Command Language (TCL) code is written to setup the wireless simulation component: network components type, parameters like the type of antenna, the radio-propagation model, the type of ad hoc routing method, communication models and node movement models used by MNs etc,. The simulation generated trace files that contained a list of all major events such as packet transmission, receives, drops, type of packets, source, and destination during the simulation. The events for the both the AGENT module (the data source) and the ROUTER module (the module that implements the routing algorithm) were trace.

5.1.1 Movement Model

Nodes in the simulation move according to random waypoint model. The movement scenario files we used for each simulation are characterized by a pause time. Each MN begins the simulation by remaining stationary for a certain period of time (i.e., a *pause time*). Once this time expires, the MN then chooses a random destination in the 670m x 670m simulation space area and moves to that destination at a speed distributed uniformly between 0 and some maximum speed [*0*, *maximum speeds*]. The MN then travels toward the newly chosen destination at the selected speed. Upon reaching the destination, the MN pauses again for *pause time* seconds, selects another destination, and proceeds there as previously described, repeating this behavior for the duration of the simulation. Each simulation ran for 300 seconds of simulated time.

An example traveling pattern of 50 MNs using the random waypoint mobility model starting at randomly chosen point or position in area (670m x 670m); the speed of the MNs in the figure uniformly chosen between 0 and 20 m/s is shown in Figure 5.1. The direction of movement is chosen randomly, if a node’s movement “hits” a wall of the 670m x 670m region, the node bounces and continuous to move after reflection. Two MNs are considered disconnected if they are outside each other’s transmission range of 250 meters.

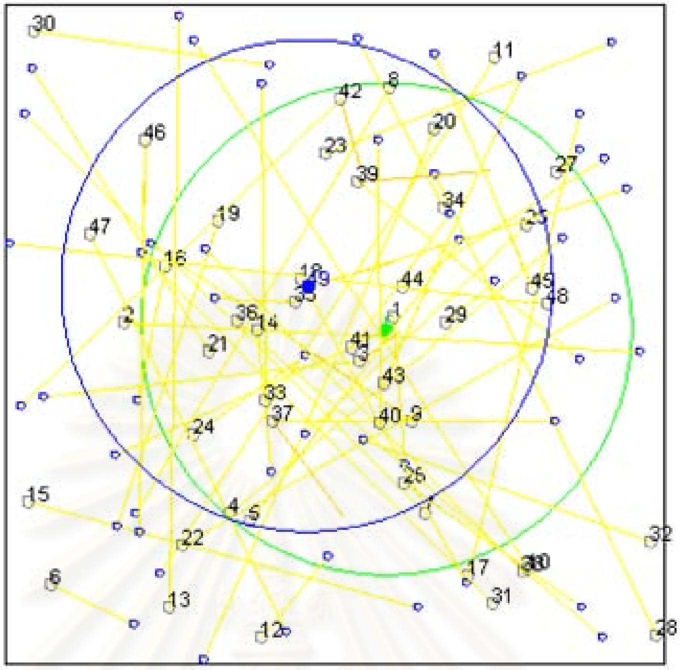

Figure 5.1: Random Waypoint Mobility Model.

We ran our simulations with movement patterns generated for 5 different pause times: 0, 25, 50, 150, and 300 seconds. A pause time of 0 seconds corresponds to continuous motion, and a pause time of 300 seconds (the length of the simulation) corresponds to no motion.

Because the performance of the methods is very sensitive to movement pattern, we generated scenario files with 25 different movement patterns, 5 for each value of pause time. All four routing methods were run on the same 25 movement patterns.

We tested with four different maximum speeds of node movement: 5 m/s, 10 m/s, 15 m/s, and 20 m/s.

5.1.2 Communication Model

As the goal of our simulation was to compare the performance of each routing method, we chose our traffic sources to be constant bit rate (CBR) source. When defining the parameters of communication mode, we tested with the packet sending rate 4 packets per seconds, networks containing 10, 20, and 30 CBR traffic sources, and packet size of 64 bytes.

Varying the number of CBR traffic sources was approximately equivalent to varying the sending rate. Hence, for these simulations we chose to fix sending rate at 4 packets pet second, and used three different communication patterns corresponding to 10, 20, and 30 sources.

All communication patterns were peer-to-peer, and connections were started at times uniformly distributed between 0 and 180 seconds. The three communication patterns (10, 20, and 30 sources), taken in conjunction with the 25 movement patterns, provide a total of 75 different scenario files for each maximum node movement speed (5 m/s, 10 m/s, 15 m/s, and 20 m/s) with which we compared the four routing methods.

We did not use TCP sources because TCP offers a conforming load to the network, meaning that it changes the times at which it sends packets based on its perception of the network's ability to carry packets.

5.1.3 Scenario Characteristics

To characterize the challenge scenarios placed on the routing methods, we measured the total number of topology changes in each scenario.

Table 5.1: Average number of link connectivity changes during each 300–second simulation as a function of pause time.

Pause Time	**# of Connectivity Changes**			
	5 m/s	10 m/s	15 m/s	20 m/s
0	1,856	3,378	4,509	5,605
25	1,566	2,476	3,265	4,174
50	1,364	2,089	2,549	2,902
150	749	1,010	941	1,042
300	0	0	0	0

Table 5.1 shows the average number of link connectivity changes that occurred during each of the simulations runs for each value of pause time. We count one link connectivity change whenever a node goes into or out of direct communication range with another node. For the specific scenarios we used, the 15 m/s scenarios at 150-pause time actually have a lower average of link connectivity change than the 10 m/s scenarios, due to an artifact of the random generation of the scenarios.

5.1.4 Performance Metrics

We will compare the performance of four unipath routing and multipath routing methods under the same movement models and communication models. We evaluate the performance according to the following metrics:

1. *Packet delivery fraction* – The ratio of the data packets delivered to the destinations to those generated by the Constant Bit Rate (CBR) sources.
2. *Average end-to-end delay* of data packets – This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation and transfer times.
3. *Control packet overhead* – The average number of routing control packets produced per MN. Routing control packets include route requests, replies and error messages.

The first two metrics are the most important for best-effort traffic. The routing overhead metric evaluates the efficiency of the routing protocol. However, these metrics are not completely independent. For example, lower packet delivery fraction means that the delay metric is evaluated with fewer samples. In the conventional wisdom, the longer the path lengths, the higher the probability of a packet drop. Thus, with a lower delivery fraction, samples are usually biased in favor of shorter path lengths and thus have less delay.

5.2 Simulation Results

As noted in Section 5.1.1, we conducted simulations using four different node movement speeds: a maximum speed of 5 m/s, 10 m/s, 15 m/s and 20 m/s. we compare the four methods based on these maximum speed of node movement. For all simulations, the communication patterns were peer-to-peer, with run having either 10, 20, or 30 sources sending 4 packets per second.

We used the same communication models and movement models for each method and repeated simulations five times for each scenario and combination to obtain an average data point.

We point out that the scripts used for analysis of results for LAR and MLAR were identical, but not the same as the scripts used for AODV and AOMDV. However, both provide approximately equivalent results in most of the parameters we measured from the counters used during the simulation or by parsing the trace files from each simulation run. The reason we could not use the same scripts was because the formats of trace files used for the two methods (AODV, LAR) were different.

5.2.1 Packet Delivery Fraction as a Function of Pause Time

As is visible from the following Figures (Figure 5.2 to Figure 5.13) on packet delivery fraction versus the maximum movement speeds in various traffic communication scenarios, AOMDV performs better than AODV and all the other methods consistently, and MLAR does better than LAR in most cases.

All of the methods deliver a greater percentage of the originated data packets when this is little node mobility (i.e., at large pause time). At lower speeds or in very high pause time scenarios (fast movement of MNs that move less frequently); the performance of all four methods seems to converge.

When the number of sources is under low traffic conditions where paths are reused less frequently, the performance of LAR and MLAR are inferior to AODV and AOMDV. This is because the stale routes may still remain in the cache after long periods due to the spare and slow traffic patterns and the lack of automatic expiration of such routes.

When the number of sources is large, The performance of four methods follow the number of connections of 20 and 30 sources, at low pause times, the performances of AODV almost are inferior to LAR and MLAR (also AOMDV). This is because at lower pause time or higher mobility of nodes (nodes move more frequently), when a route is broken from a source to a destination in LAR and MLAR, the source is able to use location information on the destination to find a new route to the destination more efficiently than AODV's route discovery method.

It is the presence of multiple paths in the routing tables of AOMDV and MLAR that allows them to do better than AODV and LAR respectively.

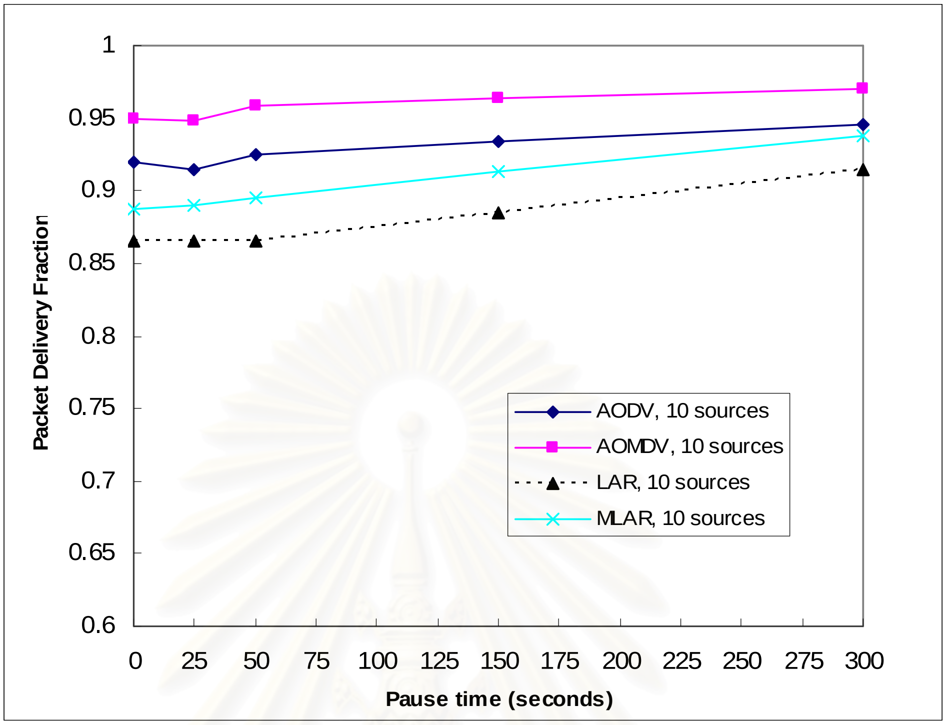

Figure 5.2: Packet Delivery Fraction for 10 Sources at the Maximum Speed of 5 m/s

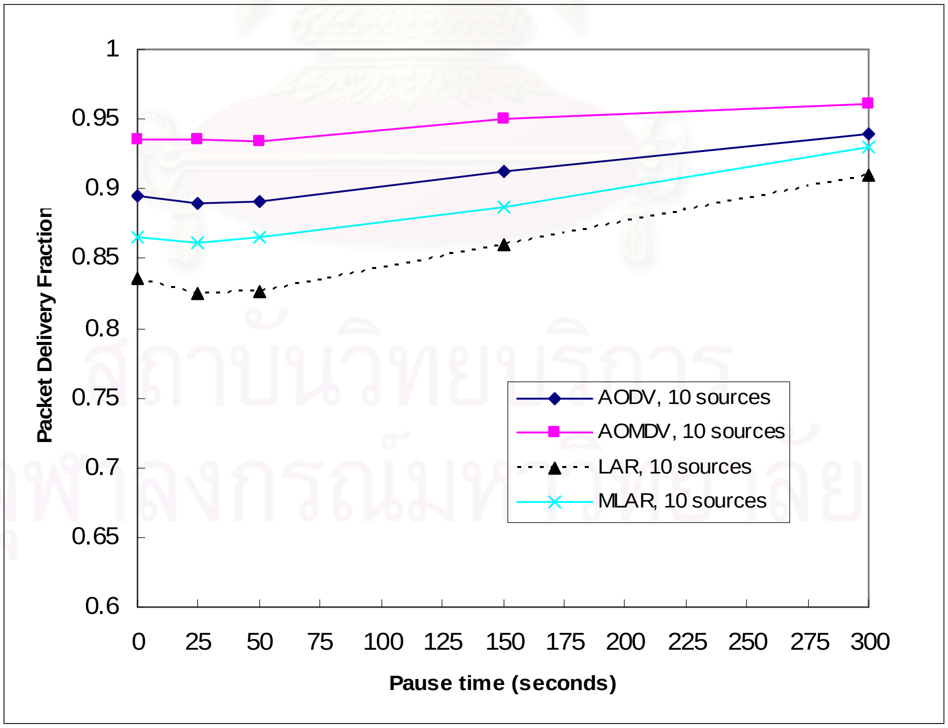

Figure 5.3: Packet Delivery Fraction for 10 Sources at the Maximum Speed of 10 m/s.

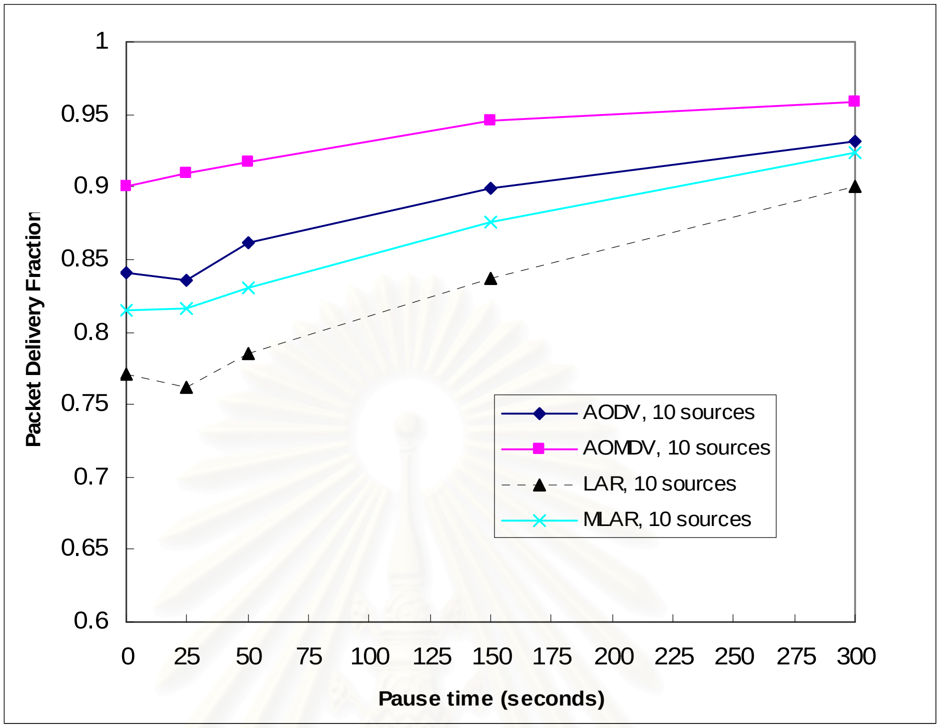

Figure 5.4: Packet Delivery Fraction for 10 Sources at the Maximum Speed of 15 m/s.

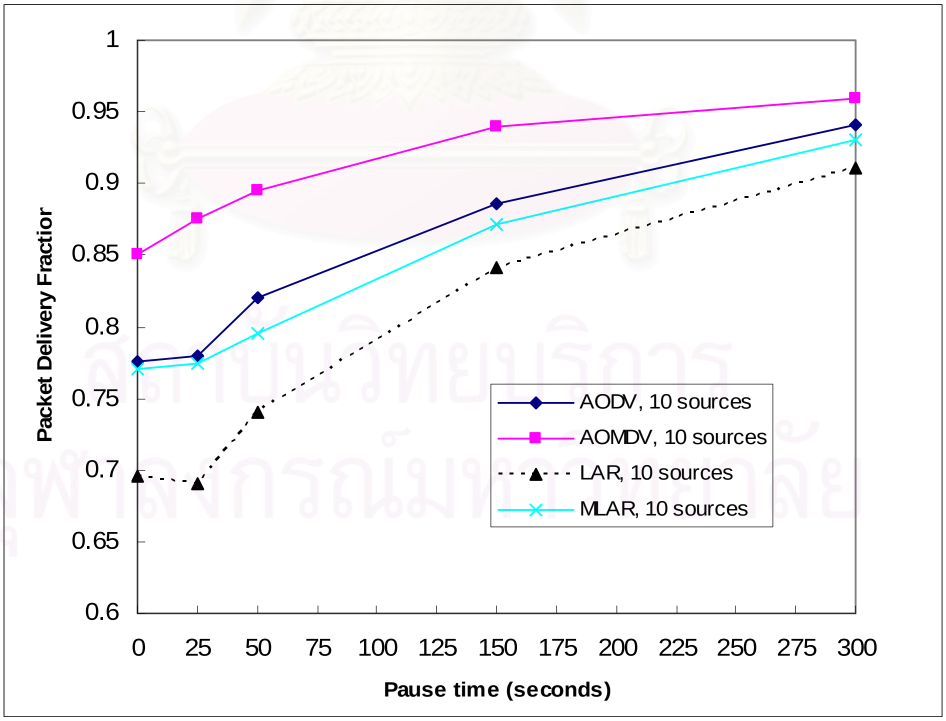

Figure 5.5: Packet Delivery Fraction for 10 Sources at the Maximum Speed of 20 m/s.

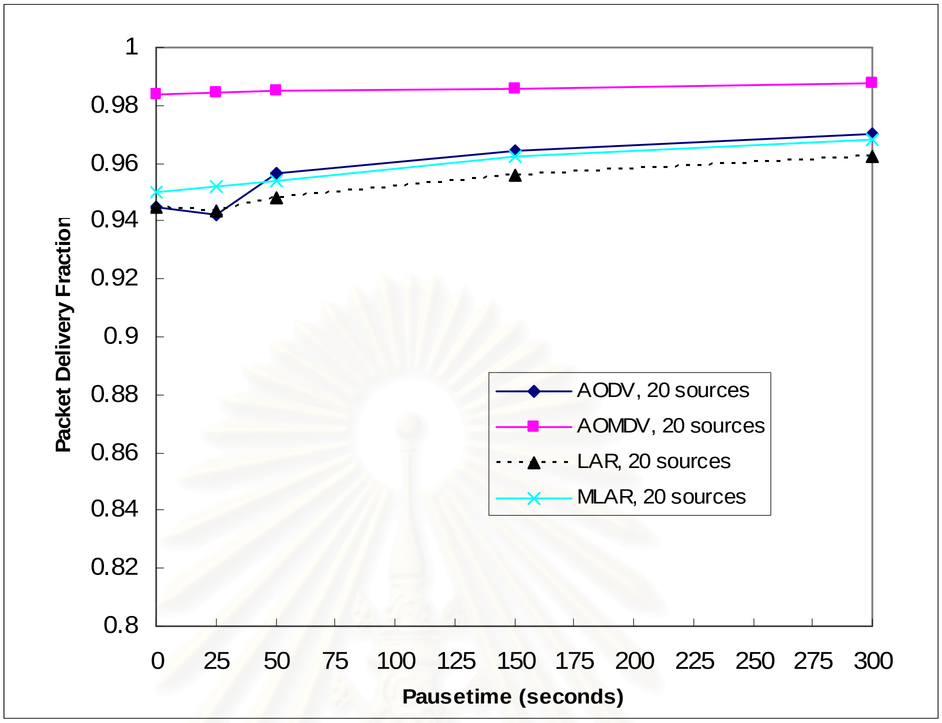

Figure 5.6: Packet Delivery Fraction for 20 Sources at the Maximum Speed of 5 m/s.

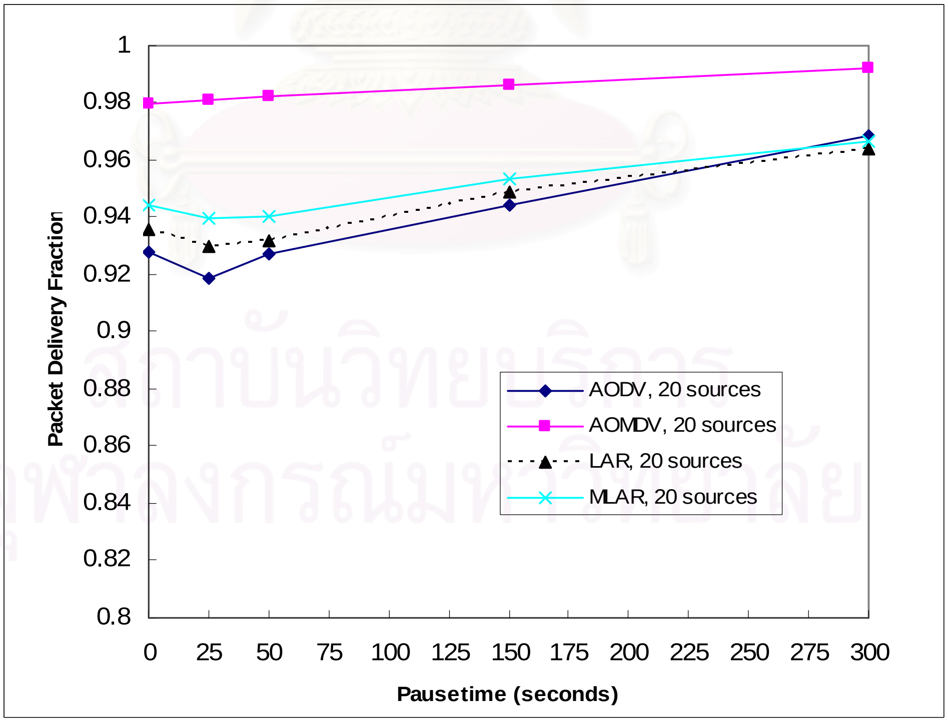

Figure 5.7: Packet Delivery Fraction for 20 Sources at the Maximum Speed of 10 m/s.

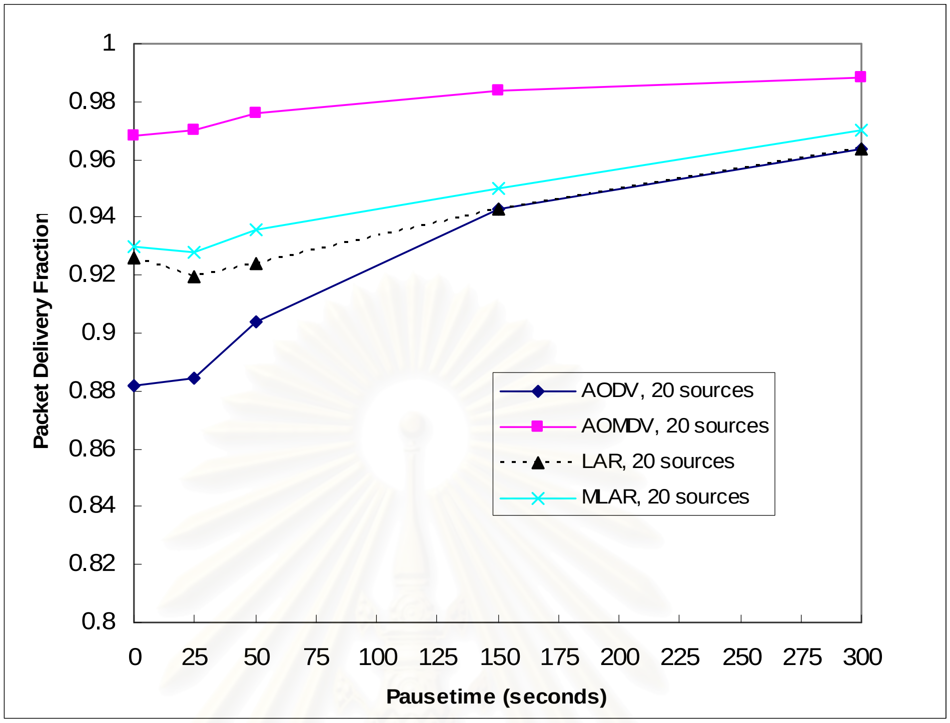

Figure 5.8: Packet Delivery Fraction for 20 sources at the Maximum Speed of 15 m/s.

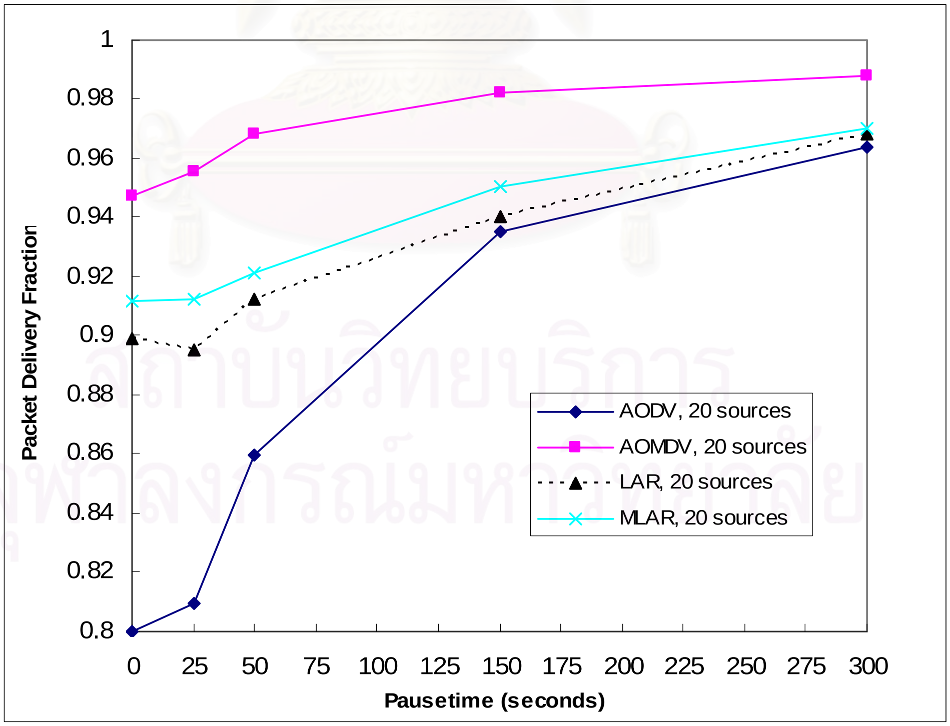

Figure 5.9: Packet Delivery Fraction for 20 Sources at the Maximum Speed of 20 m/s.

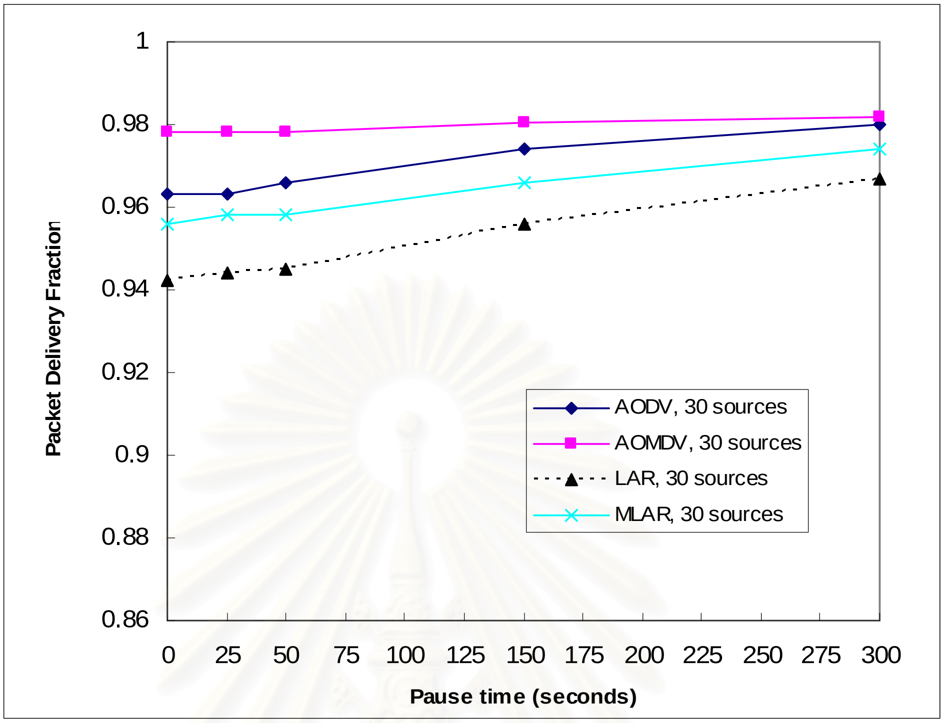

Figure 5.10: Packet Delivery Fraction for 30 Sources at the Maximum Speed of 5 m/s.

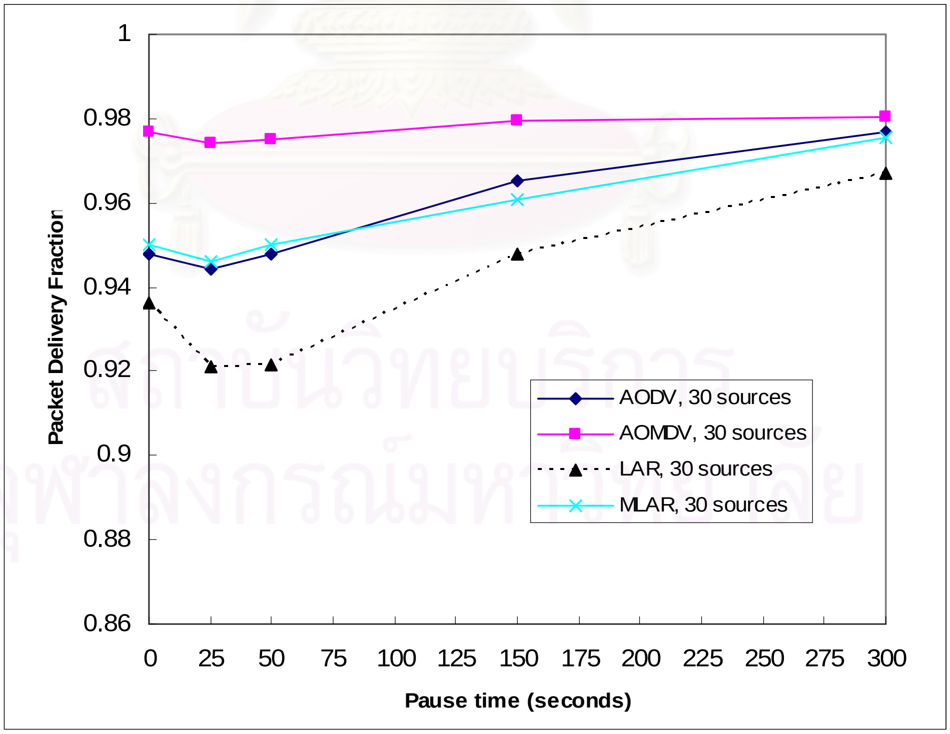

Figure 5.11: Packet Delivery Fraction for 30 Sources at the Maximum Speed of 10 m/s.

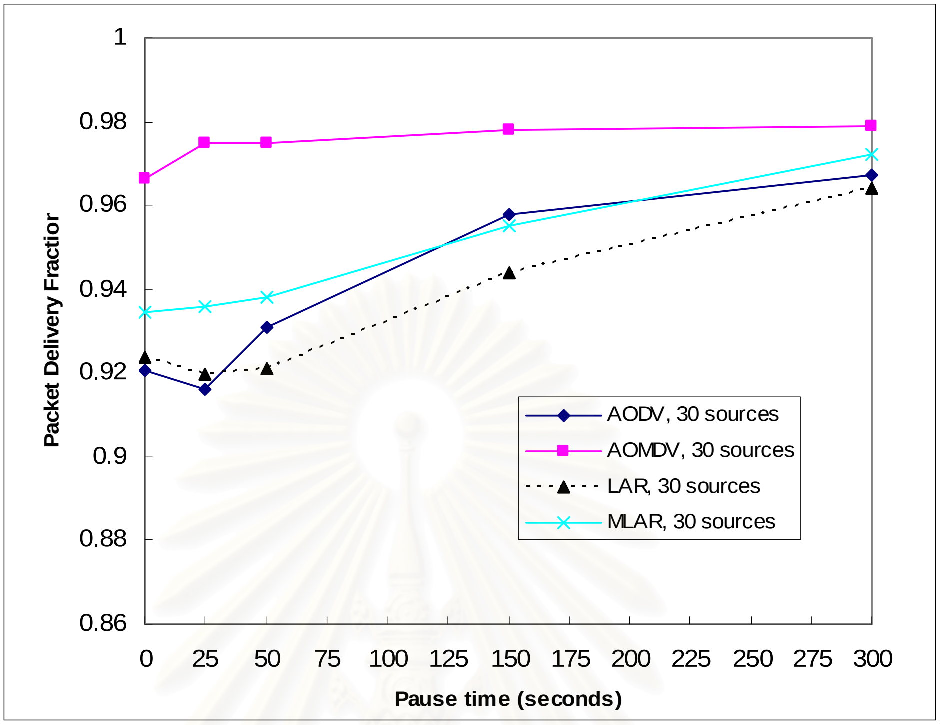

Figure 5.12: Packet Delivery Fraction for 30 Sources at the Maximum Speed of 15 m/s.

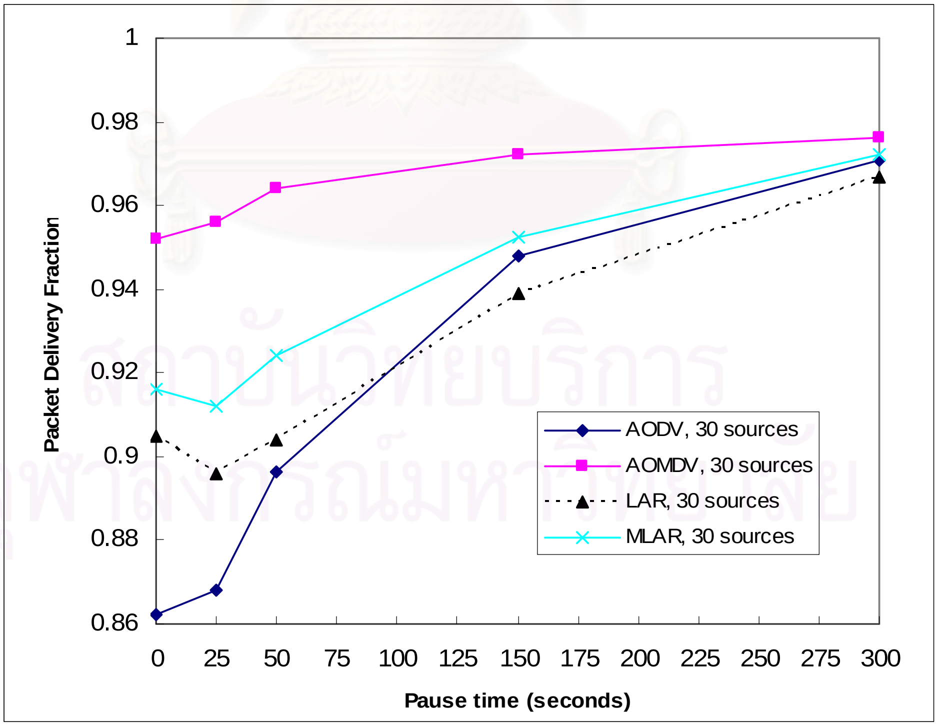

Figure 5.13: Packet Delivery Ratio for 30 Sources at the Maximum Speed of 20 m/s.

5.2.2 Packet Delivery Fraction as a Function of Maximum Speed

The following Figures (5.14 to 5.16) show packet delivery fraction of routing methods according to the increase of node's maximum speed. Here we can see the difference between the three traffic scenarios (10, 20, and 30 maximum connections) as we vary the maximum speed for nodes that never pause (continuous motion). As the nodes maximum speed increase, a packet delivery fraction of methods decreases. This because, in higher speeds, more frequent link breakage may occur and therefore a packet loss fraction is increased.

At lower speeds, the difference between the four methods is negligible. However, at high speed like 20 m/s AOMDV does much better while the performance of MLAR is still better than LAR and AODV does the worst.

When the number of maximum connections is low (10 sources), infrequent reuse is probably why AODV does better than LAR and MLAR. The performance of AOMDV is a little surprising since it seems unusually high even at 20 m/s, which indicates that the increased flooding is not saturating the network. AODV drops packets frequently and generally does the worst.

In all cases, the performance of MLAR is significantly better than LAR in terms of delivery fraction. The difference for 10 sources is larger; MLAR provides an improvement up to about 7.5 % in packet delivery at the speed of 20 m/s, the difference reduces for lower movement speed. With 20 and 30 sources, the difference is much smaller.

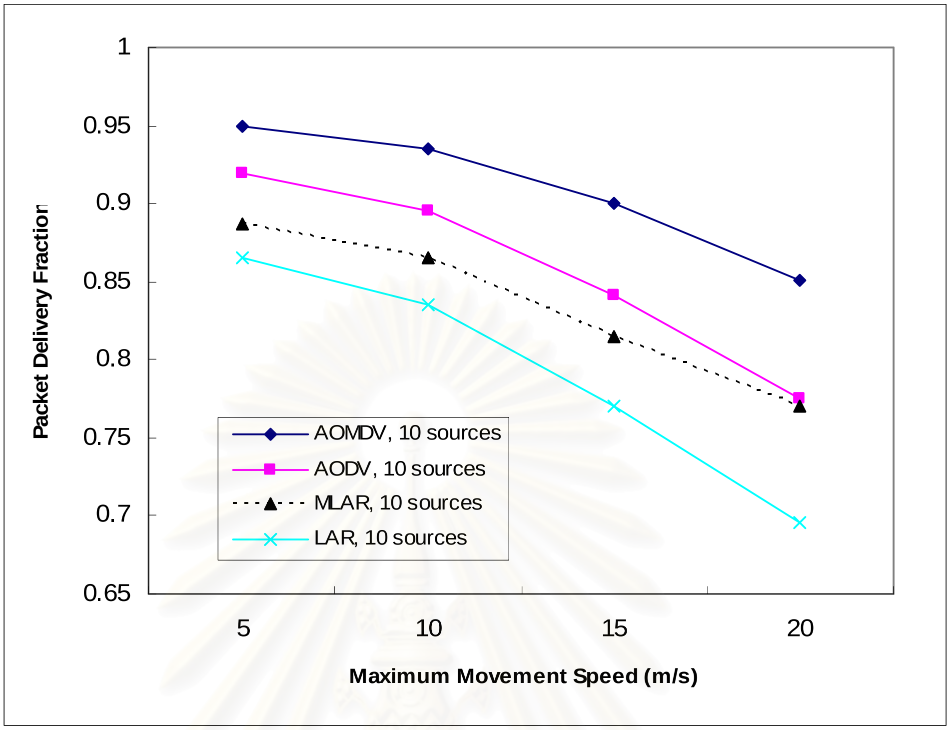

Figure 5.14: Packet Delivery Fraction versus Node's Maximum Speed for 10 Sources at Zero Pause Time.

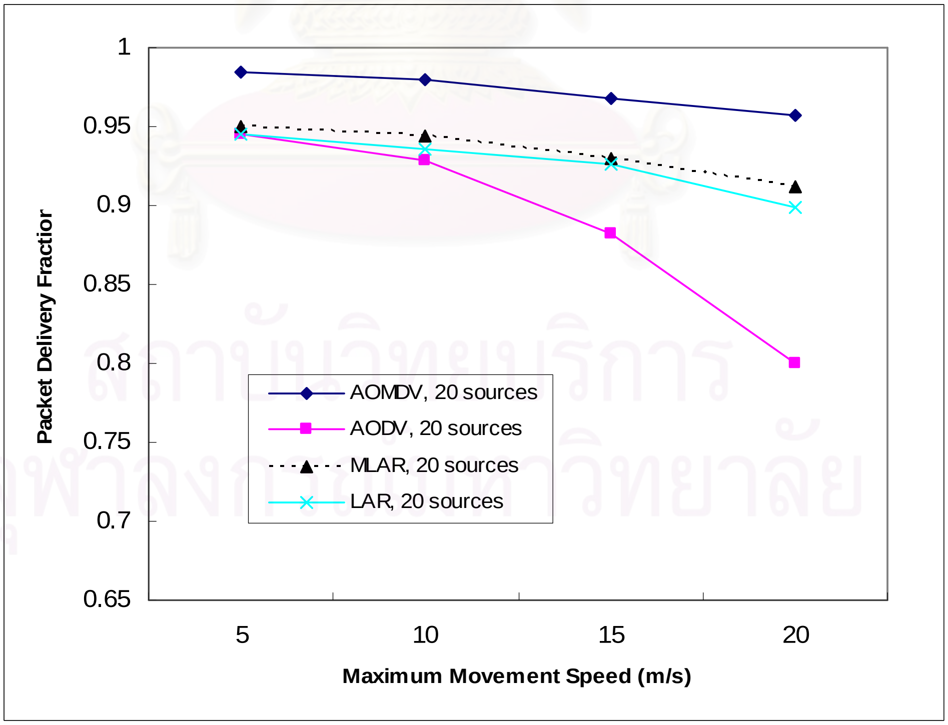

Figure 5.15: Packet Delivery Fraction versus Node's Maximum Speed for 20 Sources at Zero Pause Time.

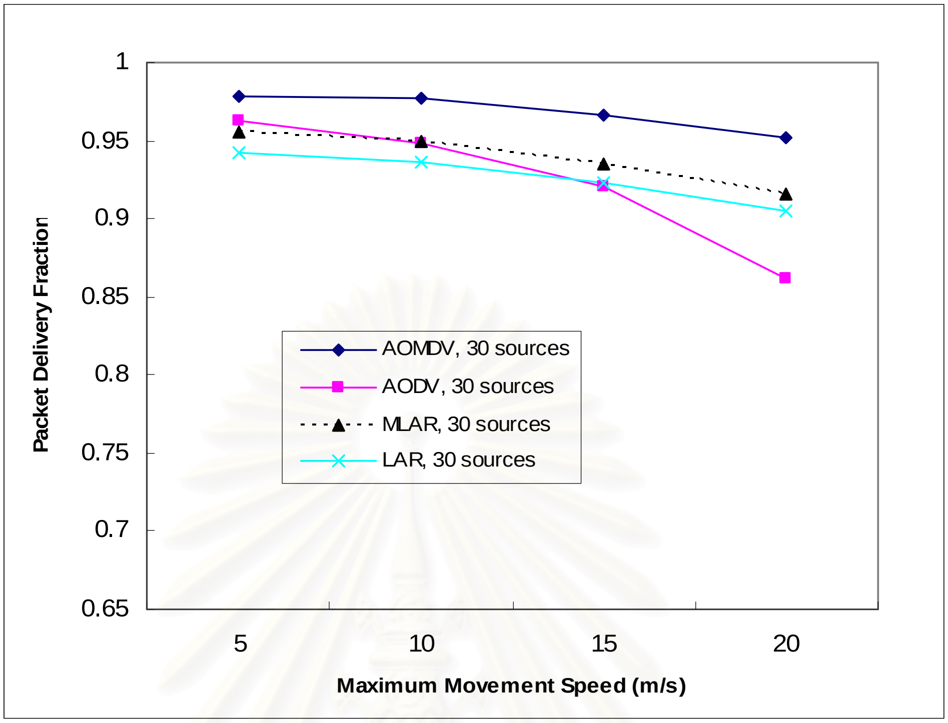

Figure 5.16: Packet Delivery Fraction versus Node's Maximum Speed for 30 Sources at Zero Pause Time.

5.2.3 Average End to End Delay

We have demonstrated that MLAR does better than LAR and in most cases better than AODV in terms of delivery fraction for most scenarios. We now take a look at average end to end delay in LAR and MLAR as calculated by scripts. Whenever a node receives a data packet it notes in a cumulative sum the exact time it received the packet minus the time it was originally sent and finally at the end of the simulation, we divide the sum of these transit times by the total number of packets received to get an average end to end latency.

Figure 5.17 shows simulation result on the aspect of average end-to-end delay performance of routing methods by varying the node's maximum movement speed from 5 m/s to 20 m/s to increase mobility. The number of connections and pause time are fixed at 20 and zero second, respectively.

The increase of movement speed induces more frequent topology change and therefore the probability of broken links grows. Broken links may cause additional route recovery process and route discovery process. Because of this reason, the average end-to-end delay of packet increases as node speed increases.

MLAR and LAR show better performance than AODV because they reduce the delay by limiting the broadcast region of control packets using the concept of request zone and expect zone.

MLAR does better than LAR in term of delay. This is because availability of alternate path from route cache reduces route discovery latency that contributes to the delay.

There is a large reduction in the average end-to-end delay of AOMDV compared with AODV as shown in Figure 5.16. This is because AOMDV that extends the single path AODV to compute multiple loop-free and link-disjoint paths, this mechanism eliminates route discovery by availability of alternate routes on route failures.

As shown in Figure 5.17, AOMDV has (almost) the lowest average end to end delay of all four methods. At low speed, the difference of delay is small, compared to higher speeds; all four methods have a higher end to end delay. Since as speed increases, more route requests are needed thus, delay increase with speed in all methods.

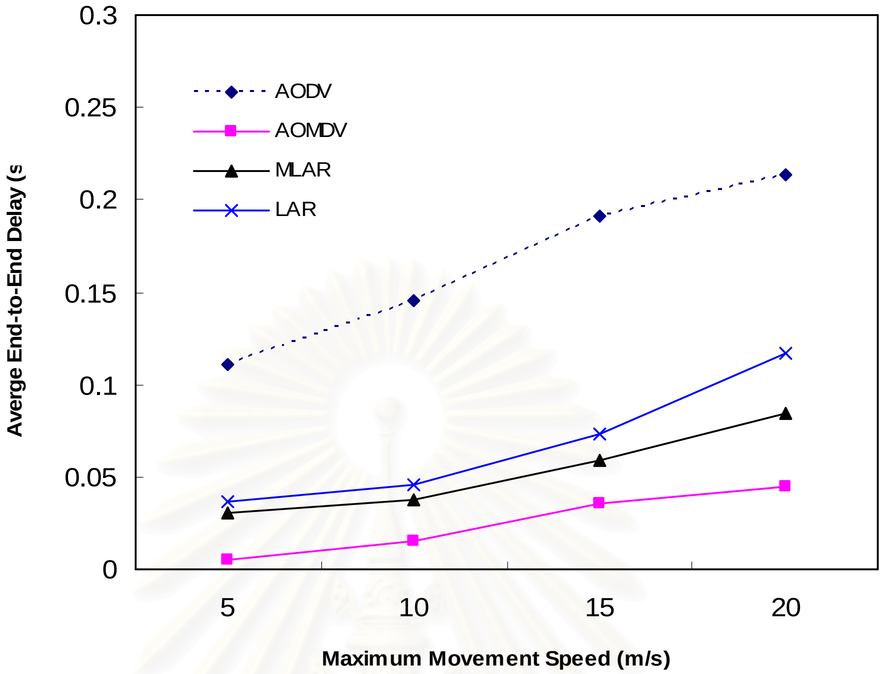

Figure 5.17: Average End-to-End Delay.

5.2.4 Control Packet Overhead

During analysis we kept several counters to measure the total number of control packets such as route requests, route replies, route errors, number of packets flooded, etc. AOMDV allows for more RREQ and RREP packets in the network in order to build multiple paths to each destination for each node. AODV allows only for a single RREP packet, for the first RREQ the destination node received to be sent back via the reverse route it arrived in.

As a result we see in Table 5.2 that AOMDV has sent 10 % more RREQs than AODV and about 4 times as many RREP packets sent in overall as seen consistently in most scenarios. Consider the following data from a high traffic and very high mobility scenario (20 m/s with zero pause time).

Table 5.2: The Number of Control Packets Sent for Movement of 20 m/s and 30 Traffic Sources with Zero Pause Time.

Method	The number of flooded RREQ packets sent (packets)	The number of RREP packets sent (packets)	The number of total packets (packets)
AODV	67,364	3,585	70,949
AOMDV	68,965	10,110	79,075
LAR	12,874	3,401	16,576
MLAR	14,726	4,919	19,645

Table 5.3: The Number of Control Packets Received for Movement of 20 m/s and 30 Traffic Sources with Zero Pause Time.

Method	The number of flooded RREQ packets received (packets)	The number of RREP packets received (packets)	The number of total packets (packets)
AODV	574,576	6,585	581,161
AOMDV	607,368	26,284	633,652
LAR	45,219	5,828	51,047
MLAR	61,624	10,275	71,899

Figure 5.18 shows that the number of control packets injected into the network in AODV and AOMDV is almost ten times compared with that of LAR and five times compared with that of MLAR and the most important figure is the number of flooded RREQs.

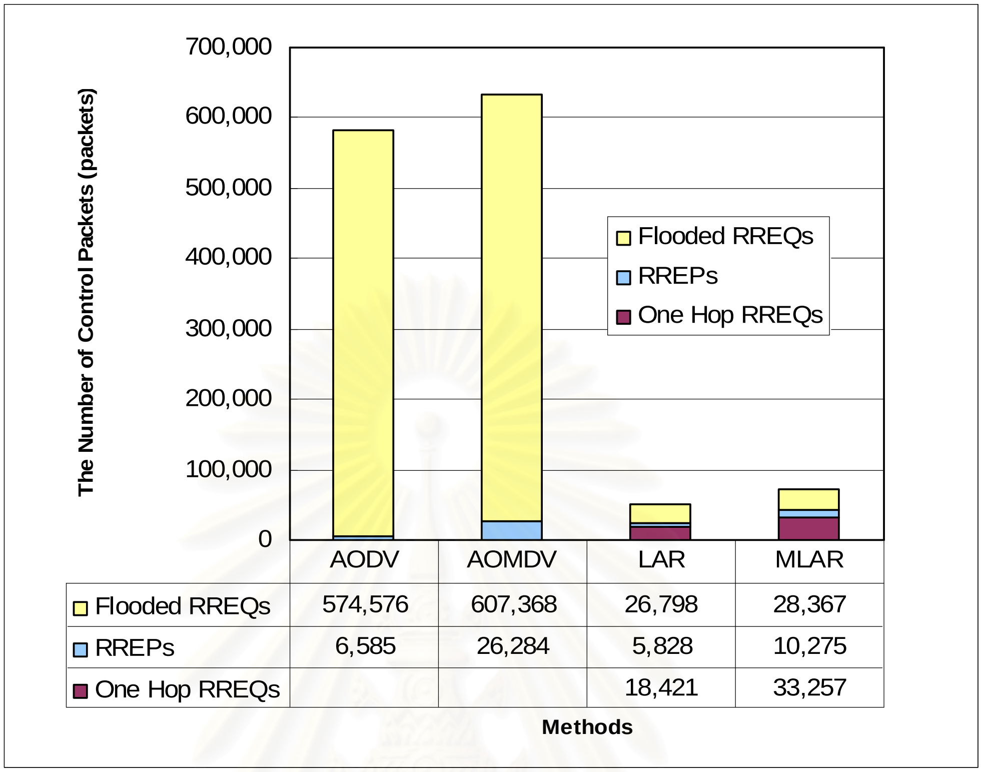

Figure 5.18: The Number of Control Packets Received for Movement of 20 m/s and 30 Traffic Sources with Zero Pause Time.

In Figure 5.18, in case of one hop RREQs, RREQ packets received in MLAR are about two times compared with those received in LAR. The rest were flooded but even if the total number is considered to be significantly lower than those of AODV and AOMDV. Flooding is another factor why LAR and MLAR flood significantly less than AODV and AOMDV. For this scenario LAR generated the average of 1108 error packets while MLAR correspondingly generated 1346 error packets indicating that the cached primary and alternate routes failed often in high mobility situation and more routes are likely to fail. The higher number of error packets for MLAR can be interpreted as being due to the number of times MLAR may have attempted an alternate path that was stale and thus produced an additional error packets.

Another point to be noted is that out of the 61624 RREQ packets received in MLAR, 33257 of them were not flooded throughout the network but only traveled one hop from the source. The lower number of RREQs received for LAR and MLAR also can be attributed to the use of flooding since several of the RREQ packets were not retransmitted by nodes which knew they were not in the expected and defined request zone and dropped the packets whereas AODV and AOMDV would simply retransmit the packet to all available neighbors. While we do observe that the number of control packets generated by AODV and AOMDV is significantly higher, the effect on bandwidth used is slightly lower since the size of LAR and MLAR control packets are slightly bigger than those for AODV and AOMDV since they include a few additional bytes of information to store the entire source route in each header. The additional number of bytes appended for the source route depends on the length of the route which is variable from packet to packet.

The cached routes were successful on a number of occasions, however, which explains the significantly improved delivery fraction of MLAR over LAR and of AOMDV over AODV. The higher number of failures is also the reason why MLAR sends more RREQs than LAR, as RREQs are generated at the source when it receives a RERR.

We noticed that these relative characteristics were observed in all the scenarios and was very consistent and practically independent of the mobility parameters.

We conclude that the control overheads for AODV and AOMDV is at least five to ten times higher than those of LAR or MLAR in terms of the total number of generated, flooded and received packets by the nodes in the network as observed from the simulations.

CHAPTER VI

CONCLUSION AND FUTURE WORK

In this research, we tried to evaluate the performances of unipath and multipath methods of well-studied-non-position routing and location information based routing for mobile ad hoc networks in network simulator.

Our goal was to utilize position information to provide route packets in a more reliable and effective in most situations and investing to develop a multipath by applying an alternate path caching strategy to the original LAR method to work as multipath of LAR (MLAR).

We have directly compared the performance of four routing methods: AODV, AOMDV, LAR and MLAR on a common situation platform under a range of mobility and communication models. We used a detailed simulation model to demonstrate the different performance characteristics of the four methods. We demonstrated clearly the significant benefits of MLAR over LAR as well as AODV in terms of routing performance.

We have observed that AOMDV has the best performance in terms of packet delivery, average end to end delay compared with the three others consistently, and MLAR does better than LAR in almost cases.

We also observed that the simulation results shown AOMDV consistently performs better than MLAR in terms of overall packet delivery, but does more frequent flooding of control packets and thus higher bandwidth usage than MLAR.

Furthermore, the simulation has shown that the number of control packets in AODV proposed by Perkins et al 1999 [8], [9] and AOMDV proposed by Marina et al 2001 [28] is almost ten times comparing with that of LAR proposed by Ko et al 2000 [18] and five times comparing with that of MLAR.

The general observation from the simulation in terms of packet delivery fraction versus mobility in various traffic sources scenarios shown that all of the methods deliver a greater percentage of the originated data packets when there is little mobility of MNs (at large pause time). The performance of all four methods comes to converge at lower speeds or in very high pause time, converging up to 90% delivery when there is no node motion. AOMDV almost outperformed others, delivering over 95% of the data packets regardless of mobility rate.

The performance evaluation has studied in relation of MLAR to LAR under a wide range of movement and communication scenarios. We observe that MLAR offers a significant improvement in packet delivery about 8.5%. It also reduces end to end delay, often more than a factor of one. In general, MLAR always offers a better overall routing performance than LAR in a variety of movement and communication conditions.

Future works.

We have demonstrated the benefits of using MLAR method versus LAR in terms of increased delivery fraction for most movement and communication scenarios. In terms of future work, we would definitely consider optimizing the timeout values and other parameters used in MLAR for further evaluation via simulation.

It may be interesting to evaluate the performance of an MLAR method that uses simultaneous paths (as in Split Multipath Routing (SMR) proposed by S. Lee and M. Gerla).

Some the open research questions are how MNs can actually find out their own location information in different scenarios such as sensor in the oceans or within a rooftop and what limits of accuracy can they do so.

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Biography

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