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LE MULTIMEDIA ET LES RESEAUX AD HOC
EVALUATION ET OPTIMISATION DE LA QUALITE DE SERVICE

Présenté par
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Preface and Acknowledgments

وَقَالُوا الْحَمْدُ لِلَّهِ الَّذِي هَدَانَا لِهَٰذَا وَمَا كُنَّا لِنَهْتَدِيَ لَوْلَا أَنْ هَدَانَا اللَّهُ

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You are the best anyone could ever wish for! I know that I have not always showed you the appreciation you deserve. This is my way to make it up to you. .

Dedication

I dedicate my modest work to

My beloved Wife and Sweetheart sons Abderrahim and Abdennour

My Small Family

My Big Family

My Family in-law

And all my precious friends and colleagues

Résumé

Au cours des dernières années, les réseaux mobiles Ad hoc (MANETs) ont eu beaucoup d'attention de la communauté de recherche. Les MANETs sont composés d'un ensemble d'équipements mobiles géographiquement distribués, partageant un seul canal de communication. Un réseau dans MANETs est créé spontanément et tous les nœuds dans le réseau travaillent en collaboration pour acheminer l'information sans l'utilisation d'une infrastructure. Ainsi, ce type de réseau offre une grande flexibilité et l'économie en coût de mise en œuvre. Toutefois, avec la flexibilité, de nombreux problèmes se posent à cause de la mauvaise qualité du support de transmission et de l'insuffisance des ressources. Dernièrement, les applications multimédia et temps réel sont devenues très répandues dans les réseaux Ad hoc ce qui a engendré une motivation croissante pour introduire la Qualité de service (QoS) dans ce genre de réseaux. Cependant, les caractéristiques des MANETs rendent la tâche d'assurer la QoS extrêmement difficile.

Les protocoles de routage pour MANETs fournissent un service « best effort » pour acheminer les paquets jusqu'à leurs destinations. Ces protocoles doivent être adaptés pour assurer la QoS.

Les protocoles de routage avec QoS travaillent en collaboration avec les mécanismes de gestion des ressources pour établir les chemins dans le réseau qui répondent aux exigences de QoS, tels que la gigue, la bande passante et la stabilité des chemins à travers le réseau. A cause de la grande mobilité des nœuds dans les réseaux MANETs, les informations de routage deviennent inconsistantes, les ruptures de liens deviennent fréquentes et la recherche des chemins alternatifs est exigée. Pour remédier à ces problèmes, plusieurs techniques ont été proposées dans la littérature.

Cette thèse propose des approches simples et efficaces de routage avec QoS basées sur la fiabilité des chemins dans les MANETs et la cohérence d'information de routage.

D'une part, Des mécanismes prédictifs et préventifs de maintenance des chemins pour réduire les ruptures des liens ont été proposés.Dans ce travail, nous avons proposé une approche qui combine à la fois les méthodes préventives et prédictives de maintenance de route afin de recueillir les avantages de ces approches. L'objectif principal de notre approche est l'amélioration de la qualité de service des protocoles de routage pour MANETs, afin d'avoir des chemins plus stables en minimisant les ruptures de liens. La performance de notre approche a été évaluée en utilisant une étude de simulation détaillée. En se servant des métriques de performances les plus connues, nous avons prouvé que la technique proposée a généré de bons résultats.

D'autre part, pour résoudre le problème de l'incohérence d'information de routage dans le protocole Dynamic source routing protocol (DSR) plusieurs techniques ont été proposées. Dans ce travail, nous avons amélioré le mécanisme de gestion du cache de route. L'amélioration consiste à ajouter un temps d'expiration pour chaque chemin inséré dans le cache. L'efficacité de cette approche a été évaluée en utilisant une étude de simulation détaillée. Les résultats de la simulation montrent que la technique proposée donne de bons résultats.

الملخص

خلال السَنَواتِ الماضيةِ، لاقتِ الشّبكاتُ الآنيةُ المتحركةُ (MANETs) اهتمامًا كبيرًا مِنْ طرفِ الباحثّينَ. تشتملُ هذهِ الشبكاتُ على مجموعةٍ مِنَ العُقدِ (المضيّفات) النقّالة مُوَزّعة جغرافيًا، حَيثُ تستخدمُ قناةً إذاعيةً مشتركةً وتتّصلُ عبْرَ وصْلاتٍ لاسلكيَّةٍ متعدّدةِ القفزات. تتشكّل الشّبكة آنياً عندما تَتعاونُ هذه العُقدُ لإرْسالِ المعلوماتِ إلى بعضها البعض بدون الاعتماد على بُنْيَةٍ تحتيَّةٍ ثابتةٍ .

توفرُ هذهِ الشبكات الكلفة المنخفضة والمرونة. تَظْهرُ العديد مِنْ المشاكلِ بسبب المرونةِ وذلك يعود إلى سوء نوعيةِ وسيطِ الإرسالِ وندرة الموارد التي تُؤثّرُ بدورها على ثبات الممر. ظهَرت حوافزٌ متزايدةٌ لتَقديم نوعيةِ الخدمةِ (QoS) في مثل هذه الشبكاتِ بسبب الاستخدام الواسع للاتصالات الفوريةِ فيها، لكن العديد مِنْ خصائص الشّبكات الآنية تجعل تأمينَ نوعيةِ الخدمةِ مهمّة صعبة جداً.

تقوم بروتوكولات التمرير التقليدية في الشبكات الآنية بتقديم خدمةِ "أفْضَلِ جُهْدِ" فقط لتَسليم حزَمِ المعلوماتِ إلى وجهتها النهائيةِ. لكن، لضمان نوعيةِ الخدمةِ يجب تكييف هذه البروتوكولات لدعم نوعية الخدمة. يَجِبُ أنْ تتعامل بروتوكولات التمرير التي تدعم نوعية الخدمة سوية مع آلياتِ إدارةِ الموارد لإنشاء ممرات تَلبّي متطلباتَ نوعيةِ الخدمةِ خلال الشبكةِ، مثل استقرار الممر. بسبب حركة الدائمة للعقد تصبح معلومات التوجيه متضاربة، يزداد عدد الممرات المقطوعة. لمُعَالَجَة هذه المشكلة تم اقتراح عدة تقنيات.

تَقترحُ هذه الأطروحة تقنيات تمرير تعتمد على ثبات الممرات في الشبكات الآنية، الهدف الأساسي لهذه التقنيات التقليل من معلومات التمرير المتضاربة و من الممرات المقطوعة.

من ناحية، تم اقتراح عدة آلياتٍ تنبؤيةٍ وأخرى وقائيةٍ لصيانةِ الممرات. اقترحنا في هذا العمل تقنية تَدْمجُ كلتا آليتي صيانة الممرات التنبؤيةِ والوقائيةِ للاستفادة من منافعهما. الهدفُ الرئيسيُ مِنْ مقترحنا هو تحسينُ نوعية الخدمةِ للحصول على مسارات أكثر استقراراً.

لتقييم فعالية أداء الطريقة المُقتَرَحة نستخدم محاكاةٍ مفصلةٍ. لهذا الغرض استعملنا مجموعة من معايير لتقييم الأداء.تظهرُ نَتائِجَ المحاكاةَ بأنّ التقنية المُقتَرَحة تبلي حَسناً.

من ناحية أخرى، وللتقليل من معلومات التمرير المتضاربة تم اقتراح عدة دراسات على البروتوكول التمرير المصدري (DSR). من خلال أعمالنا اقترحنا تحسينا على آلية إدارة ذاكرة الممرات، وذلك بإضافة زمن صلاحية لكل ممر مخزن في الذاكرة. قمنا بتقييم أداء الآلية المُقتَرَحة ومُقارنتها بالنسخةِ الأصليةِ لنفس البروتوكول باستخدام محاكاةٍ مفصلةٍ. اظهر نتائج المحاكاة تفوقَ التقنية المُقتَرَحة على البروتوكول الأصلي.

Abstract

Over the last years, Mobile Ad-hoc Networks (MANETs) have received tremendous attention of the research community. MANETs are comprised of geographically distributed mobile hosts (nodes), sharing a common radio channel and communicating via multihop wireless links. A network is created spontaneously as these nodes cooperate to transmit information to each other without the use of a pre-existing fixed infrastructure. Thus, such a network provides both flexibility and cost savings. However, along with the flexibility, many problems arise due to the bad quality of transmission media, the scarcity of resources that affect path reliability. Since real-time communications will be common in MANETs, there has been an increasing motivation to introduce Quality of Service (QoS) in such networks. However, many characteristics of MANETs make providing QoS assurance an extremely challenging task.

The conventional routing for MANETs provides only a best effort service to deliver packets to their final destinations. However, to ensure QoS, traditional routing protocols for MANETs must be adapted. Routing protocols supporting QoS work together with resource management mechanisms to establish routes through the network that meet QoS requirements, such as path reliability. Due to mobility, routing information become inconsistent, route failures become frequent and new route discoveries are required. To remedy this problem many approaches have been proposed in literature.

This thesis proposes path reliability-based routing approaches in MANETs. The main goal is to avoid as possible route failure and inconsistent routing data.

On one hand, Predictive and preemptive route maintenance have been proposed to solve the problem of route failure. In this thesis, an approach that combines both predictive and preemptive route maintenance to gather benefit aspects of those approaches have been proposed. The main goal of our approach is improving the MANETs quality of service capabilities by getting more stable routes.

The effectiveness of the proposed approach is evaluated throw a detailed simulations using GlomoSim Simulator. Depending on the common performance metrics, the simulation results show that the proposed technique performs well.

On the other hand, many techniques have been proposed to overcome the problem of inconsistent routing information in the Dynamic source routing protocol (DSR). In this thesis, an improvement of route cache management has been proposed. The amelioration consists of adding an expiration time for each route inserted into the cache.

The performance of the proposed method is evaluated by detailed simulations and compared with DSR using GlomoSim Simulator. The simulation results show that the proposed technique performs well .

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List of Abbreviations

AODV	Ad hoc On Demand Distance Vector routing protocol
AP	Access Point
AQOR	Ad hoc QoS on-demand routing
ARPANET	Advanced Research Projects Agency Network
CBR	Constant Bit Rate
CCITT	Consultative Committee for International Telegraph and Telephone
CEDAR	Core Extraction Distributed Ad hoc Routing
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
DARPA	Defense Advanced Research Projects Agency
DCF	IEEE 802.11 Distributed Coordination Function
DFRP-AODV	Divert Failure Ad-Hoc On Demand Distance Vector routing protocol
DiffServ	Differentiated Services
DSDV	Destination-Sequenced Distance Vector routing protocol
DSR	Dynamic Source Routing
DVR	Distance Vector Routing
DYMO	Dynamic MANET On-demand
ECN	Explicit Congestion Notification
FQMM	Flexible QoS Model for MANETs
GLOMOSIM	Global Mobile Information System Simulator
GPS	Global Positioning System
HD-PPAODV	High Definition PPAODV
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
INSIGNIA	In-band signaling supportfor QOS in mobile ad hoc networks
IntServ	Integrated Services
ISM	unlicensed Industrial/Scientific/Medical bands
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LAN	Local Area Network
LET	Link Expiration Time
LLC	Logical Link Control
LSR	Link State Routing
MAC	Media Access Control
MACA	Mobile Assisted Channel Allocation
MANET	Mobile Ad hoc Networks
MPR	MultiPoint Relay
ODMRP	On-Demand Multicast Routing Protocol
OLSR	Optimized Link State Routing protocol
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
PARSEC	Parallel Simulation Environment for Complex Systems
PLRR	Preemptive Local Route Repair
PPAODV	Predictive Preemptive Ad-hoc On-Demand Distance Vector

PPAOMDV	Predictive Preemptive Ad-hoc On-Demand Multipath Distance Vector
PQR	Prediction Based QoS Routing
PrAODV	Preemptive Ad-hoc On-Demand Distance Vector
PRNet	DARPA Packet Radio Network
QAODV	Quality of service for Ad hoc On-Demand Distance Vector
QMRB-AODV	Quality of service Mobile Routing Backbone over AODV
QoS	Quality of service
RERR	Route ERRor Message
RFC	Request For Comments
RIP	Routing Information Protocol
RREP	Route REPly message
RREQ	Route REQuest message
RSS	Recieved Signal Strength
RSVP	ReSerVation Protocol , Resource Reservation Protocol
RTS	Request To Send
SWAN	Service differentiation in stateless Wireless Ad hoc Networks
TBRPF	Topology Broadcast Based on Reverse-Path Forwarding
TCP	Transport Control Protocol
TORA	Temporally-Ordered Routing Algorithm
TOS	Type of Service
TSMA	Time-Spread Multiple-Access
UDP	User Datagram Protocol
WLAN	Wireless Local Area Network
WRP	Wireless Routing Protocol
ZRP	Zone Routing Protocol

CHAPTER 1 :
INTRODUCTION

1 Introduction

1.1 Scope of the thesis

Nowadays, Wireless mobile networks and mobile devices are becoming increasingly popular as they provide user access to any resource, anytime and anywhere.

The conventional wireless networks rely on a wired fixed infrastructure. A communication in those networks is done through a single-hop wireless radio communication between pairs of mobile devices by accessing a base-station that connects them through it to the wired infrastructure. In contrast, ad hoc networks (MANETs) (also called mobile packet radio network or mobile multi-hop wireless network) are spontaneously and infrastructureless networks. Nodes (mobile devices) within a mobile ad hoc network intercommunicate with each other using wireless multi-hop paths in a peer-to-peer fashion, using the support of intermediate nodes between each pair of communicant nodes. Nodes within MANET act as communicating nodes as well as routers.

In general, mobile nodes in ad hoc networks are free to move randomly and organize themselves arbitrarily. The network topology may change with time as the nodes move randomly and rapidly.

There has been a growing interest in ad hoc networks in recent years and many efforts have been done on. One of the important and famous groups developing ad hoc networks is Mobile Ad-hoc network Group (MANET). Many routing protocols have been designed in order to facilitate communication between mobile nodes within a network. Routing protocols must be able to respond rapidly to topological changes and use only valid routing information. Those protocols have been classified according to their mechanisms of searching routes to destination nodes into proactive, reactive and hybrid. Some of the most famous routing protocols are Ad hoc On Demand Vector (AODV), Dynamic Source Routing (DSR), Optimized Link State Routing protocol (OLSR), and Zone Routing Protocol (ZRP).

MANETs routing protocols are mostly designed for best effort transmission without any guarantee of transmission's quality, however, a majority of actual applications involves the transmission of multimedia data flows. This kind of application demands uninterrupted and reliable connections for entire transmission duration. Thus, Quality of Service (QoS) is desired to provide the required service differentiation to the demanding connections. Different applications have different QoS requirements, such as bandwidth, delay or delay jitter. However, providing QoS assurance in MANETs is a very complex and difficult task because of the mobile nature of nodes, scarce wireless bandwidth that varies with the changing environmental conditions, limited mobile device power, the requirement of node cooperation to relay packets through the network and generally imprecise network state information. These characteristics not only make ad hoc networks differ from conventional wireless networks, but also make providing QoS assurance an extremely challenging task in MANETs. This area has become an intensely active area of research in the last few years [Ilyas,2003] and much amelioration on wireless routing protocols have been proposed to insure QoS. QoS routing protocols work together with resource management mechanisms to establish routes through the network that meet QoS requirements, such as delay, jitter, available bandwidth, packet loss rate, hop count and path reliability. Routing protocols supporting QoS must also deal with route maintenance to improve protocols QoS by minimizing route failure.

1.2 Problematic

Mobile Ad-hoc Networks are spontaneous networks that can provide both flexibility and cost savings, because, this kind of networks does not depend on pre-existing fixed infrastructure and dynamically adjusts itself as some nodes join or leave the network. Those characteristics are the most attractive possibilities of this technology. However, along with the flexibility, many problems that affect path reliability arise[Zhang,2004]. On the other hand, the widespread of multimedia and real time applications had motivate the introduction of QoS in MANETs. Although, many characteristics of MANETs make ensuring QoS an extremely challenging task. The traditional routing protocols for MANETs must be adapted to ensure QoS. Routing protocols supporting QoS work together with resource management mechanisms to establish routes through the network that meet QoS requirements. These protocols must also deal with route maintenance to improve protocols QoS by minimizing route failure[Ivascu, Samuel et al.,2009]. To remedy this problem many approaches have been proposed in literature.

This thesis proposes a path reliability-based routing approaches in MANETs. The main goal is to avoid as possible route failure and inconsistent routing data.

On one hand, Predictive[Su, Lee et al.,2001] [Cahill, De Leon et al.,2002] [Crisostomo, Sargento et al.,2004] and preemptive[Srinath, Abhilash et al.,2002] [Goff, Abu-Ghazaleh et al.,2003] [Boukerche and Zhang,2004] route maintenance had been proposed to solve the problem of route failure. However, these approaches suffer from the lake of GPS accuracy and excessive computing.

In this thesis, an approach that combines both predictive and preemptive route maintenance to gather benefit aspects of these approaches and overcome existing problems have been proposed. The main goal of our approach is improving the MANETs quality of service capabilities by getting more stable routes[BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007].

On the other hand, many techniques have been proposed to overcome the problem of inconsistent routing information in the Dynamic source routing protocol (DSR)[Chen and Hou,2002] [Mathur,2005] [He, Raghavendra et al.,2007]. In this thesis, an improvement of route cache management has been proposed[BOUKLI-HACENE, Lehireche et al.,2007; BOUKLI-HACENE, Lehireche et al.,2008; BOUKLI-HACENE and Lehireche,2011].

1.3 Aim and objectives

The aim of this thesis work is to give an overview of the popular routing protocols in ad hoc networks and explain how QoS can be added to these networks, especially in the network layer. The main goal is to adapt routing protocols for multimedia and real time transmissions. Various methods of QoS are presented. Simulations will be done by using GlomoSim network simulator to evaluate the performance of existing routing protocols and the ameliorations proposed to improve QoS capabilities of routing protocols by reducing the route failure. A predictive preemptive mechanism is implemented on Ad hoc On-Demand Distance Vector (AODV) protocol to anticipate route failure and to get more stable routes. Comparison study will be done between AODV and PPAODV routing protocols using performance metrics.

People who are going to do research on QoS aware routing protocols and the amelioration of protocols capabilities to ensure QoS in ad hoc networks can get benefits from reading this manuscript. In addition, reader can also get a clear idea of how an ad hoc network as a system works both from the theoretical part review and simulation one.

1.4 Contribution

In order to enhance QoS for routing protocols especially path reliability, two approaches have been proposed in this thesis. The main goal is to avoid as possible route failure and inconsistent routing data.

On one hand, a combination of predictive and preemptive route maintenance had been proposed. This approach gathers benefit aspects of predictive and preemptive approaches[BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007].

In this approach, we consider that a node is in an unsafe or preemptive region if the signal of a received data packet from a predecessor node is below a threshold signal strength Pt. Once a node enters this zone, the algorithm of our approach collects at least three consecutive measurements of the signal strength of packets received from the predecessor node, and predicts link failure using the Lagrange interpolation.
The effectiveness of our approach is evaluated by integrating it in the well known Ad hoc on-demand distance vector routing protocol (AODV) and comparing it with the original version of AODV throw detailed simulations using GlomoSim Simulator. Depending on the common performance metrics, the simulation results show that the proposed technique performs well. It can overall generate lower overhead, fewer broken active links, lower end-to-end delay and higher delivery ratio.

On the other hand, an improvement of route cache management in the Dynamic source routing protocol (DSR) has been proposed. The goal of this enhancement is to overcome the problem of stale routes and incoherent routing information[BOUKLI-HACENE, Lehireche et al.,2007; BOUKLI-HACENE, Lehireche et al.,2008; BOUKLI-HACENE and Lehireche,2011].

The amelioration consists of adding an expiration time for each route inserted into the cache. This technique has been inspired from routing table management in AODV.

The performance of our method is evaluated by detailed simulations and compared with DSR using GlomoSim Simulator. The simulation results show that the proposed technique performs well in terms of the end-to-end delay and link break.

1.5 Research method

This thesis work is based on the literature research method relying on the materials listed in the references. In addition, the approach used as a study case is simulations. The simulations are done using the well-known GlomoSim network simulator.

1.6 Thesis outline

We start by an introduction in which we focus on the scope and the aim of this thesis work, followed by the outline of the thesis.

Chapter 2 introduces wireless networks in general and simply explains Mobile ad hoc networks, their characteristics and their application domains.

Chapter 3 presents the routing layer protocols. It introduces routing notion, presents the categories of the most popular routing protocols, and then, shortly describes those protocols.

Chapter 4 dwells on what QoS is and how QoS is provided. After that, the most important open issues in terms of QoS for MANETs and some of the most compelling proposals and ongoing research efforts done are presented in this chapter.

In Chapter 5, a performance evaluation study of the most important routing protocols for mobile ad hoc networks is done. In this chapter, the well-known GlomoSim simulator is presented and the performance metrics and factors that affect the performance are described.

Chapter 6 predictive and preemptive mechanisms for route maintenance in MANETs are presented followed by a detailed description of our approach predictive preemptive AODV (PPAODV) that combines predictive and preemptive mechanisms that aim to improve QoS capability of AODV and its performance evaluation.

In chapter 7, a new method of resolving the problem of stale routes for the dynamic source routing protocol (DSR) is detailed with a performance comparison study and Chapter 8 concludes the thesis and gives some suggestions for further works.

CHAPTER 2 :
WIRELESS NETWORKS

2 Wireless Networks:

Marchese Guglielmo Marconi said in 1932, “It is dangerous to put limits on wireless.” However, even Marconi might not have dreamed what has already been achieved and what may happen next in the field of wireless communications [Prasad and Muñoz,2003].

Wireless communication has recently captured the attention and the imagination of users from all walks of life. The major goal of wireless communication is allowing a user to have access to the capabilities of global networks at any time without regard to location or mobility. Since their emergence in the 1970s, the mobile wireless networks have become increasingly popular in the networking industry. This has been particularly true within the past decades, which has seen wireless networks being adapted to enable mobility. Since the inception of cellular telephones in the early 1980s, they have evolved from a costly service with limited availability toward an affordable and more versatile alternative to wired telephony [Mukherjee, Bandyopadhyay et al.,2003].

Mobile wireless networks are broadly classified into two distinct categories: infrastructured (cellular) and infrastructureless (ad hoc). Cellular networks rely on a pre-constructed fixed wired infrastructure. A mobile node within these networks connects to, and communicates with, other nodes via the nearest fixed base station that is within its communication radius using a single-hop wireless link. These networks represent a great way to allow communication between mobile equipments (Fig.2). However, it takes time and potentially a high cost to setup the required infrastructure. Furthermore, there are hostile environments where a fixed communication infrastructure is unreliable or unavailable, such as in a battlefield or in a natural disaster area struck by an earthquake or flood. The alternative is the mobile ad hoc networks [Zhang,2004].

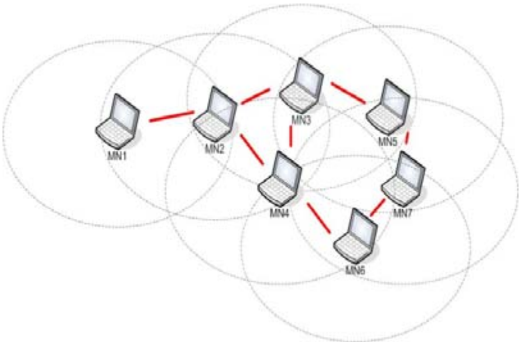

Figure 1: Ad Hoc network (infrastructureless)

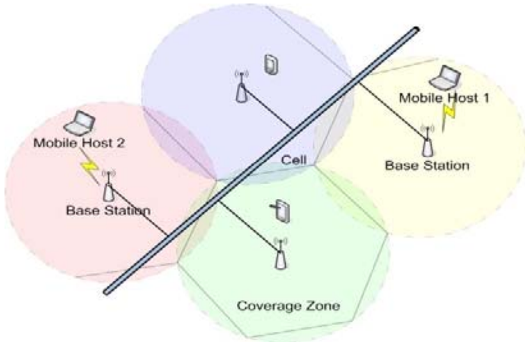

Figure 2: Cellular network (infrastructured)

2.1 Mobile Ad hoc Networks:

Ad hoc networks are spontaneously infrastructureless networks. They are composed of wireless mobile nodes that can freely move and self-organize into arbitrary and temporary network topologies. Mobile devices within a MANET communicate directly with other devices that are within their coverage zone forming a multi-hop wireless network without using a pre-existing infrastructure as shown in figure 1. Each node of the network behaves as router and communicant. Nodes cooperate to route data to its destination[Basagni, Conti et al.,2004].

The term "ad hoc" implies that this network is established for a special, often extemporaneous service customized to applications. Therefore, the typical ad hoc network is set up for a limited period of time [Mohapatra and Krishnamurthy,2005].

2.2 Mobile Ad Hoc Networks Applications

The concept of mobile ad hoc networks is not new. It dates back to the Defense Advanced Research Projects Agency (DARPA) Packet Radio Network (PRNet) project in the 1970's [Perkins,2001]. With current technology and the increasing popularity of PDAs and laptops, interest in ad hoc networks has greatly increased. New technologies such as IEEE (Institute of Electrical and Electronics Engineers) 802.11a [IEEE802.11a,1999], b [IEEE802.11b,2000], g [IEEE802.11g,2003], and Bluetooth [Bisdikian,2001] also provide demand for practical commercial applications of ad hoc networks. MANETs have a wide range of applications in emergency search-and-rescue operations, disaster relief (e.g., earthquake), battlefields, meetings, videoconferencing or conventions in which people wish to quickly share information, sensors, communication between automobiles on highways, data acquisition operations in inhospitable terrain, and even for personal use –Personal Area Network and Bluetooth -. In general, MANETs are used in situations where no fixed infrastructure is available, either because it may not be economically practical or impossible to provide the necessary infrastructure.

2.3 Mobile Ad Hoc Networks Characteristics

Ad hoc networks have several significant characteristics [Corson and Macker,1999]:

Dynamic topologies: The frequent changing in network information, signal propagation conditions, and the high mobility of nodes leads to frequent reconfigurations of the network and sometimes excessive exchanges of control information over the wireless medium.

Asymmetric link characteristics: the communication between two nodes may not work equally well in both directions. In other words, even if a node "n" is within the transmission range of a node "m", the reverse may not always be true.

Multihop communication: Nodes within an ad hoc network acts as a router. Therefore, when any node (source) wants to communicate with another (destination) which is maybe not in its transmission range, it is obliged to use other nodes –intermediate nodes- to reach this destination in multiple hops through several intermediate relay nodes.

Decentralized operation: Ad hoc networks do not need any centralized control or any kind of relation with a pre-existing infrastructure, unlike cellular wireless networks, where there are a number of centralized entities (e.g., Base Station (BS)) related. Therefore, Ad hoc networks need an efficient distributed Algorithm to coordinate it components.

Bandwidth-constrained variable-capacity links: The capacity of wireless links and the realized throughput are lower than their hardwired counter parts; this is due to many properties like the effect of multiple access, fading, noise, and interference conditions.

Energy-constrained operation: One of the most important system design criteria for optimization in mobile nodes is energy conservation, because the battery's energy is limited for few hours, and the consumption of this energy is big. Therefore, the way of achieving this goal is to optimize the transmission power of each node composing an ad hoc network.

These characteristics of ad hoc networks create a set of performance concerns for protocol design that extend beyond those guiding the design of protocols for conventional networks with preconfigured topology [Mukherjee, Bandyopadhyay et al.,2003].

In the next chapter, we will expose in some details the most important routing protocols in MANETs. Those protocols permit and facilitate communication within a MANET and respect the principal characteristics of mobile Ad hoc networks.

CHAPTER 3 :
PROTOCOLS IN MANETS

3 Protocols in MANETs:

3.1 Routing Protocols in MANETs:

Mobile Ad hoc networks Routing protocols offer two basic operations: **route discovery** and **route maintenance**. To allow communication between any pairs of mobile nodes (source, destination) within a MANET, a suitable route must be discovered and conserved until communication ends.

Routing in ad hoc networks is basically different from conventional routing in wired networks on account of MANETs characteristics. The routing depends on many factors including the request initiation, network topology and routes selection. Consequently, new routing protocols are needed to meet the specific requirements of this kind of networks.

The usual routing protocols for wired networks commonly use either *distance vector* or *link-state* protocols [Perlman,1992]. Route discovery and route maintenance are fused by sending routing update packets. If a router or a link fails, this update must be propagated across the network. These kinds of protocols are named *Proactive Protocols*, because they always try to find new routes and maintain them.

In *Distance Vector Routing* (DVR) protocols, each router reveals its distance view to all other routers within the network, by periodically broadcasting this view to its neighbours; then each router computes the shortest path to every other router based on the advertised information and decides which hop is the correct next hop to each destination. The communication in this kind of protocols is simply forwarding the data packets from the source to the correct next-hop router towards the destination until reaching it. Distance Vector Routing suffers from slow convergence and loop formation. Examples of DVR protocols include the routing protocol used in the DARPA Packet Radio Network [Jubin and Tornow,1987] and the original routing protocol for the ARPANET [McQuillan, Ira et al.,1980] [Mukherjee, Bandyopadhyay et al.,2003].

On the other hand, *Link-State Routing* (LSR) protocols, each node in the network broadcast periodically a list of its neighbours and the cost to reach them in order to maintain a view of the entire network. Each node after receiving this information must compute the optimal path to each possible destination. The communication in this kind of protocols is simply forwarding the data packets from the source to the correct next-hop router based on the computed optimal path until reaching the destination node. Unlike DVR, LSR protocols converge much more quickly when conditions in the network change. But, it generally requires more computation time than that taken by the distance vector algorithms and consumes more network bandwidth. Examples of LSR protocols include the "new" routing protocol that replaced the original protocol for the ARPANET [McQuillan, Ira et al.,1980] and Open Shortest Path First (OSPF) [Moy,1994]. [Mukherjee, Bandyopadhyay et al.,2003].

Other categories of protocols that are more adopted in MANETs are named *Reactive protocols*; these protocols separate between Route discovery operation and route maintenance and do not require periodic route updates. In the context of these routing protocols, route discovery operation is invoked only when a route is needed, in other words, on demand. Examples of protocols in the family of reactive protocols Dynamic Source Routing (DSR) [Johnson and Maltz,1996a; Johnson and Maltz,1996b] and Ad hoc on demand Distance Vector (AODV) [Perkins and Belding-Royer,1999; Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003].

When discovering a new route, information about this route may not be available at the time when a request is received, which engender excessive control traffic and has a significant impact on the delay required to determine a route, especially in a highly dynamic environment, where these schemes become less efficient. However, the advantage of the proactive schemes is that, once a route is needed, it is immediately available from the route table. Because of this, pure reactive routing protocols may not be convenient to real-time communication.

When a source needs to communicate with a destination, it broadcasts a Route Request packet, this packet is then forward until reaching the destination. A Route Reply packet is sent back to the source node throw nodes that participate to deliver the Route Request packet to this destination. When a link break occurs, the route is conserved by a route maintenance operation, until either the destination becomes unreachable, or the route is no longer desired.

The number of route discovery needed and maintenance required to get a steady communication between communicant nodes affects this approach.

When node's mobility and the demand of communication between them are high, this automatically implies a big communication and computation overhead. To improve performance of this approach and to reduce the overhead, aggressive route caching and full use of information in the cache were proposed in [Johnson,1994].

The advantage of proactive protocols is that whenever a route is needed it is immediately selected from the routing table, which gives a minimal delay, but the problem with those protocols is that they consume large bandwidth. Unlike reactive protocols that adopt the inverse approach by finding a route to a destination when needed only, which provokes a high delay and often consume much fewer bandwidth than proactive protocols. In order to get better performance some proposals using a hybrid approach have been suggested. Currently, there has been a great effort on trying to standardize a new protocol, DYMO (Dynamic MANET On-demand) [Chakeres and Perkins,2007]. The figure below shows a classification of unicast routing protocols depending on their route discovery and maintenance.

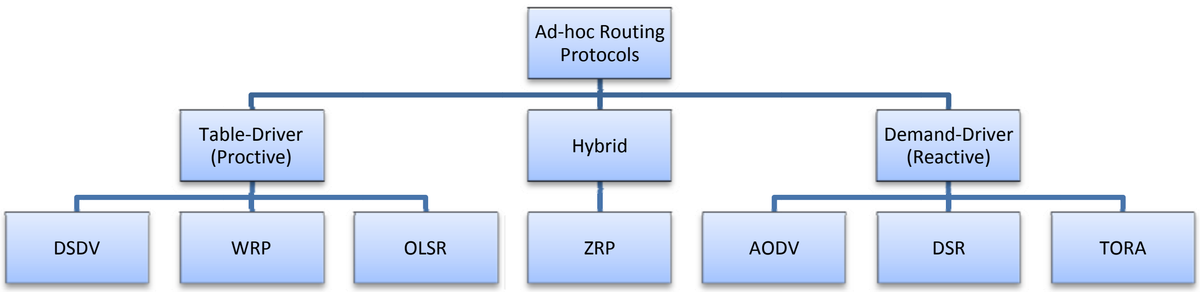

Figure 3: Unicast routing protocols

All these protocols (proactive, reactive and hybrid) have been analyzed and compared in several studies (with an exception to DYMO, since it is still very recent). The main conclusion of these comparisons is that none of them is the best for all environments. Depending on several aspects – such as mobility, network load, network diameter - one protocol may behave better than another may.

Below, we will present some of the important Unicast routing protocols in Ad hoc networks and associated techniques, and we will not discuss multi-destination routing such as multicast or geocast.

3.2 Proactive Routing Approach

As described previously, proactive routing approaches designed for ad hoc networks are inspired from the conventional distance vector [Malkin and Steenstrup,1995] and link state [Moy,1995] protocols developed for use in the wired Internet with a fixed topology.

The main characteristic of proactive approaches is that each node in the network maintains a route to every other node in the network at all times regardless of whether all routes are actually used.

Proactive routing is done through some combination of periodic and event-triggered routing updates. Periodic updates consist of routing information exchange between nodes each interval of time regardless of changes in network characteristics. Event-triggered updates, on the other hand, are transmitted whenever some event occurs. The mobility rate directly affects the frequency of event-triggered updates because link changes are more likely to occur as mobility increases.

Proactive approaches have the advantage that routes are available the moment they are needed. Because each node consistently maintains an up-to-date route to every other node in the network, a source does not have to incur any delay for route discovery, it can simply check its routing table when it has data packets to send to some destination and begin packet transmission. However, the primary disadvantage of these protocols is that the control overhead can be significant in large networks or in dynamic networks. Proactive protocols tend to perform well in networks where there is a significant number of data sessions within the network. In these networks, the overhead of maintaining each of the paths is justified because many of these paths are utilized [Basagni, Conti et al.,2004].

3.2.1 Distance Vector Protocols

3.2.1.1 The Destination-Sequenced Distance Vector (DSDV) routing protocol

DSDV [Perkins and Bhagwat,1994] is one of the earliest protocols developed for ad hoc networks. It is a proactive distance vector protocol; it was designed in order to preserve the simplicity of the distance vector-based protocol RIP [Hedrick,1988] for wired network. The main idea in DSDV is to use per-node monotonically increasing sequence numbers to avoid the *counting to the infinity* problem common in many distance vector protocols. The sequence number of a node changes whenever there is a change in its local neighbourhood, also, the node maintains the highest known (greatest) sequence number (called "destination sequence numbers") and distance/metric information for each destination in its routing table. This ensures utilization of fresh routing information (the node with a higher destination sequence number has the more recent information).

The routing table contains an entry per destination with the following information per each entry: *destination address, destination sequence number, next-hop address, hop count (Distance), and install time.*

DSDV also uses triggered incremental routing updates between periodic full updates to quickly propagate information about route changes. In every time interval of periodic full updates, each node broadcasts to its neighbours its current sequence number, along with any routing table updates. The routing table updates are of the form: < *destination IP address, destination sequence number, hops count* >.

Upon receiving an update message, the neighbouring nodes compare this information to the existing information regarding the route and utilize it to compute their routing table entries using an iterative distance vector approach [Malkin and Steenstrup,1995]. DSDV also utilizes event-triggered updates to announce important link changes, such as link removals. Such event-triggered updates ensure timely discovery of routing path changes.

As stated previously, a routing table must contain only an entry per destination, but a node can learn many distinct paths to a destination, the node selects the path with the greatest associated destination sequence number. This ensures the utilization of the most recent routing information for that destination. When given the choice between two paths with equal destination sequence numbers, the node selects the path with the shortest hop count. On the other hand, if all metrics are equivalent, then the choice between routes is arbitrary.

Finally, DSDV implements a mechanism to damp routing fluctuations. It estimates a route settling-time (time it takes to get the route with the shortest distance after getting the route with a higher distance) based on past history and uses it to avoid propagating every improvement in distance information. This reduces bandwidth utilization and power consumption by node [Basagni, Conti et al.,2004; Mohapatra and Krishnamurthy,2005].

3.2.1.2 Wireless Routing Protocol (WRP)

WRP [Murthy and Garcia-Luna-Aceves,1996] is another distance vector protocol optimized for ad hoc networks. WRP belongs to a class of distance vector protocols called *path finding algorithms*. To overcome the looping problem present in the distance vector algorithm, WRP includes second-to-last hop (predecessor) information for each destination. This predecessor information is sufficient to determine locally the shortest path-spanning tree at each node. This information is included in two tables kept at each node: a distance table and a routing table. The distance table of node "*i*" is a matrix containing, for each destination "*j*" and each neighbour "*k*", the distance to "*j*" and the predecessor when "*k*" is chosen as the next hop to reach "*j*". The routing table contains an entry for each destination, and the attributes for each destination include the next hop, distance, and the predecessor.

To keep a consistent view of the network and to respond to topological changes, each node is updated with the shortest path-spanning tree of each of its neighbours by exchanging update packets containing distance and second-to-last hop information to each destination with its neighbours. After updating the distance table, each node also updates its routing table accordingly by choosing the neighbour that offers the smallest cost to the given destination as the next hop to reach that destination. The major advantage of WRP is that it reduces temporary looping by using the predecessor information to identify the route, which in turn results in faster convergence time. However, as in all the proactive protocols, in WRP, each node constantly maintains full routing information to all destinations in the network, requiring significant communication overhead[Mukherjee, Bandyopadhyay et al.,2003; Mohapatra and Krishnamurthy,2005].

3.2.2 Link State Protocols

3.2.2.1 Optimized Link State Routing (OLSR)

OLSR [Clausen and Jacquet,2003] is an optimization of the pure link-state algorithm tailored to the requirements of a mobile WLAN. The key concept used in the protocol is *multipoint relay* (MPR) nodes to disseminate link state updates across the network in an efficient way. In This protocol, each node "*s*" selects independently the near minimal set of MPR nodes, denoted as MPR(*s*). The nodes in MPR(*s*) have the following property: each two hops neighbour of "*s*" must have a link to MPR(*s*). In other words, the union of the one-hop neighbour set of MPR(*s*) contains the whole two-hops neighbour set as shown in the figure below. When a node "*s*" wants to flood a message, it sends the message only to the nodes in MPR(*s*), which in turn send the message to their MPR nodes and so on. This technique substantially reduces the packet overhead in comparison to pure flooding mechanism where every node retransmits the packet when it receives the first copy of the packet, especially when the network is very dense.

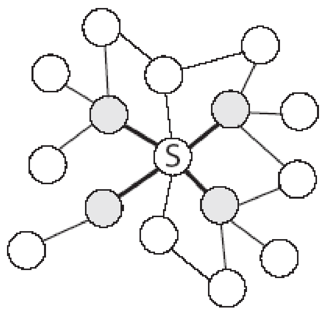

Figure 4: Multipoint relays MPR(S)

OLSR uses periodic updates for link state dissemination using a special type of control message called a Topology Control (TC) message. A TC message contains a sequence number that is incremented when the MPR selector set changes. A node announces to the network that it has reachability to the nodes of its MPR selector set using this message [Ilyas,2003; Mohapatra and Krishnamurthy,2005].

3.3 Reactive (On-demand) Routing Approach

Unlike in Proactive routing protocols, route discovery and route maintenance procedure in on-demand routing protocols are separate. This family of protocols is more suitable for ad hoc network than the proactive protocols because nodes find and maintain *only actually needed* routes. When a route is needed to some destination, a route discovery procedure is launched. The route discovery typically consists of the network wide flooding of a request message. This kind of discovery procedure generates significant traffic overhead. To reduce the overhead, the search area may be reduced by a number of optimizations [Ko and Vaidya,1998; Castaneda and Das,1999; Lee, Belding-Royer et al.,2003]. Maintaining Procedure is performed only on actually active routes. The obvious advantage with discovering routes on-demand is to avoid incurring the cost of maintaining routes that are not used. However, the delay to determine a route can be quite significant because route information may not be directly available the moment when it is needed. Furthermore, the global search procedure of the reactive protocols generates significant traffic overhead.

3.3.1 Temporally-Ordered Routing Algorithm (TORA)

Temporally Ordered Routing Algorithm (TORA) [Park and Corson,1997] is a highly adaptive loop-free distributed routing protocol for multihop networks; it was proposed to operate in a highly dynamic mobile networking environment. TORA provides multiple routes for any desired source/destination pair. The key design concept of TORA is the localization of control messages to a very small set of nodes near the occurrence of a topological change. To accomplish this, nodes need to maintain routing information about adjacent (1-hop) nodes. The protocol performs three basic functions: (a) route creation, (b) route maintenance, and (c) route erasure.

During the route creation and maintenance phases, nodes use a height metric to establish a directed acyclic graph (DAG) rooted at the destination. Thereafter, links are assigned a direction (upstream or downstream) based on the relative height metric of neighbouring nodes. Each node has a unique ID and a height, which is computed starting from the destination node that has the lowest height. The destination node sends a reply containing its ID (Fig.5).

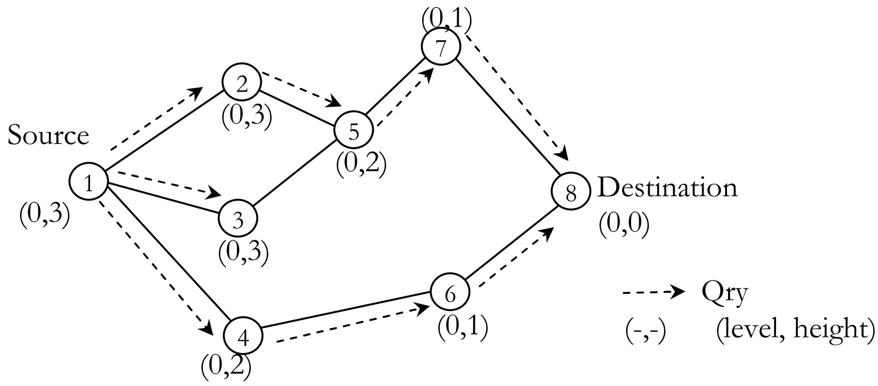

Figure 5: Route creation in TORA

Each node receiving this reply update its height relying on the height of the node that sends the reply. The node forwards this reply with the new height and ID. This operation continues until reaching the source node. When the source node receives this reply, it updates its ID to an ID higher than the one received in the reply, which makes it the node with highest ID, and the route is determined. The goal of giving IDs to nodes is to prevent loops in the routes and to create a directed route. If the destination becomes unreachable because of a network partition, the protocol erases (route eraser phase) all invalid routes and rebuilds new routes. This protocol is rapid but does not guarantee generation of shortest path routes.

3.4 Hybrid Routing Protocols:

Hybrid protocols are protocols that use reactive and proactive routing protocols in the same time, it is suitable for a wide variety of mobile ad hoc networks, especially those with large network spans and diverse mobility patterns. The network is divided into zones; each zone is constituted of nodes that are far "n" hops from a node. A proactive routing protocol is employed as an intra-zone routing protocol and a reactive one is used inter-zone, i.e. between zones. These kinds of protocols reduce the communication overhead comparison to the pure proactive protocols and the route discovering is faster than the pure reactive protocols. The Zone Routing Protocol (ZRP) [Haas,1997; Pearlman and Haas,1999; Haas and Pearlman,2001] is an example of this kind of protocols.

The protocols described above are not suitable as they are for real time applications such as multimedia and other time - or error - sensitive applications. Those protocols do their best to transport the user packets to their intended destination, although without any guarantee. To ensure such a service, many enhancements on routing protocols have been proposed.

In the next chapter, we will define what Quality of service is? and depict the most significant efforts done in this research area to ensure Quality of service.

CHAPTER 4 :
QUALITY OF SERVICE

4 Quality of Service (QoS):

QoS is a term widely used during last recent years in the area of wire-based and wireless networks. QoS stands for Quality of Service and the truth is that there is much debate on what exactly QoS is supposed to mean. Many definitions have been proposed in literature and most of them made a reference to some characteristics, such as Bandwidth or Delay, or mechanisms, such as Admission Control, Signalling Protocol.

The Recommendation E.800 Of the International Telecommunication Union (ITU -CCITT-) has proposed a widely accepted definition because it avoids details on characteristics and mechanisms: "The QoS is the collective effect of service performance, which determines the degree of satisfaction of a user of the service" [ITU–E.800,1994].

For non real time applications such as Telnet, FTP, E-mail and web browsing, timing is not a critical issue. As a result, the non real time network could work well with a Basic Best effort (Best effort in the sense that it will do its best to transport the user packets to their intended destination, although without any guarantee [Mishra,2008]) level of service. This level of service is unsuitable for real time applications such as multimedia and other time - or error - sensitive applications such as VoIP (Voice over IP), video conference and video streaming in which People cannot tolerate large delay. Such applications require some level of guaranteed throughput and delay in addition to their other constraints. QoS mechanisms are needed to ensure the differentiations between real and non-real time applications.

The key factors that influence Quality of Service (QoS) from the perspective of the end-user have been detailed and a broad classification of end-user QoS categories has been determined in the ITU Recommendation G.1010 [ITU–G.1010,2001]. The figure 6 illustrate QoS categories for user's application defined by the ITU.

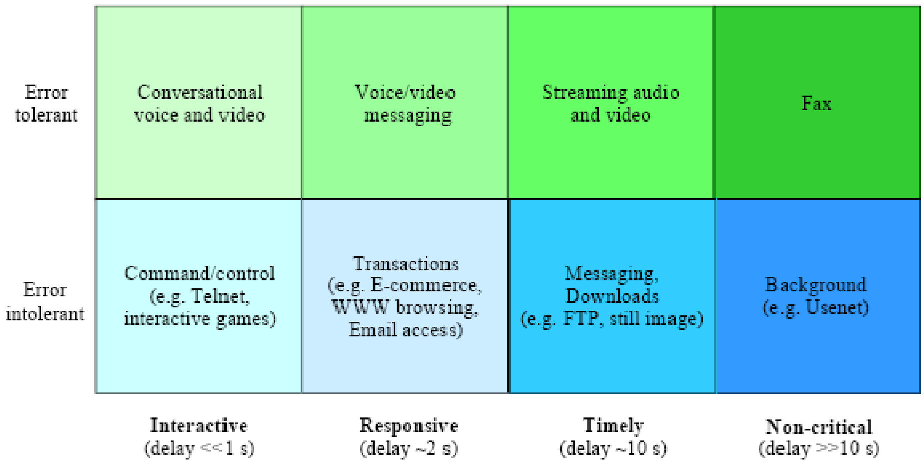

Figure 6: Model for user-centric QoS categories.

Due to the huge amount of research on this field that has appeared in the literature and the number of models that have been proposed during the last decade, QoS support is recognized as a challenging issue for the Internet [Chen and Nahrstedt,1998].

Two approaches have been proposed to obtain QoS in wired networks: an *over-provisioning* and *network traffic engineering*. Over-provisioning approach consists of offering a huge amount of resources on the network to be able to accommodate all the demanding applications. Instead, network traffic engineering consists of using a set of established rules to classify needs of applications and treat them [Masip-Bruin, Yannuzzi et al.,2006].

Integrated Services (IntServ) [DiffServ,2003] and Differentiated Services (DiffServ) [IntServ,2000] are two methods that belong to the network traffic engineering approach.

In one hand, users in IntServ request for the QoS parameters they need, this method is a reservation-oriented method. To setup resource reservations, The Resource reSerVation Protocol (RSVP) [Braden, Zhang et al.,1997] has been proposed by IETF.

On the other hand, DiffServ is a reservation-less method. To support various types of applications using DiffServ, a set of differentiated classes of QoS are offered and IPv4 Type of service (TOS) byte or the IPv6 Traffic Class (TC) byte is used to specify a particular QoS class to data packets.

4.1 QoS for MANETs:

The efforts proposed for Internet wired network are inappropriate for MANETs because of their ephemeral nature and specific aspects. During the last few years, QoS for ad hoc networks has emerged as an active and fertile research topic with a growing number of researchers. Many major advances are expected in the next few years [Perkins and Hughes,2002; Becker,2007; Hanzo (II) and Tafazolli,2007; Hanzo (II) and Tafazolli,2008].

QoS mechanisms are implemented for each layer of the OSI reference model.

Physical layer QoS means the quality in terms of transmission performance (transmission power control, energy control) to ensure the quality of reception and to optimize the capacity.

QoS implemented in MAC layer is also very important for stations to gain access to the wireless medium. It provides a high probability of access with low delay when stations with higher user priority. This is achieved by setting shorter back off time. IEEE 802.11e contains a QoS enhancement in order to differentiate between real and non-real time data flows.

The main goal of routing with QoS is to find a route which provides the required quality using the metric which helps to choose the route for not only the number of needed hops along the route but also some other metrics like minimum delay and maximum data rate, e.g. QAODV, which will be described later.

4.1.1 QoS Routing :

For obtaining QoS on a MANET, it is not sufficient to provide a basic routing functionality. Other aspects should also be taken into consideration such as power consumption, bandwidth constraints and dynamic topology. The problem of QoS Routing with those multiple additive constraints is known to be NP-hard. So, the perfect knowledge on the essence of QoS Routing dynamics, and the proposed solutions to this complex problem should be indeed feasible and affordable to conceive and deploy network services.

Over-provisioning approach cannot be adopted for MANETs because resources are scarce. IntServ/RSVP generates a considerable signalling overhead and it might require unaffordable storage and processing for MANETs nodes. DiffServ on the other hand, is a lightweight overhead model that may be more suitable for MANETs. However, DiffServ organization in customers and service providers does not fit the distributed nature of MANETs. These have motivated numerous QoS proposals targeting MANETs.

In the rest of this chapter, we shall present the most important open issues in terms of QoS for MANETs and briefly present some of the most compelling proposals and ongoing research efforts done that have been presented in the literature.

QoS proposals can be categorized into three categories: *Reservation-Oriented*, *Reservation-Less* and other Approaches. In Reservation-oriented approach, we will refer to proposals using reservation mechanisms. These proposals typically take ideas similar to the IntServ approach, achieving a higher degree of QoS guarantees by reserving resources and keeping some flow state information in mobile nodes. On the contrary, in Reservation-Less approach, we will refer to proposals that take ideas similar to the DiffServ approach. These proposals targeted to lightweight QoS by minimizing the state information kept by the network to achieve QoS.

4.1.1.1 Reservation-oriented approaches

A) Core Extraction Distributed Ad hoc Routing (CEDAR)

Most routing protocols designed for ad-hoc networks assume that every node behaves as edges of the flows (source and destination) and as routers. This means that every node must maintain the state of the network and must exchange this information with every other node. In proactive protocols, this information is exchanged periodically, while in reactive algorithms, it is exchanged on demand.

In order to avoid the overhead generated by maintaining the state of the network and exchanging this information between mobile nodes within MANET, the *Core Extraction Distributed Ad hoc Routing* (CEDAR) [Sivakumar, Sinha et al.,1999] protocol proposes the election of core network that is responsible for route computation.

A set of nodes is distributedly and dynamically elected to form the core of the network by approximating a minimum dominating set of the ad hoc network using only local computation and local state. The figure 7 demonstate an election of core nodes in within an ad hoc network. QoS routing in CEDAR is achieved by propagating the bandwidth availability information of stable links in the core network. The basic idea is that the information about stable high-bandwidth links can be made known to nodes far away in the network, while information about dynamic links or low bandwidth links should remain local. By doing this, all route computations are restricted only to the core nodes.

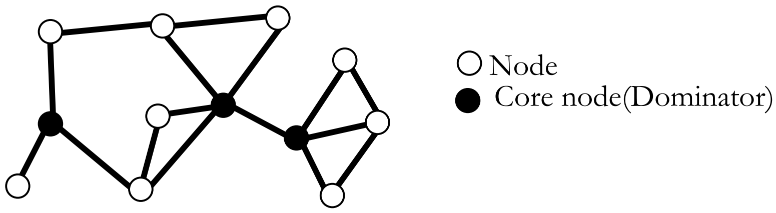

Figure 7: CEDAR: Core nodes in network

Whenever a source node needs to establish a connection to a destination node, it contacts the core node of its domain. The core of the source establishes a core route to that of the destination. The core route provides the directionality of the route from the source to the destination. Using this directional information, CEDAR computes a route adjacent to the core route, that is the short stable admissible QoS route from the source to the destination.

B) INSIGNIA

INSIGNIA [Lee, Ahn et al.,2000] is a QoS framework. It consists on an in-band signalling protocol in contrast with "out-of-band signalling" protocols as RSVP. This means that signalling information related to QoS mechanisms is encapsulated in data packets, making this approach easy and ´lightweight´. This implies that there are no special packets for doing the signalling. INSIGNIA is just the signalling protocol and a routing protocol, such as DSR, AODV, OLSR or TBRPF, is still needed.

INSIGNIA supports fast flow reservation, restoration, and adaptation algorithms that are specifically designed to deliver adaptive real-time services in MANETs. It encapsulates control signals in an IP option of every data packet, which is called INSIGNIA option[Nahrstedt, Shah et al.,2006].

C) Quality of service for Ad hoc On-Demand Distance Vector (QAODV)

QAODV is an extended version of the basic ad hoc on-demand distance vector (AODV) routing protocol providing QoS support in Ad hoc wireless networks (AWNs)[Perkins and Belding-Royer,2003].

To compute the routes according to QoS requirements, four new elements are included in the structure of the routing tables: *Maximum Delay*, *Minimum Available Bandwidth*, *List of Sources Requesting Delay Guarantees,* and *List of Sources Requesting Bandwidth Guarantees.*

In QAODV, each node must verify QoS requirements before sending or forwarding a RREP message to the source. If after the route is established an intermediate node detects that the QoS requirements cannot be fulfilled any longer, that node must send an ICMP QOS LOST message to all sources potentially affected by the change in the QoS parameter.

The advantage of QoS AODV protocol is the simplicity of extension of the AODV protocol that can potentially enable QoS provisioning. However, if no resources are reserved along the path from the source to the destination, this protocol is unsuitable for applications that require hard QoS.

D) Ad hoc QoS on-demand routing (AQOR)

Another interesting example of IntServ inspired proposals is the Ad-hoc QoS On-demand Routing protocol (AQOR) [Xue and Ganz,2003]. It proposes a resource reservation-based routing and signalling algorithm that tries to provide quality of service support, in terms of bandwidth and end-to-end delay. It provides a superficial analysis of the bandwidth consumed by a connection and the computation of the available bandwidth for the establishment of new connections in a given node. It also does not take into account the multirate capability of current networks.

4.1.1.2 Reservation-Less Approaches

A) Load-Balancing Schemes

Load balancing schemes in ad-hoc networks are considered as trivial QoS mechanisms. Many considerable proposals [Kazantzidis, Gerla et al.,2001; Al_Agha, Pujolle et al.,2003; Argyriou and Madisetti,2006; Chakrabarti and Kulkarni,2006; Ivascu, Samuel et al.,2009] represent this kind of lightweight QoS mechanism. The mean idea behind these approaches consists on letting the nodes estimate the available bandwidth. This is done by means of measurements at mobile nodes during the transmission time of the packets and its activity periods.

In[Kazantzidis, Gerla et al.,2001], in order to propagate measurements when a new route is searched using AODV, an additional field is added to Route Request (RREQ) packets. This information is taken into account by the destination before sending the Route Reply (RREP) packet, so that several RREQs are received and a RREP is sent only over the less congested path. In the case of OLSR [Al_Agha, Pujolle et al.,2003], nodes propagate the available bandwidth together with the state to the rest of the network. This information is used by the Shortest Path First (SPF) algorithm when searching for a new route.

In [Ivascu, Samuel et al.,2009], Ivascu et al present a new approach called Quality of service Mobile Routing Backbone over AODV (QMRB-AODV) for supporting QoS in mobile ad hoc networks. This method makes use of a mobile routing backbone to dynamically distribute traffic within the network and to select the route that can support best a QoS connection between a source and its destination. Nodes in real-life MANETs are heterogeneous, possess different communication capabilities and processing characteristics. This approach aim to identify those nodes whose capabilities and characteristics will enable them to take part in the mobile routing backbone and efficiently participate in the routing process. Moreover, the route discovery mechanism dynamically distributes traffic within the network according to current network traffic levels and nodes processing loads. QoS support is realized by relaying packets having special requirements to nodes rich in resources and connected through stable links.

Chakrabarti and Kulkarni [Chakrabarti and Kulkarni,2006] present a novel way of preserving QoS guarantees in DSR by pre-computing alternate routes to a destination and using these alternate routes when the current route fails. Their method ensures that traffic load is balanced among the alternate routes but also that an appropriate amount of bandwidth will be available for a flow even when nodes move.

In [Argyriou and Madisetti,2006], Argyriou and Madisetti introduce a novel end-to-end approach for achieving the dual goal of enhanced reliability under path failures, and multi-path load balancing in MANETs. These goals are achieved by fully exploiting the presence of multiple paths.

B) Courtesy Piggybacking

The Courtesy Piggybacking [Liu, Chen et al.,2004] also proposes a service differentiation solution. It focuses on trying to avoid the bandwidth starvation suffered by low priority traffic when high priority traffic is intense. The idea of this proposal is to piggyback low priority traffic into the high priority packets, whenever there is a free space, i.e, whenever a MAC frame is not completely filled by the high priority data. An intense coordination between the MAC and network layer is needed, since the MAC layer may request low priority data to the network layer in order to fill its frames[Guimaraes, Cerdà et al.,2009].

C) SWAN

Service differentiation in stateless Wireless Ad hoc Networks (SWAN) Project [Ahn, Campbell et al.,2002] is a distributed and stateless network model to support the delivery of real-time traffic over a multi-hop ad hoc network. It is a simple and effective solution. SWAN avoids signalling and state information to simplify the whole architecture and uses only feedback information from the network. It manages two different types of traffic: real-time and best effort, does not maintain per-flow state at each node, and it requires only a best-effort 802.11 MAC layer without any QoS capability. SWAN provides a differentiation between real-time and best effort, prioritizing the former by guaranteeing minimum delay at each node.

By measuring MAC delays, a mobile node automatically configures the rate control mechanism and, by measuring the rate of real-time traffic that passes through its neighbours, it evaluates the amount of bandwidth that is still available for new real-time connections, configuring thus the admission control. Whenever a node suffers from QoS degradation, it marks every forwarded packet with an Explicit Congestion Notification (ECN) flag. The destination of a packet marked with ECN should notify the source of the flow, so that it blocks transmission or adapts it to the new conditions [Nahrstedt, Shah et al.,2006].

4.1.1.3 Other Approaches

A) Flexible QoS Model for MANETs (FQMM)

Flexible QoS model for mobile ad hoc networks (FQMM) [Xiao, Seah et al.,2000] is a hybrid service model that takes advantage of the per-flow granularity of IntServ and the services aggregation into a number of classes performed by DiffServ.

Based on the assumption that the number of flows requiring per flow QoS guarantees is much smaller than the low priority flows. FQMM is designed to provide per flow QoS guarantees for the high priority flows while the lower priority flows are aggregated into a number of classes as in DiffServ. Although FQMM combines the advantages of both IntServ and DiffServ, it has also some unresolved issues such as the traffic classification policy, the amount of traffic that will be provided to each per flow service and the allotment of per flow or aggregated service for the given flow [Reddy, Karthigeyan et al.,2006; Cranley and Murphy,2008].

B) Prediction Based QoS routing

Many QoS routing algorithms that consider delay, throughput, Link Stability and Lifetime as QoS requirement have been proposed in literature. Predictive location-based [Shah and Nahrstedt,2002] and PQR [Mohrehkesh, Fathy et al.,2006] consider delay as QoS requirement.

The predictive location-based QoS routing protocol [Shah and Nahrstedt,2002] is mainly proposed to alleviate the scalability issue with respect to communication overhead in implementing source routing. Instead of disseminating the state of each link network-wide, each node broadcasts its node status (including its current position, velocity, moving direction, and available resources on each of its outgoing links) across the network periodically or upon a significant change. With such information, at any instant each node can locally form an instant view of the entire network. To accommodate a QoS request, the source locally computes a QoS satisfied route (if available) and route data packets along the computed path. Moreover, the source can predict route break and predicatively compute a new route before the old route breaks by using the global state it stores. This routing protocol is suitable for providing soft QoS in small or medium-sized networks wherein mobile hosts are equipped with Global Positioning System (GPS) receivers and their moving behaviour is predictable.

In [Mohrehkesh, Fathy et al.,2006], a new QoS routing algorithm is proposed that focuses on delay as the main QoS parameter. PQR tries to predict future states of nodes and decide whether to choose a node as a forwarder or not. The future state of a node includes its future buffer occupancy percentage as well as its future location in relation to its downstream node.

High-speed node movement causes an increase in packet delays and packet loss, QoS violation and as well as decreasing network throughput. To decrease these kinds of QoS violation, PQR predicts whether a node's future position could have stable links to forward packets or not. Hence, node's position in relation to its downstream neighbourhood is predicted. If two nodes will be in the range of each other in the future, then the upstream node is selected as a router. To predict time duration which nodes will be in the range of each other, Link Expiration Time (LET) [Su, Lee et al.,2001] method is used. The method will be detailed later.

In [Chen and Heinzelman,2005], Shen and Heinzelman present a QoS-Aware Routing protocol. This protocol considers bandwidth constraints for supporting real-time video or audio transmissions. QoS-aware routing protocol incorporates an admission control scheme and a feedback scheme to meet the QoS requirements of real-time applications. The novelty in this protocol is the use of the approximate bandwidth estimation to react to network traffic. The protocol implements these schemes by using two bandwidth estimation methods to find the residual bandwidth available at each node. QoS is included into the route discovery procedure; and the feedback is provided to the application through a cross-layer design.

In [Mamun-Or-Rashid and Hong,2007], a QoS routing algorithm that formulates a trade-off between link stability and cost that will ensure a disruption free communication for transmission has been proposed. This algorithm relies on the idea of link stability calculation based on the mobility prediction and best path in terms of cost and lifetime along with QoS support. QoS aware routing problem is expressed as maximizing the link stability and lifetime while minimizing the cost. Link failure due to mobility or power failure always hinder communication and increase number of packet loss, which in turn cause glitch for quality assurance. This algorithm selects the best path in terms of link stability and lower cost lifetime prediction to minimize blocking probability along with QoS support.

In [Jiang, Liu et al.,2004], a new predictive link metric that can reduce the impact of node mobility on QoS routing has been presented. This new metric is integrated in a link-caching scheme and implemented in the dynamic source routing (DSR) protocol to equip it with adaptability to changing topologies caused by user mobility. Many other studies [McDonald and Znati,1999; Su, Lee et al.,2001; Boleng, Navidi et al.,2002; Qin and Kunz,2003; Jiang,2004; Samar and Wicker,2004] have focused on link or path stability to ensure QoS and various mobility metrics have been proposed as measures of topological change in networks. That metrics describing the link or path stability allow adaptive routing in MANETs based on predicted link behaviour. A range of routing protocols based on predictive mobility metrics has been shown to increase the packet delivery ratio and to reduce routing overhead.
Novel QoS approaches have been proposed in [Cheng and Heinzelman,2008; Mottola, Cugola et al.,2008; Shen and Thomas,2008].

Mottola, Cugola and Picco [Mottola, Cugola et al.,2008] propose a new content-based routing (CBR) protocol to organize a MANET's nodes in a tree-shaped network. This network organization tolerates frequent topological reconfigurations and minimizes changes that impact the CBR layer exploiting the tree.

Shen and Thomas [Shen and Thomas,2008] propose a unified mechanism for a distributed dynamic management system, which aims to maximize QoS and security while maintaining a minimum user acceptable level even as network resource availability changes. In order to achieve this objective, they use three basic elements: a policy-based security framework, multilayer QoS guided routing, and a proportional, integral, derivative controller.

In [Cheng and Heinzelman,2008], Cheng and Heinzelman propose two new algorithms to discover long lifetime routes (LLRs) that allow traffic to remain continuous for a longer period of time. The proposed algorithms can be implemented as an extension to existing routing protocols, improving the performance of the transport layer protocols without modifying them.

We have observed that, all previous QoS routing proposals rely on either extending an existing routing protocol, adding a signalling protocol or balancing load within a network.

To evaluate the performance of those techniques, a comparison study must be done. Many metrics and parameters influencing them have been used.

The next chapter introduces chapters that follow it . It contains a detailed performance evaluation of the most promising routing protocols in MANETs. Performance metrics recommended by the MANET Group are used. This study is done using the well-known GLOMOSIM simulator.

Our proposed approaches that are detailed in chapter 6 and 7 will be evaluated in the same manner.

CHAPTER 5 :
PERFORMANCE EVALUATION OF ROUTING PROTOCOLS IN MANETS

5 Performance evaluation of routing protocols in MANETs

Ad hoc networks are characterized by multi-hop wireless connectivity, dynamic changing in network topology and the need of efficient dynamic routing protocols. The Efficient routing protocols can provide significant benefits to mobile ad hoc networks, in terms of both performance and reliability. Many routing protocols for such networks have been proposed so far, they are broadly classified depending on route discovery and maintenance mechanisms into reactive, proactive, and hybrid routing protocols. Amongst the most popular ones Ad hoc On-demand Distance Vector (AODV), Destination-Sequenced Distance-Vector Routing protocol (DSDV), Dynamic Source Routing Protocol (DSR), and Optimum Link State Routing (OLSR). All these protocols have been analyzed and compared in several studies. Those studies have shown that none of them is the best for all environments. Depending on several aspects – such as mobility, network load, network diameter - one protocol may behave better than another may.

5.1 Routing Protocols

5.1.1 Dynamic Source Routing Protocol (DSR)

The Dynamic Source Routing (DSR) [Johnson and Maltz,1996a; Johnson and Maltz,1996b] protocol is an innovative approach to routing in a MANET in which nodes communicate using the whole source route stored in data packet's header. It is referred as one of the purest examples of an on-demand protocol [Perkins,2001].

In DSR, each mobile node maintains a route cache that contains the source routes of which the mobile is aware. Entries in the route cache are continually updated as new routes are learned.

As all reactive Protocols, DSR consists of two major phases: route discovery and route maintenance. When a mobile node has a packet to send to some destination, it first consults its route cache to determine whether it has already a route to the destination. If it has an unexpired route to the destination, it will use this route to send the packet. On the other hand, if the node does not have such a route, it initiates route discovery by broadcasting a route request packet (RREQ). This RREQ contains the address of the destination, along with the source node's address and a unique identification number. Each node receiving the packet checks whether it knows a route to the destination. If it does not, it adds its own address to the route record of the packet and then forwards the packet (Fig. 8). To limit the number of route requests propagated on the outgoing links of a node, a mobile node only forwards the RREQ if the mobile has not yet seen the request and if the mobile's address does not already appear in the route record.

A route reply (RREP) is generated when the RREQ reaches either the destination itself or an intermediate node that contains in its route cache an unexpired route to the destination. If the node generating the RREP is the destination, it places the route record contained in the route request into the route reply. If the responding node is an intermediate node, it appends its cached route to the route record and then generates the RREP. To return the RREP, the responding node must have a route to the initiator. If it has a route to the initiator in its route cache, it may use that route. Otherwise, if symmetric links are supported, the node may reverse the route in the route record. If symmetric links are not supported, the node may initiate its own route discovery and piggyback the RREP on the new route request.

Route maintenance is accomplished using route error packets (RERR) and acknowledgments. RERR packets are generated at a node when the data link layer encounters a fatal transmission problem. When a RERR packet is received, the hop in RERR packet is removed from the node's route cache and all routes containing the hop are truncated at that point. In addition to RERR packets, acknowledgments are used to verify the correct operation of the route links. These include passive acknowledgments, where a mobile is able to hear the next hop forwarding the packet along the route.

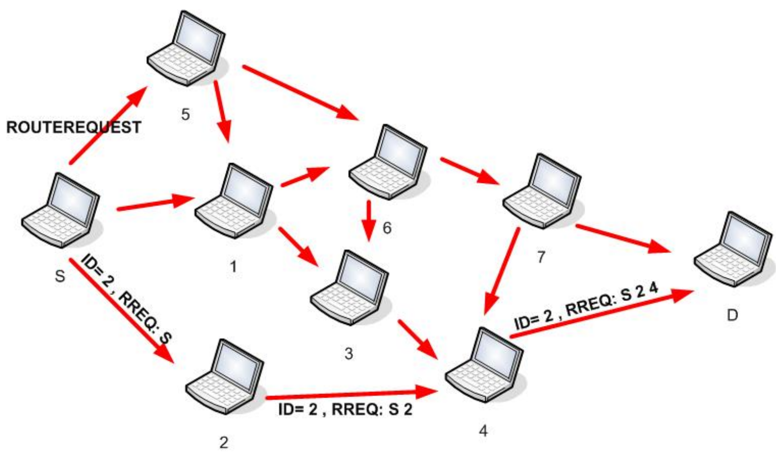

Figure 8: DSR route Discovery

5.1.2 Ad-hoc on-demand distance vector routing (AODV)

AODV [Perkins and Belding-Royer,1999; Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003] shares the same on-demand characteristics as DSR, but adopts a very different mechanism to maintain routing information. In AODV, each node maintains a traditional routing table, one entry per destination. Each entry records the next hop to that destination and a sequence number generated by the destination that indicates the freshness of this information. In addition, each entry also records the addresses of active neighbours through which packets for the given destination are received. Therefore, once the corresponding link of this entry is down, the upstream nodes using this link can be notified immediately.

Like DSR, AODV consists of two major phases: route discovery and route maintenance. When a need for a route arises, source node launches a route discovery operation. Route discovery operation is done through network-wide broadcasting. The source node starts a route discovery by broadcasting a route request (RREQ) packet to its neighbours. In the RREQ, there is a requested destination sequence number which is greater than the destination sequence number currently known to the source. This number prevents old routing information to be used as a reply to the request, which is the essential reason for the routing loop problem in the traditional distance vector algorithm. Unlike DSR, the RREQ does not record the nodes it has passed but only counts the number of such nodes. Instead, each node the request has passed sets up a temporary reverse link pointing to the previous node from which the request has come, so that the reply can be returned to the source node. An intermediate node can reply to a request only if it has a route entry for the destination that has the same or higher destination sequence number than the requested number. A route reply (RREP) packet contains the total hop count of the route and its destination sequence number. As a RREP travels back to the source, each intermediate node sets up the forward link as a route entry and records the destination sequence number. If the node receives further route replies later, it updates its routing entry and propagates the reply back to the source only if the reply has either a greater destination sequence number, or the same sequence number with a smaller hop count. Once the source node receives a RREP packet it starts sending data packets to the destination node. The figure below illustrates the two phases of a route discovery in AODV.

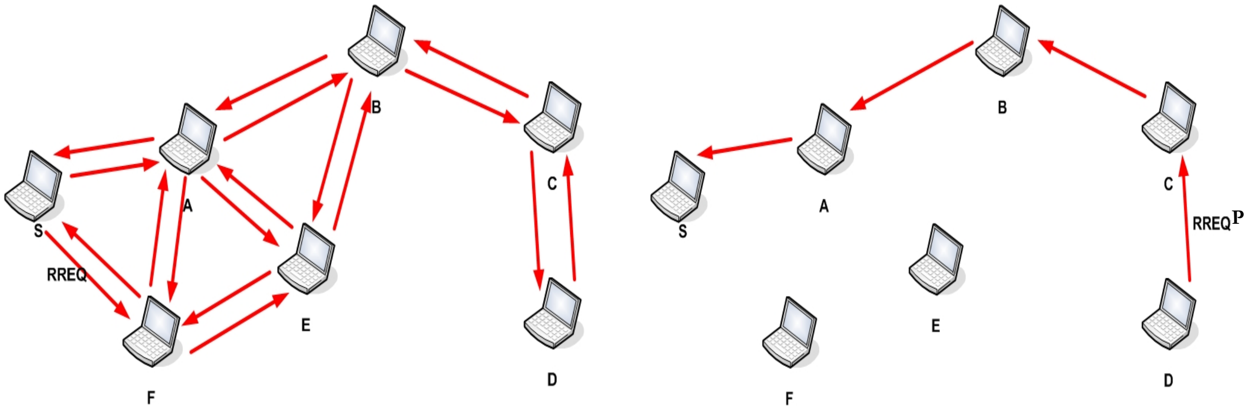

Figure 9: Route discovery in AODV

Route maintenance in AODV is similar to DSR. An invalid link can be detected through link layer acknowledgement, or by letting each node broadcasting periodic hello messages to neighbours. Hello messages can also be used to discover neighbours. Whenever a link in use is no longer valid, the upstream node of that link immediately sends a route error message (RERR) to its neighbours toward the source nodes using this link. Each neighbour must invalidate in its routing table the entries corresponding to the unreachable destinations and in turn notifies its active neighbours for the route and so on until the source nodes using that link are reached. The figure 10 shows a global repair mechanism for AODV.

The source node continues to send data packets until it receives RERR message. The number of lost data packets increases as the path length grows. To reduce the number of lost data packets, the node upstream of the break can perform a *local repair* instead of issuing the RERR (*global repair*). During a local repair, the intermediate node attempts to repair the link break itself by sending a RREQ for the destination. The sequence number for the destination node indicated in the RREQ must be incremented by one to prevent loops to nodes earlier in the path that still believe they have a valid route to the destination. While waiting for a RREP, the intermediate node buffers incoming data packets for the destination node. If the local repair is successful, a RREP will be returned either by the destination or An inermediate node with a valid route to the destination. Once the node that initiated the local repair receives this RREP, the route is repaired and any buffered data packets can be forwarded to the destination, otherwise, the local repair is not successful and a RERR message is sent to the source nodes.

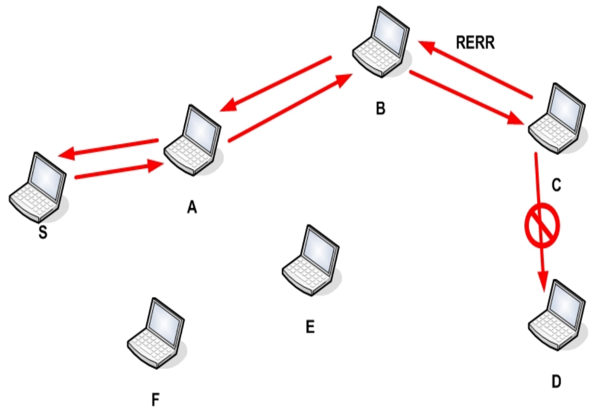

Figure 10: Global route maintenance in AODV

5.2 Performance evaluation

5.2.1 Global Mobile Information System Simulator (GlomoSim 2.03)

Global Mobile Information System Simulator (GlomoSim) is a library-based sequential and parallel simulator for wireless networks from University of California in Los Angles (UCLA). It is designed as a set of library modules, each of which simulates a specific wireless communication protocol in the protocol stack. The library has been developed using PARSEC, a C-based parallel simulation language [Zeng, Bagrodia et al.,1998]. GlomoSim was designed to be extensible. Wireless network communication protocols are divided into seven layers network architecture similar to OSI reference model. Every protocol with its own application programming interface (API). With only these APIs the models of protocols at one layer will interact with the lower or higher layer. Like the most network systems and standard APIs will be used between these layers:

Application layer: Here there are four class services available:

- CBR (constant bit rate): It simulates a constant bit rate generator.
- FTP (File transfer protocol): the protocol for exchanging files over the internet. It uses TCP/IP network traffic (tcplib).
- Http (hypertext transfer protocol): HTTP simulates single-TCP connection web servers and clients.
- Telnet: Is a terminal emulation program for TCP/IP networks; it runs on our machine and connects our PC to a server on network.

Transport layer: The transport layer provides two transport protocols:

- UDP (User Datagram Protocol): a connectionless protocol, runs on top of IP networks. It is used over by CBR.
- TCP (Transmission Control Protocol): It enables two hosts to establish a connection and exchange streams of data. It is used by the rest of applications.

Network layer: This layer implements routing protocols such as AODV, DSR, ODMRP, FISHEYE, LAR1 and ZRP. In this layer, the only protocol supported is Internet Protocol (IP).

MAC layer: This layer has the following protocols IEEE802.11, CSMA, TSMA, MACA.

Mobility: Random waypoint, Random drunken, Trace based

Radio Propagation: Two ray ground and Free space

5.2.2 Simulation Model

To evaluate performance of AODV and DSR a detailed simulation study is done. In the physical, data link, and medium access control (MAC) layers on *GlomoSim* the IEEE 802.11 model is used. The coordination function of IEEE 802.11 selected is the Distributed Coordination Function (DCF). An unslotted carrier sense multiple access (CSMA) technique with collision avoidance (CSMA/CA) is used to transmit the data packets. The radio model uses characteristics similar to a commercial radio interface, Lucent's WaveLAN [Tuch,1993]. WaveLAN is modelled as a shared-media radio with a nominal bit rate of 2 Mb/s and a radio range of 250 m.

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 30s. 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 it served in FIFO order.

5.2.3 The Traffic and Mobility Models

Constant (Continuous) bit rate (CBR) traffic sources are used. The source-destination pairs are spread randomly over the network. Only 512-byte data packets are used. The number of source-destination pairs and the packet-sending rate in each pair is varied to change the offered load in the network.

The mobility model uses the *random waypoint* model in a rectangular field. The field configurations used is 300 m x 1500 m field with 50 nodes. Here, each node starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0–20 m/s). Once the destination is reached, another random destination is targeted after a pause. The pause time, which affects the relative speeds of the mobiles, is varied between 0 (high mobility) and 900 (limited mobility). Simulations are run for 900 simulated seconds. Identical mobility and traffic scenarios are used across protocols to gather fair results.

Table 1 : Summary of simulation environment

Parameters	Values	Parameters	Values
Routing Protocols	AODV, DSR	Bandwidth	2 Mb/s
Simulation time	900 sec	Radio range	250 m
MAC layer	IEEE 802.11 (DCF)	Send Buffer size	64 packets
Physical layer	WaveLAN	Send Buffer timeout	30 sec
Traffic model	CBR	interface queue size	50 packets
Packet size	512 bytes	Network size	50 nodes
Simulation Area	1500m × 300m	Max. speed	20 m/s
Source number	10, 20, 30,40	Pause time	0, 60,120 300,600, 900 s
Packet rate	4 Packets/s		

5.2.4 Performance Metrics

Three important performance metrics [Corson and Macker,1999] are evaluated:

- *Packet delivery fraction* — The ratio of the data packets delivered to the destinations to those generated by the CBR sources.
- *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, and propagation and transfer times.
- *Routing overhead (Normalized routing load)* — The number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.

The first two metrics are the most important. The routing load metric evaluates the efficiency of the routing protocol. Note, however, that these metrics are not completely independent.

5.3 Performance comparison of the protocols:

To compare performance the two protocols a simulation study must be carried out with the same simulation environment. For all the simulations, the same movement models were used, the number of traffic sources was fixed to 10 sources, the maximum speed of the nodes was set to 20m/s, the packets were sent at a rate of 4 packets/sec and the pause time was varied as 0s, 60s, 120s, 300s, 600s and 900s. The same simulations were carried out with the number of traffic sources as 20, 30 and 40. Each simulation is repeated 10 times with changing seed value and the average values of the results are computed.

5.4 Simulation results

5.4.1 Packet delivery Comparison:

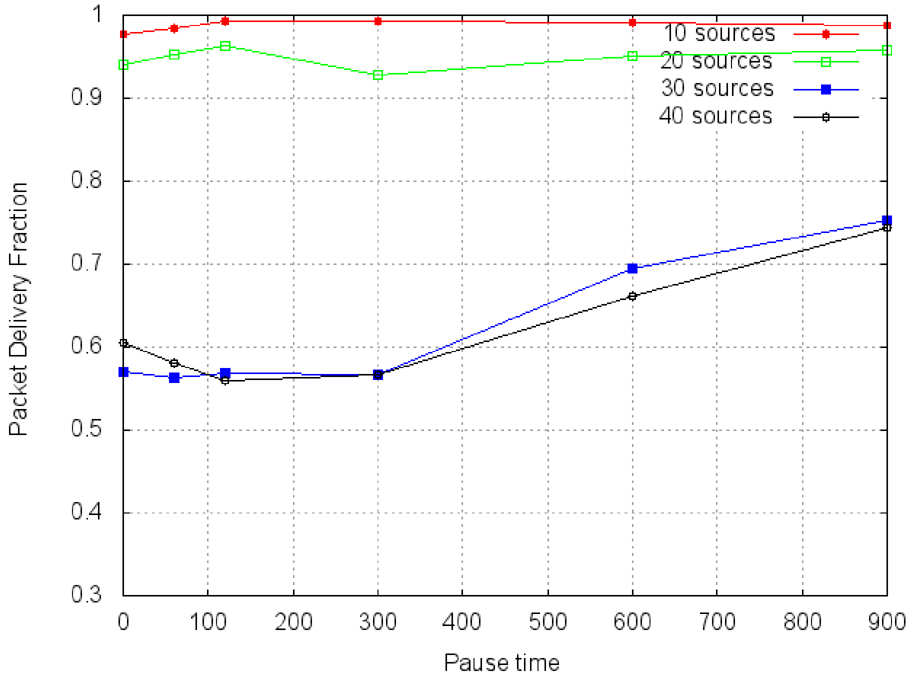

Figure 11: AODV Packet Delivery Fraction

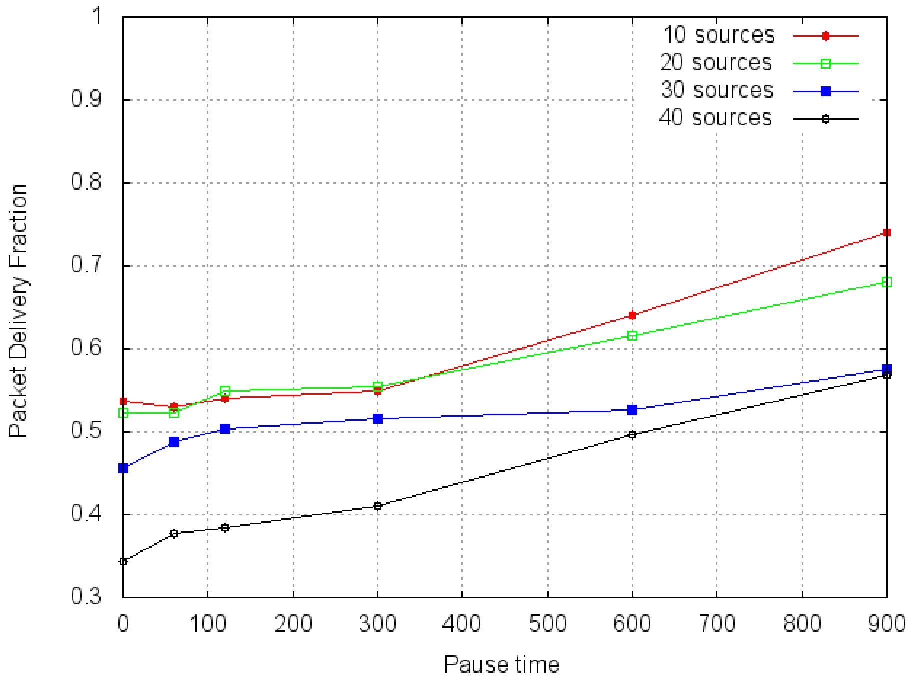

Figure 12: DSR Packet Delivery Fraction

The above figures depict a high performance of AODV in term of the packet delivery fraction (PDF) in comparison to DSR, especially, at lower pause times (higher mobility) and lower load (number of sources).

The presence of high mobility implies frequent link failures and each routing protocol reacts differently during link failures.

The abundance of cached routes and the aggressive use of caching at each node in DSR lead to a mild reaction of DSR link failures that causes route discovery less often than AODV. However, with high mobility, this advantage may become a disadvantage because of the possibility that a cached route becomes stale is quite high in DSR, which leads to a high number of dropped packets and a degeneration of the packet delivery ratio.

5.4.2 Average End-to-end delay:

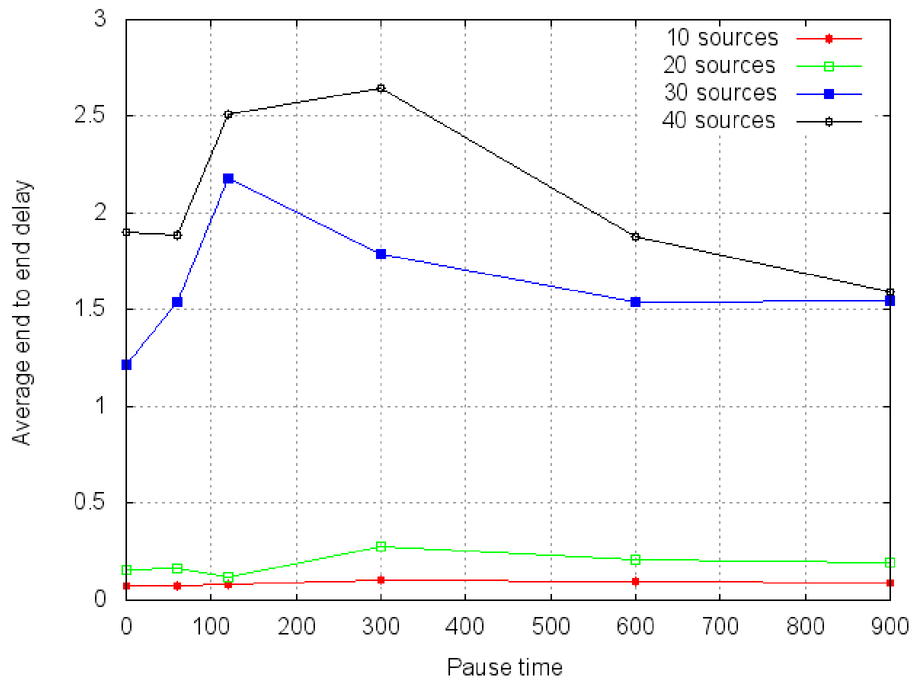

Figure 13: AODV Average End-to-end Delay

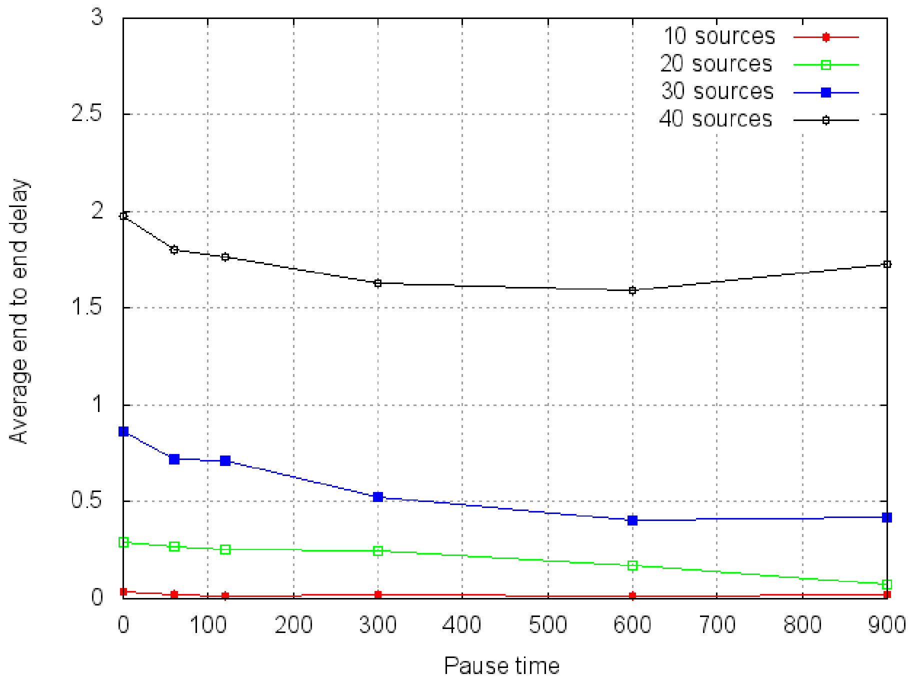

Figure 14: DSR Average End-to-end Delay

The results of the average end-to-end delay show that AODV outperforms DSR at 20 sources only. This is due to the frequency of route discoveries in AODV that is directly proportional to the number of broken route, especially with high mobility. Many sources may be affected when a link breaks in a high load (number of sources) scenario, which results in a new route discovery per source node.

5.4.3 Routing overhead:

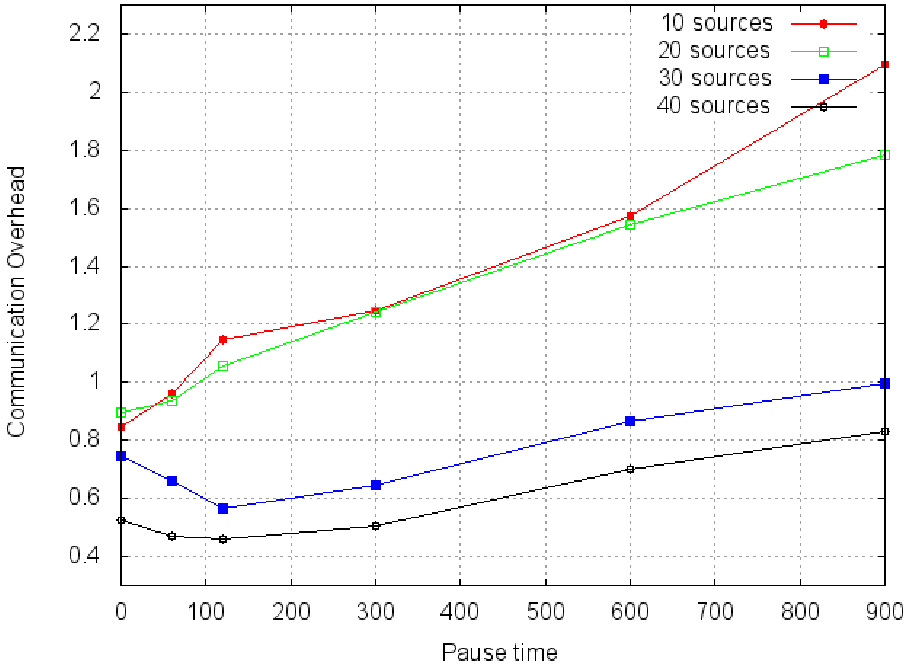

Figure 15: AODV Overhead

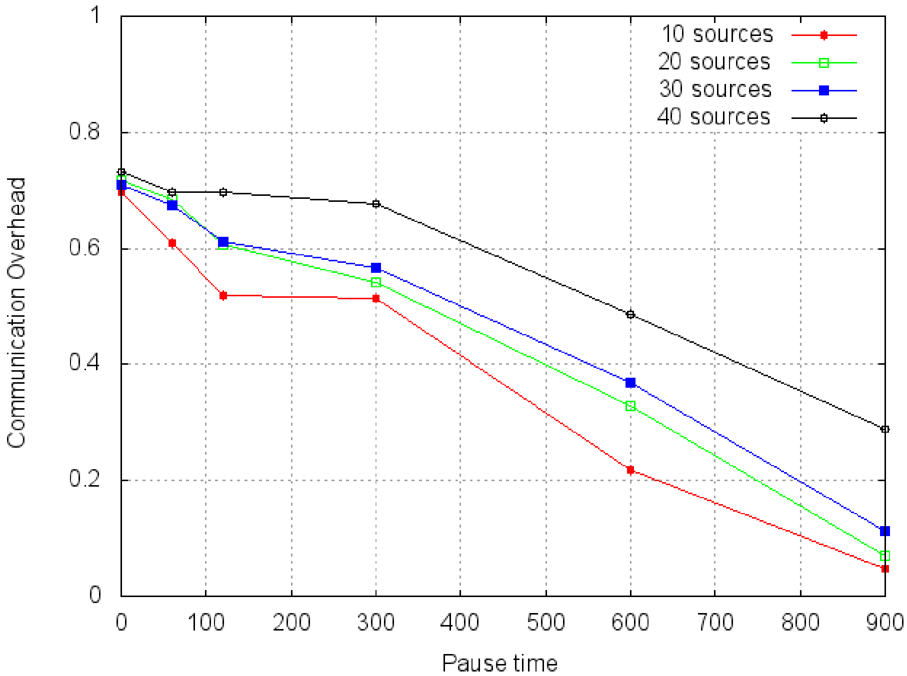

Figure 16: DSR Overhead

In lower mobility scenarios, DSR may often perform better than AODV, because the chances of find the route in one of the caches is much higher.
DSR usually has a lower routing load than AODV. This can be attributed to the caching strategy used by DSR. By virtue of aggressive caching, DSR is more likely to find a route in the cache, and hence resorts to route discovery less frequently than AODV.

5.5 Conclusion

This study compared the performance of AODV and DSR routing protocols for ad hoc networks using GlomoSim simulations.

Both DSR and AODV use on-demand route discovery, but with different routing mechanics. In particular, DSR uses source routing and route caches, and does not depend on routing tables. DSR exploits caching aggressively and maintains multiple routes per destination. AODV, on the other hand, uses a routing table, that contains only one route per destination, and destination sequence numbers which is a mechanism to prevent loops and to determine freshness of routes.

The general observation from the simulation results is that AODV outperforms DSR in more "stressful" situations (i.e., smaller number of nodes and lower load and/or mobility), with widening performance gaps with increasing stress (e.g., more load, higher mobility). In addition, AODV is more scalable and the packet delivery ratio is better in case of AODV in comparison to DSR. DSR, however, consistently generates less routing overhead than AODV. The poor performances of DSR are mainly attributed to its slow reaction to link changes, aggressive use of caching and lack of any stale routes expiration mechanism or determine the freshness of routes when multiple choices are available. Aggressive caching, however, seems to help DSR at low loads and keeps its routing overhead down.

The Route failures have a significant negative impact on packet delivery. Packet dropping and higher delays are the main consequences of route failures. The time elapsed between link break detection and alternative path establishment can be high. Therefore, many studies have focused on improving route repair by adding preemptive or predictive mechanisms.

In the next chapter, we will present predictive, preemptive techniques and our approach that combines them to benefit from the advantages and limit the disadvantages of both techniques.

CHAPTER 6 :
PREDICTIVE PREEMPTIVE MECHANISMS FOR ROUTE MAINTENANCE IN MANETS

6 Predictive Preemptive mechanisms for route maintenance in MANETs:

The conventional routing for MANETs provides a best effort service to transport user packets to their intended destinations. To meet QoS routing, traditional routing protocols for MANETs must be enhanced. QoS routing protocols create routes using nodes and links that possess the resources required to fulfill QoS requirements. In other words, this kind of routing protocol identifies routes in the network that obey the constraints required by the source application and selects between these routes the one to be used [Wang and Crowcroft,1996]. QoS routing protocols work together with resource management mechanisms to establish routes that meet end-to-end QoS requirements, such as delay, jitter, available bandwidth, packet loss rate, hop count and path reliability. Routing protocols supporting QoS must also deal with route maintenance [Ivascu, Samuel et al.,2009]. Indeed, nodes in MANETs are free to move, this can cause routes to become unusable. A node on a route from a source to a destination may become unreachable from its predecessor node because of node movement. These route failures have a negative impact on packet delivery and QoS.

6.1 Introduction

A mobile ad hoc network consists of a set of mobile wireless devices that can communicate with each other without requiring the existence of fixed networking infrastructure. Nodes cooperate with their neighbours to route data packets to their final destinations. As nodes are mobile, routes between sources and destinations need to be determined and adjusted dynamically. Routing protocols for MANETs typically consist of a route discovery mechanism and a route maintenance mechanism. The route discovery mechanism is invoked to determine a route between a sender and a receiver. The route maintenance mechanism finds new valid routes as substitutes for broken active routes. Several approaches to route maintenance have been proposed in the literature. In the Ad-hoc On-Demand Distance Vector (AODV) protocol, a node that detects the failure of a link to a destination propagates a link failure control packet to all upstream (towards sources) neighbours. This process is repeated until all sources that use the link are notified. Source nodes invoke the route discovery mechanism if they need a route to the destination. Link failures can be detected via link-layer acknowledgements or periodic HELLO packets [Perkins, Belding-Royer et al.,2003]. In addition to this global maintenance by the sources, a local mechanism is also added to AODV.

A node that detects the failure of a link to a destination attempts to find an alternative sub-path that can reach the destination [Perkins and Belding-Royer,1999; Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003].

A problem with waiting for a link to fail before route maintenance is carried out is the time failure notification and route re-establishment operations. Schemes that use Global Positioning System (GPS) information for detecting and handling expected link failures early have been proposed in [Cahill, De Leon et al.,2002], [Crisostomo, Sargento et al.,2004], and [Su, Lee et al.,2001]. The power of received signals has also been used for detecting expected link failures in DSR [Goff, Abu-Ghazaleh et al.,2003]. The area covered by the transmission range of a signal is subdivided into a safe range and a preemptive range. When it is determined that a node is in the preemptive range, a link failure warning message is sent to the source of the packet. The source then finds and uses a substitute route. This approach can result in unnecessary warning messages and route maintenance operations because the link that is expected to break may not fail soon, depending on movement speed and direction.

In this chapter, we propose an approach entitled Predictive Preemptive AODV (PPAODV) that uses the Lagrange interpolation for estimating whether an active link to a neighbouring node will fail. When link failure is expected between a node and an upstream neighbour, the upstream neighbour itself first attempts to find a route to the destination. If such route is not found within a discovery period, a link failure message is propagated from the upstream nodes to sources that use this link. Source nodes invoke the route discovery mechanism if they need a route to the destination. This approach is a predictive path reliability-based QoS routing technique.

To evaluate this approach of link failure prediction, we have added it to AODV using the well known GlomoSim simulator. This simulator includes implementations for many ad hoc routing protocols, and it has been validated by its frequent use by researchers.

Subsequent sections of this chapter describe briefly route maintenance operation in a promising routing protocol in MANETs. This is followed by defining preemptive and predictive route maintenance and classifying studies treating the subject. Next, we present our approach that gathers the advantages of preemptive and predictive approaches of route maintenance followed by a simulation based performance evaluation of our approach. The used simulator used in our experimentations is described briefly and simulation results are discussed in the next section followed by presenting recent efforts that propose an enhancement of our approach. Finally, we conclude.

6.2 AODV Routing Protocol

AODV [Perkins and Belding-Royer,1999; Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003] is an on-demand routing protocol. Route discovery is initiated only when a source node needs to communicate with a destination for which it does not have a route in its routing table. To discover a route to a destination, the source node broadcasts a route request message (RREQ) that contains a request ID. If a node receives a RREQ that it has already received, it drops the request. Otherwise, it stores the address of the node from which it received the request to establish a reverse route to the source that it uses later. If the RREQ reaches a node that has a route to the destination, the node sends, over the reverse route, a route reply message (RREP) to the source. The reply message contains the number of hops needed to reach the destination from the node. If the RREQ reaches the destination, it sends a route reply to the source over the reverse route. Intermediate nodes that do not have a path to the destination re-broadcast the request. When the RREP is sent back to the source over the reverse path, each node stores the address of the node that sent the reply. The forward path thus determined from the source to the destination is used for sending packets to their destination. AODV uses sequence numbers maintained for the different destinations so to guarantee freshness of routing information.

A link breaks when a node within an active route moves out of the transmission range of its upstream neighbour. When a link break occurs, the node upstream the break invalidates all routes that become unusable due to the loss of this link. It then creates a Route Error (RERR) message, in which it lists the destinations that have become unreachable because of the loss of the link. The RERR is sent to all source nodes that use the link. This procedure is named global repair. AODV also includes a local repair mechanism to locally recover from link losses. Local repair is triggered when a link break occurs between nodes within an active route. In this repair, the node upstream the break tries to find alternative sub-paths to the destinations of packets that it has received, and it is unable to forward them because of the link break.

6.3 Route Maintenance Mechanisms

Route failures have a significant negative impact on packet delivery. Packet dropping and higher delays are the main consequences of route failures. The time elapsed between link break detection and alternative path establishment can be high. Therefore, many studies have focused on improving route repair by adding preemptive or predictive mechanisms[BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007].

The idea behind preemptive route maintenance is to use techniques to look for alternative route to a destination, before a route failure happens.

The predictive route maintenance in based on predicting mobility. By definition, Mobility Prediction is the capacity to evaluate a future position given past positions[Härri, Bonnet et al.,2007]. In this technique, a route prediction function is used to predict a failure and repair this route if it is needed. This technique prevents route failure.

6.4 Predictive route maintenance

Su et al. [Su, Lee et al.,2001] propose a prediction based QoS routing (PQR). They propose the inclusion of mobility information in data packets so as to estimate the expiration time of routes at the destinations in on-demand routing protocols. Predicted link expiration times are appended to data packets as they travel to their destinations. A Distance Vector with Mobility Prediction (DV-MP) routing protocol is also proposed. This protocol selects route links based on their predicted expiration times. Mobility prediction utilizes GPS location information (Fig.17). Su et al. predicate the value Link Expiration Time (LET) using the formula below:

$$LET_{i,j} = \frac{-(a \times b + c \times d) + \sqrt{(a^2 + c^2) \times r^2 - (a \times d - b \times c)^2}}{a^2 + c^2}$$

Where:

$$a = v_i \cos\theta_i - v_j \cos\theta_j \qquad c = v_i \sin\theta_i - v_j \sin\theta_j$$

$$b = x_i - x_j \qquad d = y_i - y_j$$

(x_i ,y_i) are coordinates of the mobile host "*i*" and (x_j ,y_j) are that of mobile the host "*j*" where each mobile host is within the transmission range "*r*" of each other. "v_i" and "v_j" are the speeds, and "θ_i" and "θ_j" ($0 \le \theta_i , \theta_j < 2\pi$) are the moving directions of nodes "*i*" and "*j*", respectively.

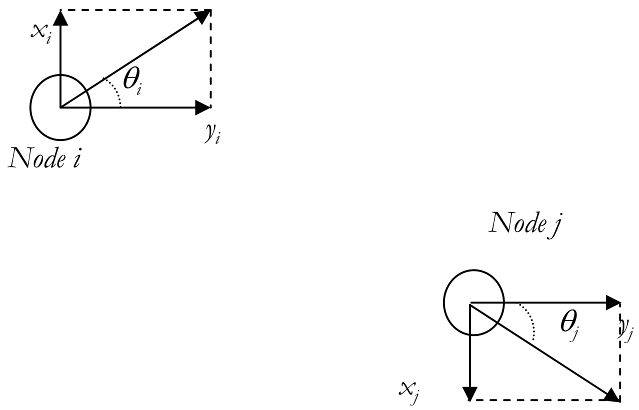

Figure 17: Mobile nodes moving at random speeds and directions.

Its general goal is enhancing the performance of unicast and multicast routing protocols by selecting stable routes and performing route reconstruction proactively. An issue with global positioning systems is the cost associated with their use in term of time and precision. A second issue is that they may not work properly because of fading.

Cahill et al. [Cahill, De Leon et al.,2002] propose the use of node position and mobility information in the route discovery mechanism of DSR. When multiple routes to a destination exist, route selection is based on route stability and hop count. Moreover, nodes upstream of links that are predicted to break carry out preemptive local repair. This proposal uses DSR caching [Johnson and Maltz,1996a; Johnson and Maltz,1996b]. Therefore, it is not applicable to AODV. Moreover, a GPS is used.

In [Crisostomo, Sargento et al.,2004], Crisòstomo et al. propose a Preemptive Local Route Repair (PLRR) extension to AODV. Nodes trigger the preemptive local route repair procedure when they predict that a link on the route to a destination is about to break. All packets are modified to contain node positions and mobility information obtained using GPS receivers that nodes are equipped with.

The prediction function adopted in this work is an extension of the function proposed in Su et al. [Su, Lee et al.,2001]:

$$LET_{i,j} = \frac{-(a \times b + c \times d) + \sqrt{(a^2 + c^2) \times (r - errpos_i - errpos_j)^2 - (a \times d - b \times c)^2}}{a^2 + c^2}$$

Where $errpos_i$ and $errpos_j$ are the maximum position error of neighbours *i* and *j* to account for position inaccuracies.

The problems with this approach are the cost associated with using a GPS and the need for synchronization between the internal clocks of nodes.

6.5 Preemptive route maintenance

In [Goff, Abu-Ghazaleh et al.,2003], Goff et al. propose a preemptive route maintenance extension to the on-demand routing protocols. Its aim is to find an alternative path before the cost of a link failure is incurred. The received transmission power is used to estimate when a link is expected to break. A link is considered likely to break when the power of the signal received over it is close to the minimum detectable power. The figure below shows a preemptive zone within a transmission range of a node.

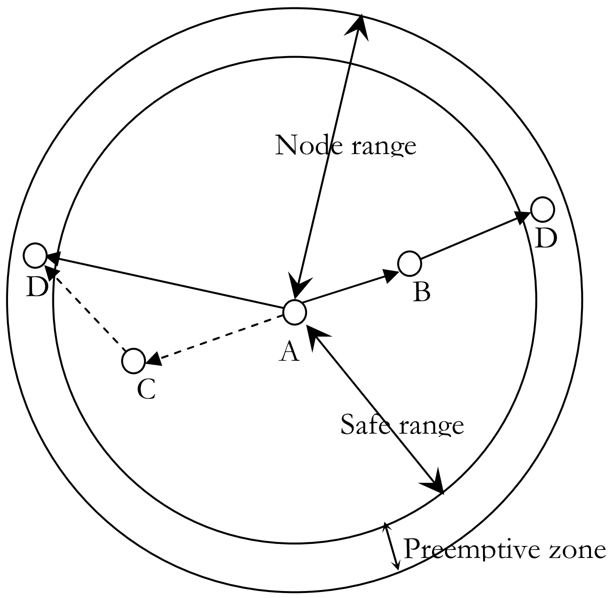

Figure 18: Preemptive Zone

Route repair is the responsibility of a source node after receiving a warning about the imminence of a link break on an active route to a destination. This mechanism has been applied to DSR; AODV is also considered, but only superficially.

In [Srinath, Abhilash et al.,2002], Srinath et al. propose a preemptive router handoff strategy based on received signal strength for AODV. Whenever a node "*X*" predicts that the previous or next link on an active path to a destination "*D*" will soon have a signal strength below a threshold value, it attempts to find a neighbour "*H*", that can reach both the predecessor "*P*" and successor "*N*" nodes with links that have superior strengths. The sub-path "*P-X-N*" is replaced with "*P-H-N*", unless when "*H*" has a better route to "*D*" that does not go through "*N*". Predicted power strengths are based on the rate at which power changes between active neighbouring nodes.

In [Boukerche and Zhang,2004], Boukerche and Zhang propose a Preemptive AODV (PrAODV). They combine two pre-emptive mechanisms, *Schedule a Rediscovery in Advance* and *Warn the Source Before the Path Breaks*. *Warn the Source Before the Path Breaks* is attained by exchanging Hello Message (ping–pong process). When the signal power of received packets is below a threshold value, the node sends to its upstream neighbours a hello message called "ping", neighbouring nodes should reply with a hello packet called "pong" within a timeout. If the node does not receive this pong message a warning message should be sent back to the source. Upon receiving a warning message, the source node starts a rediscovery. *Schedule a Rediscovery in Advance* is achieved by collecting information of the active links. When a reply packet return to the source through an intermediate node, it collects the information of the links. Therefore, when the packet arrives at the source, the information about the condition of all links, including the minimum value of the lifetime of the links, will be known. Hence, we can schedule a rediscovery $T_{rediscovery}$ time before the path breaks. An issue with this technique is the high routing cost (overhead), however, the average delay end to end delay per packet, in PrAODV, is significantly reduced.

6.6 Predictive Preemptive route maintenance

6.6.1 PPAODV

Predictive route maintenance techniques suffer of excessive computing and preemptive once generates false warning. In order to avoid those problems, we proposed an approach that combines the two techniques.

Our approach (PPAODV) [BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007] is studied by extending the Ad-hoc On-Demand Distance Vector (AODV) protocol [Perkins and Belding-Royer,1999; Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003]. However, this approach is general and can be used to enhance other routing protocols.
The main goal of our approach is improving MANETs quality of service capabilities by minimizing route failures, avoiding unnecessary attempts of route maintenance to get reliable paths. Our approach is a predictive path reliability-based QoS routing technique. In this technique, the protocole considers that a node is in an unsafe or preemptive region if it receives a data packet from a predecessor node with signal strength below a threshold signal strength P_r. Once a node enters this zone, the algorithm collects at least three consecutive measurements of the signal strength of packets received from the predecessor node, and predicts link failure using the Lagrange interpolation.

We store the power strengths of the three signals and their times of occurrence. When two consecutive measurements give the same signal strength, we store the time of the second occurrence. The expected signal strength P of the packets received from the predecessor node is computed as follows:

$$P = \left(\frac{(t-t_1)\times(t-t_2)}{(t_0-t_1)\times(t_0-t_2)} \times P_0 \right) + \left(\frac{(t-t_0)\times(t-t_2)}{(t_1-t_0)\times(t_1-t_2)} \times P_1 \right) + \left(\frac{(t-t_0)\times(t-t_1)}{(t_2-t_0)\times(t_2-t_1)} \times P_2 \right)$$

Where P_0, P_1, P_2 are the measured power strengths at the measurement times t_0, t_1, and t_2, respectively. The time t is the sum of the time needed for discovering an alternative path (Discovery Period), the last measurement time t_2, and the average value of the measurement times t_0, t_1, and t_2. That is:

$$t = t_2 + \left(\frac{t_0 + t_1 + t_2}{3} \right) + \text{Discovery Period}$$

When *P* is lower than the minimum accepted power (-81 dB) a warning message is sent to the predecessor node. This node then starts a local repair procedure to find alternative paths to the destinations reached using the link to the node that sent the warning message.

The Figure below depicts the prediction operation used in PPAODV.

1st Measurement
2nd Measurement
3rd Measurement
B
B
Predicted new state
A
B
Warning
B
Preemptive Zone

Figure 19: Predicting Link failure In PPAODV.

The pseudo code of PPAODV is presented below. The data structure used to save couples of (time and received power strength) is a linked list.

```
Each time a data_packet is received  we execute :

If (power (data_packet)< Pt) then
            {
            Collect_couples (time, power) ;
            if( number_couples() =3 ) then Predict();
            }

Collect_couples (time, power) ;
            {
            If (power = previous_power(data_packet)) then
                                    Update_time (time, power);  // update the time of the last couple
                        Else
                                    save_power_time (time, power); // insert couple into a list
            }

Predict()
            {
            P=Use_Lagrange_interpolation() ;
            If (P <= Min_Acc_Power) then
                                    Send_ warning (predecessor_node);
                        Else
                                    Delete_older_value();  // Delete the old value
            }
```

Figure 20: Pseudo code of PPAODV.

6.6.1.1 Performance Evaluation and Simulation results

A) Simulation Environment

We have used the implementation of AODV version 13 [Perkins, Belding-Royer et al.,2003] in the GlomoSim simulator and the widely used simulation environment. Our results are based on the simulation of 50 wireless nodes forming an ad hoc network moving about in an area of 1500 meters by 300 meters for 900 seconds of simulated time. The physical radio characteristics of each mobile node's network interface, such as the antenna gain, transmission power, and receiver sensitivity, are chosen to approximate the Lucent WaveLAN [Tuch,1993] direct sequence spread spectrum radio.

Nodes move according to the random waypoint model [Johnson and Maltz,1996b] in a free space model. The movement scenario files used for each simulation are characterized by a pause time. Each node begins the simulation by selecting a random destination in the simulation area and moving to that destination at a speed distributed uniformly between 0 and 20 M/S. It then remains stationary for pause time seconds. This scenario is repeated for the duration of the simulation. We carry out simulations with movement patterns generated for seven different pause times: 0, 60, 120, 300, 600, and 900 seconds. A pause time of 0 seconds corresponds to continuous mobility, and a pause time of 900 (the length of the simulation) corresponds to limited mobility. Each scenario is repeated 10 times and the average values of the results are computed.

Constant bit rate (CBR) sources are used in the simulations. The packet rate is 4 packets/sec when 10, 20, and 30 sources are assumed, and it is 3 packets/sec for 40 sources. The value of Pt is empirically determined to be equal to -80.64545 dB.

Table 2 : Summary of simulation environment

Parameters	Values	Parameters	Values
Routing Protocols	AODV, PPAODV	Bandwidth	2 Mb/s
Simulation time	900 sec	Radio range	250 m
MAC layer	IEEE 802.11 (DCF)	Send Buffer size	64 packets
Physical layer	WaveLAN	Send Buffer timeout	30 sec
Traffic model	CBR	interface queue size	50 packets
Packet size	512 bytes	Network size	50 nodes
Simulation Area	1500m × 300m	Max. speed	20 m/s
Source number	10, 20, 30,40	Pause time	0, 60,120 300,600, 900 s
Packet rate	4, 3 (40) Packets/s		

B) Performance metrics

The performance metrics [Corson and Macker,1999] used to evaluate performance are:

- **Packet delivery ratio**: The ratio of the data packets delivered to the destination to those generated by the CBR sources.
- **Average end-to-end delay of data packets:** This includes all possible delays caused by buffering during route discovery, queuing at the interface queue, retransmission delays at the MAC layer, and propagation and transfer times.
- **Routing Overhead:** The number of routing packets transmitted per data packet brings to the destination.
- **Broken links:** The number of times when a link that belongs to an active route is broken.

C) Simulation results and discussions

We report the results of the simulation experiments for the original AODV protocol with local repair (AODV-LR) and for PPAODV.

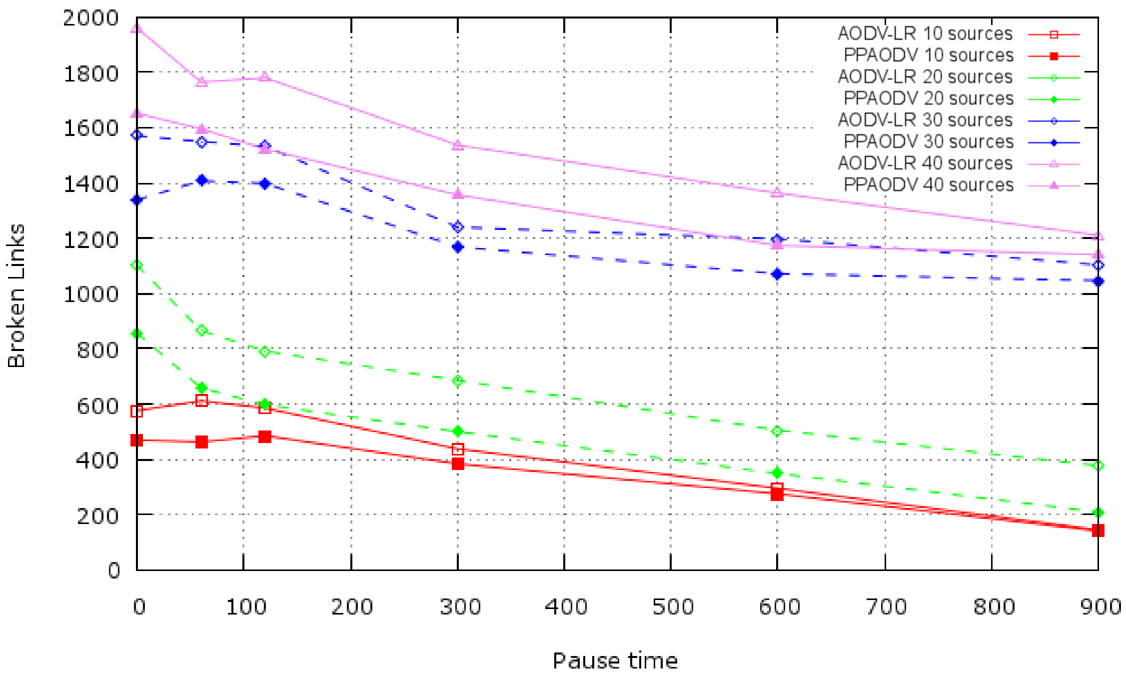

Figure 21: Number of broken links for 10, 20, 30 & 40 sources.

It is observed that the number of broken links is high when node mobility is high (Fig. 21). The number of sources also affects the number of broken links. When the number of sources increases the number of broken links also increases because the need of more routes to destinations. It can be noticed from this figure that PPAODV results in substantially fewer link breaks, especially when pause times are small.

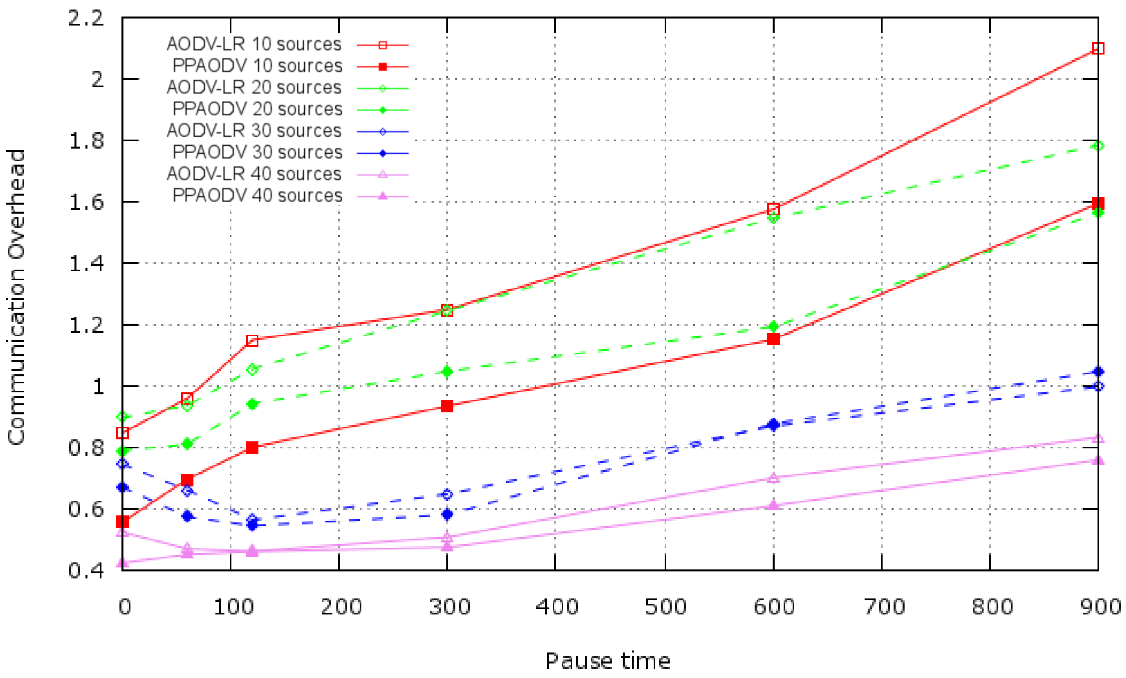

Figure 22: Routing overhead for 10, 20, 30 & 40 sources.

Fig. 22 shows how mobility and number of sources affect the routing overhead. The overhead is high when node mobility is low; this is because it is difficult to obtain an alternative link to replace a broken one when mobility is low. It is also observed that the overhead is low when the number of sources is high. This results from the fact that many sources may share one or more paths, which decreases the routing overhead. It can be observed from Fig. 22 that PPAODV results in substantially less overhead when the number of sources is moderate (10 and 20); this has a good impact on energy because the number of control packets generated is low.

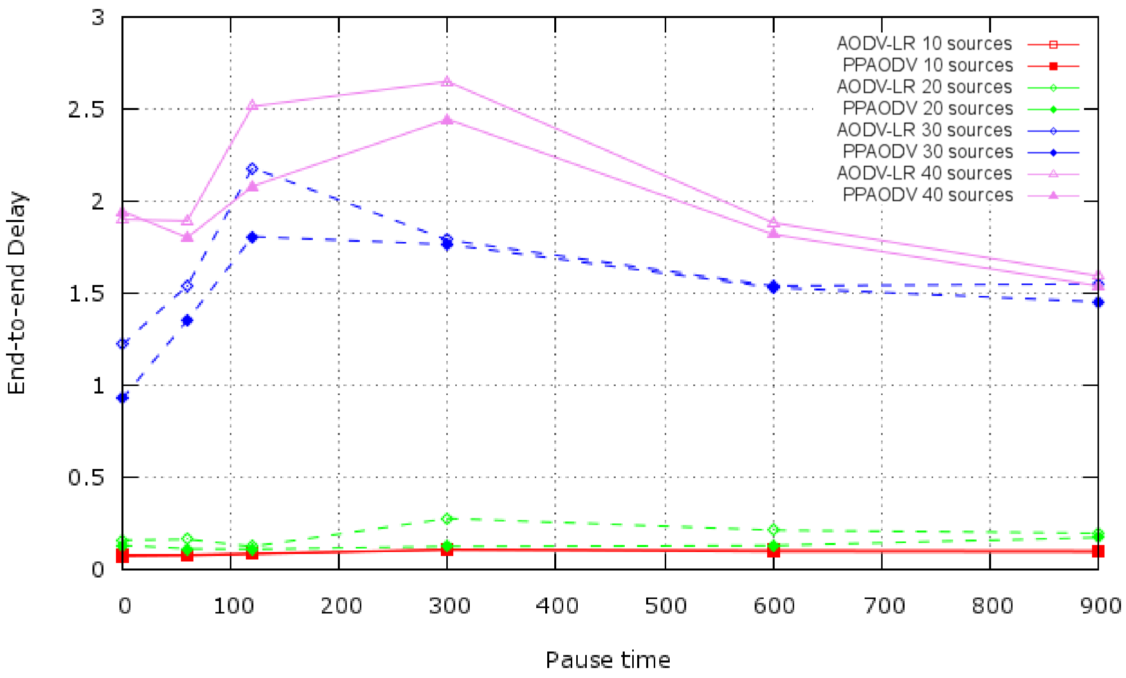

Figure 23: End-to-end Delay for 10, 20, 30 & 40 sources.

In Fig. 23 the results obtained for the end-to-end delay metric are presented. We observe that the end-to-end delay increases significantly when the number of sources increases. The delay is affected by the route repair procedure because data packets are buffered until an alternative route is found. The results show that PPAODV outperforms AODV-LR significantly when the number of sources and mobility are high. The overall delay generated by our approach is acceptable when comparing to the values recommended by ITU [ITU–G.1010,2001] ($\approx 2\,\mathrm{sec}\,ondes$) for responsive applications like voice and video messaging.

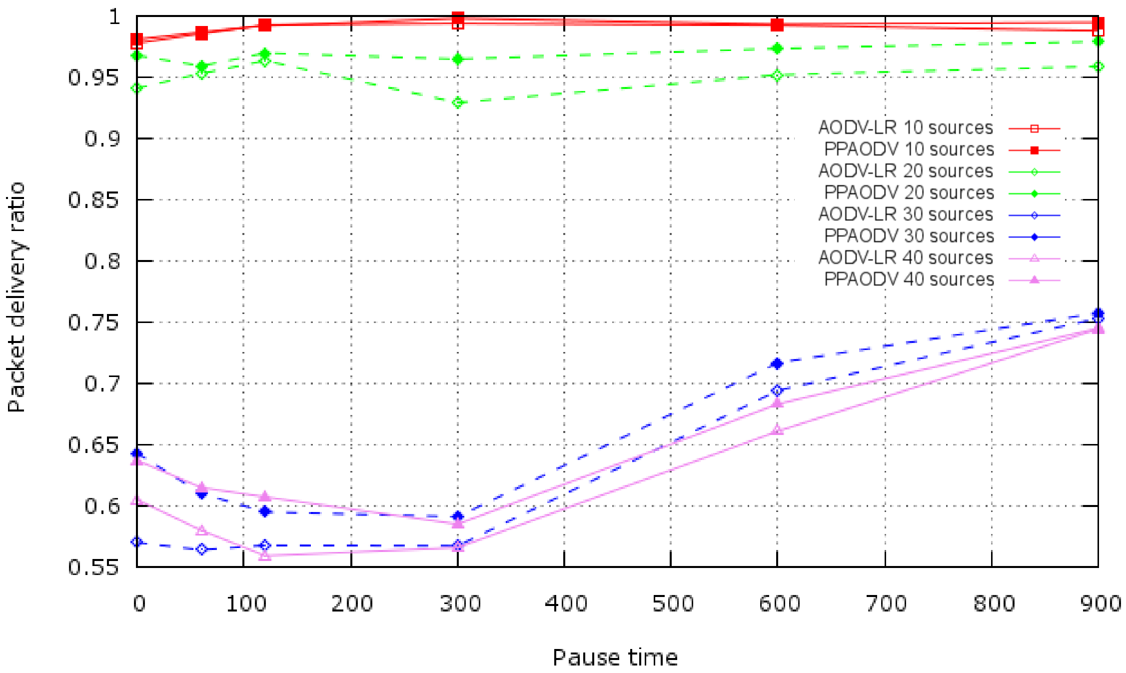

Figure 24: Packet delivery ratio for 10, 20, 30 & 40 sources.

Fig. 24 represents the simulation results for the delivery ratio metric. It can be seen that small gains in the delivery ratio were obtained from PPAODV, along with more substantial gains in the remaining performance parameters considered in this study.

Overall, the method proposed for anticipating link breaks can result in significant performance gains.

6.6.2 Ameliorations on PPAODV :

The approach proposed in [Kitamoto, Masuda et al.,2008a; Kitamoto, Masuda et al.,2008b], describes an amelioration of our approach[BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007]. A High Precision-PPAODV (HP-PPAODV) is proposed to decrease the error margin of Received Signal Strength (RSS) by avoiding the thermal noise and fading effect that results in the higher accuracy of the signal strength acquisition. Furthermore, the Dynamic Discovery Period (t_{DP}) is calculated based on the number of hops in the routing path.

By using this dynamic t_{DP} and increased precision in link failure prediction, HP-PPAODV achieves a better throughput in comparison to PPAODV [Kitamoto, Masuda et al.,2008a; Kitamoto, Masuda et al.,2008b].

Node acquires information on RSS from the Ready to Send (RTS) and DATA frames that the receiving node can acquire during each data exchange. This approach uses the Newton's Interpolation instead of Lagrange Interpolation. Newton interpolation performs better than the Lagrange interpolation when n is larger. In addition, in HP-PPAODV, node takes the average RSS (RSS_{AVE}) of RTS frame (RSS_{RTS}) and DATA frame (RSS_{DATA}) to predict the link failure. Therefore, a node can decrease the influence of the thermal noise and fading.

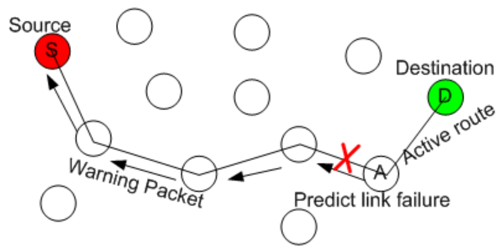

Figure 25 : Node A predict Link Failure

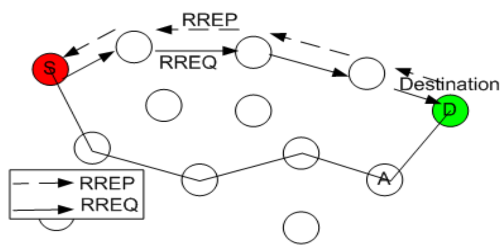

Figure 26: Searching a new route between S and D

In Fig. 25 and Fig. 26, node S, node D and node A denote the source, destination and intermediate node that predicts the link failure in the active routing path, respectively. When a node A predicts the link failure, then it sends warning packet to node S indicating the possible link failure (Fig. 25). In result, node S discovers a new route to node D by exchanging RREQ and RREP packets with node D, as shown in Fig. 26. The RREQ and RREP are the control packets used by AODV for route discovery. Based on this information, t_{DP} of HP-PPAODV is calculated as follows:

$$t_{DP} = t_{warning} \times n_{A\text{-}S} + t_{RREQ} \times n_{S\text{-}D} + t_{RREP} \times n_{S\text{-}D}$$

Where $t_{warning}$, t_{RREQ} and t_{RREP} represent the transmission time of warning packet, RREQ packet and RREP packet, respectively. Furthermore, $n_{A\text{-}S}$ and $n_{S\text{-}D}$ represent the number of hops between node "A" to node "S" of the active route and number of hops between node "S" to node "D" of a new route, respectively.

The performance of HP-PPAODV and PPAODV was compared through computer simulations. Throughputs of HP-PPAODV and PPAODV are analyzed and results show improvement in precision of link failure prediction can increase the packet delivery ratio in HP-PPAODV.

In [Mallapur,2010] , Sujata Mallapur proposed a Predictive Preemptive Ad-Hoc On Demand Multipath Distance Vector routing protocol (PPAOMDV). Predictive preemptive AOMDV is an extension of AOMDV. AOMDV choose the best path that is the path with the shortest hop count is chosen as the primary path for data transfer while other paths are used only when primary path fails.

The main goal behind the proposed protocol is to provide efficient recovery from route failure in dynamic network by saving many alternative routes in the routing table. To achieve this goal in this approach the route failure prediction technique at the time of route discovery, computes the received power of the receiver node to predict pre-emptively before the route fails.

In [Abdule, Suhaidi et al.,2010; Abdule, Suhaidi et al.,2011], authors proposed a new extension of AODV protocol namely, Divert Failure Route Protocol (DFRP-AODV). This extension utilizes the link state prediction method to avoid a link failure in advance and to sending an unnecessary warning message to the source upon link failure, thus, avoid unnecessary network congestion and overhead.

DFRP-AODV protocol uses two mechanisms in order to predict the link breakage and take action before it happens.
Firstly, it utilizes the link state prediction method to collect the current link signal strength status in order to detect link breakage. The prediction of the mobile nodes connectivity is done using two methods: distance based and time based prediction.

In the distance-based prediction, the received signal power solely depends on its distance to the transmitter. In this method, authors assume that the speed, direction, and transmission range are constant. Therefore, the speeds and directions for node A and node B do not change from t_0 to a time t , where t_0 is the start point. The distance d from A to B at time t is calculated using a formula stated in [Dajing, Shengming et al.,2000] as follows :

$$d^2 = (l + v_A t)^2 + (m + v_B t)^2 - 2\cos\theta\,(l + v_A t)(m + v_B t)$$

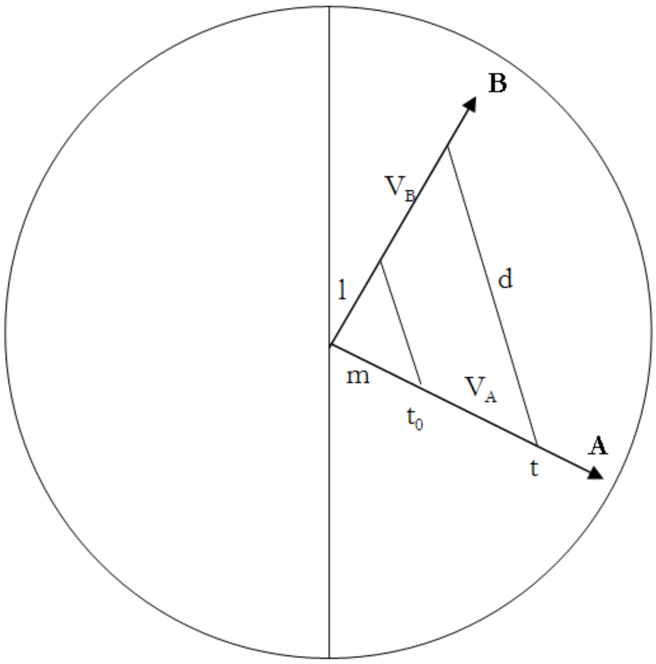

Figure 27: Calculation of link prediction

In the time based prediction, the remaining time that the link will stay connected with known transmission range r is computed using the Link Expiration time "LET" formula [Su, Lee et al.,2001].

Secondly, once an intermediate node detects that the link between two nodes is going to be broken using lagrange interpolation, it utilizes IEEE 802.11 of wireless standards for beacon frames to find the node that has a stronger signal then compares to the current connection signal strength among neighbors. Once one of those neighbors replies with positive response and have both stronger signal and route to the destination, the current-node will divert the route into that node while the current link is still on.

G.S. Sharvani et al.[Sharvani, Rangaswamy et al.,2011; Sharvani and Rangaswamy,2011a] also proposed improvement our work[BOUKLI-HACENE, Lehireche et al.,2006; BOUKLI-HACENE and Lehireche,2007]. Authors proposed a Predictive Preemptive Local Route Repair Strategy for improving QoS in term of route reliability. The QoS is improved by predicting a link failure before its occurrence thereby routing packets through an alternative path. The enhancement of our approach is done by using positions of neighbouring nodes to prepare an alternative route using this information. The aim of this work is to reduce communication overhead by avoiding unnecessary warning messages.

PPAODV was a subject of many other citations in research domain[Huang and Shie,2010; Krishnan, Ramaswamy et al.,2010; Kumar, Rafiq et al.,2011; Vineet and Jini,2011; Sharvani and Rangaswamy,2011b] and PhDs[Kassahun,2010; Hsieh,2011].

6.7 Conclusion

In this chapter, we have present in some detail studies that focus on predictive, preemptive route maintenance and detailed our new approach that combines both predictive and preemptive route maintenance to gather benefit aspects of previous approaches. We have equipped the promising AODV routing protocol for ad hoc networks with a prediction function that anticipates link breaks, and repairs them before they happen to get more stable routes.

The performance of the proposed Predictive Preemptive Ad hoc On-demand Distance Vector algorithm has been evaluated and compared with AODV with local repair using detailed simulations. Several common performance metrics are considered. The simulation results show that the proposed algorithm performs well; it can overall generate lower overhead, fewer broken active links, lower end-to-end delay and higher delivery ratio.

CHAPTER 7 :
REDUCING STALE ROUTES IN DSR

7 Reducing Stale Routes in DSR

Due to node mobility and other factors many links become unusable at any time in MANETs. Several routing protocols allow and facilitate communication between mobile nodes. Routing protocols must be able to respond rapidly to topological changes and use only valid routing information. One of the promising routing protocols is DSR (Dynamic Source Routing). This protocol presents some problems. The major problem in DSR is that the route cache contains some inconsistence routing information. This is due to node mobility. This problem generates longer delays for data packets, which affect DSR performance. In order to reduce the delays, we propose a technique that is inspirited from routing table management in AODV protocol. This technique consists on cleaning route caches for nodes within an active route. Our approach has been implemented and tested in GLOMOSIM simulator. The simulation results show that protocol performance have been enhanced.

7.1 Introduction

Each node in a mobile ad hoc network (MANET) is a router. Communication between nodes requires a multi-hop wireless path from a source to a destination, so nodes must cooperate in routing operation. All nodes are mobile and can be connected dynamically in an arbitrary manner to form a network[Amitava, Somprakash et al.,2003]. A challenge in the design of ad hoc networks is the development of dynamic routing protocols that can efficiently find routes between two nodes. The key task of routing protocols is to deliver packets from the source node to the given destination [Ramjee and Marina,2003]. The existing routing protocols are, traditionally, divided into two classes, depending on when a node acquires a route to a destination. Reactive protocols invoke a route discovery procedure on demand only. Thus, when a route is needed, some sort of flooding-based global search procedure is employed. One of the promising reactive routing protocols is DSR. In general, routing protocol presents some problems, and one of the major problems in DSR is longer data packets delays caused by the search process in the cache. In this paper, we propose a technique to solve this problem.

The remainder of the chapter is organized as follows. First, we give an overview on DSR and its operations. This is followed by focusing on stale routes problem in section 6.3. In section 6.4, a presentation of different works that tries to solve this problem is given. Next, we concentrate on the proposed technique to solve the problem of delay caused by stale routes in cache in section 6.5. In section 6.6, we present the performance evolution of the proposed approaches, and finally, we conclude in section 6.7.

7.2 Dynamic Source Routing Protocol (DSR)

Dynamic Source Routing [Johnson and Maltz,1996a; Johnson and Maltz,1996b] is based on source routing, where the source node specifies the whole path to destination node in the packet header. When a source node needs to communicate with a destination node, it first searches in its route cache for a route to the destination, if a route is found, the source node uses it, otherwise the source node initiates a route discovery mechanism to discover a route. In a route discovery mechanism, the source node floods a route request message (RREQ) to neighboring nodes. The message contains the source address, the destination address, the request id, and a list containing the complete path to destination. When a node receives this request, it proceeds as following:

A) If the node has seen this same request before, it ignored the request.

B) If the receiving node is the destination itself or a node having a route to the destination in its cache, it returns a route reply message (RREP), which contains the source address, the destination address, and the route record in the route request message. The route reply message is sent back to the source node by following the same route record in the route request message in reverse order.

c) Otherwise, it appends its own address to the route record, and re-broadcast the route request message to its neighbouring nodes.

When the source node receives the route reply message, it starts sending data packets to the destination. When a route failure happens, the node upstream the broken link sends back to the effective source a route error message (RERR). Nodes receiving RERR message remove broken link from its routes cache. The source node initiates a route discovery if it receives RERR message, it still needs a route to the destination and no alternate route in its cache.

7.3 The Stale Routes Problem in the DSR Protocol

DSR has the advantage of learning routes by scanning for information in packets that are received. A route from A to C through B means that A learns the route to C, but also that it will learn the route to B. The source route will also mean that B learns the route to A and C and that C learns the route to A and B. This form of active learning is very good and reduces overhead in the network, by this way each node in DSR can find alternative routes when link failure happens. This property will have a bad repercussion on route cache when node mobility is high. The route caches will contain in this case many stale routes to destinations that may be used to reach a destination and this generates longer delay for data packets. Several previous studies deal with stale routes problem[Chen and Hou,2002; Mathur,2005].

7.4 Related Work

Chen and Hou in [Chen and Hou,2002] used a neighbour link-state information exchange mechanism. Once a connection has been established, the neighbour link-state information is exchanged among nodes along the route from the source to the destination. As the information of the neighbour lists is piggybacked in data packets, the nodes on the source route are able to learn the partial topology around the neighbourhood of the connection. The simulation results show that with limited overhead incurred in neighbour list dissemination, the proposed protocol outperforms DSR with either path or link caches in terms of packet delivery ratio and route discovery overhead.

In [He, Raghavendra et al.,2007], He et al propose an active packet technique to improve DSR. The mean idea is allowing a packet to visit each node twice. This packet is named “Active packet”. The objective of the first visit is to obtain topology information of the network; and the objective of the second visit is to update route caches according to the obtained information. In the header active packet header contains a marker field to indicate if the packet is in the first or the second visit. The payload of the active packet is a connection matrix for the network topology. The active packet is generated periodically. Simulation results show that the method reduced the miss rates by up to 60% and routing packet numbers by up to 47%.

An enhancement to DSR by using a link breakage prediction algorithm was proposed in [Qin and Kunz,2003]. A mobile node uses signal power strength from the received packets to predict the link breakage time, and sends a warning to the source node only if the link is soon-to-be-broken. The source node can perform a pro-active route rebuild to avoid disconnection. Simulation results show that the method reduced the dropped packets (by at least 20%). The trade-off is an increase in the number of control messages by at most 33.5%.

7.5 Proposed technique

In order to minimize the delay which is experienced by data packets and reduce stale routes in caches, we add an expiration time for each route inserted in the cache [BOUKLI-HACENE, Lehireche et al.,2007; BOUKLI-HACENE, Lehireche et al.,2008; BOUKLI-HACENE and Lehireche,2011]. This idea is inspired from route management in the routing table of AODV [Belding-Royer and Perkins,2003; Perkins, Belding-Royer et al.,2003]. When learning new routes, a node must set an expiration time for each route inserted in the cache, and when this time expires, the route is removed from the route cache of the node. Each time a route is used the expiration time is set. The max value is fixed to 10 Seconds (represent approximately 1% of simulation time) empirically. Using this technique, we will be sure to have only consistent information in the cache route, which results in lower delay when searching a route from the cache.

7.6 Performance Evaluation & Simulation Results

In order to evaluate the effectiveness of the proposed technique described above, we add it to the basic version 3 of DSR available in the GLOMOSIM simulator, and we compare it with the original version using performance metrics.

The simulation environment and the performance metrics used will be described in the next paragraph, the simulation results presentation and discussion is done later.

7.6.1 Simulation Environment

We have used the implementation of DSR version 3 included in the well known GlomoSim simulator. Our results are based on the simulation of 50 wireless nodes forming an ad hoc network moving about in a rectangular area of 1500 meters by 300 meters for 900 seconds of simulated time. The source-destination pairs are spread randomly over the simulation area, sending four data packets per second following a CBR (constant bit rate) fashion. For our simulation 10-20-30 and 40 source-destination pairs are chosen. Traffic sessions are established randomly and stay active until the simulation ends. A random waypoint mobility model [Johnson and Maltz,1996b] is used. The movement scenario we used for each simulation is characterized by a pause time. Each node begins the simulation by selecting a random destination in the simulation area and moving to that destination at a speed distributed uniformly between 0 and 20 meters per second. It then remains stationary for pause time seconds. This scenario is repeated for the duration of the simulation. We carry out simulations with movement patterns generated for 10 different pause times starting by 0s varying by a step of 100s until 900s (the length of the simulation) is reached, which corresponds to limited motion. The physical radio characteristics of each mobile node's network interface, such as the antenna gain, transmission power, and receiver sensitivity, were chosen to approximate the Lucent WaveLAN direct sequence spread spectrum radio[Tuch,1993].

Table 3 : Summary of simulation environment

Parameters	Values	Parameters	Values
Routing Protocols	DSR, DSR Opt	Bandwidth	2 Mb/s
Simulation time	900 sec	Radio range	250 m
MAC layer	IEEE 802.11 (DCF)	Send Buffer size	64 packets
Physical layer	WaveLAN	Send Buffer timeout	30 sec
Traffic model	CBR	interface queue size	50 packets
Packet size	512 bytes	Network size	50 nodes
Simulation Area	1500m × 300m	Max. Speed	20 m/s
Source number	10, 20, 30,40	Pause time	0,100,200, 300,600, 900 s
Packet rate	4 Packets/s		

7.6.2 Performance Metrics

The performance metrics [Corson and Macker,1999] used to evaluate performance are:

Average end-to-end delay of data packets: This includes all possible delays caused by buffering during route discovery, queuing at the interface queue, retransmission delays at the MAC layer, and propagation and transfer times.

Communication overhead is the total number of control packets, and including route request, route reply, and route error packets generated for each delivered data packet.

Number of broken link is the number of invalid routes for sending data across it; the proposed technique reduces the use of the broken links.

7.6.3 Simulation Results and Discussions

We report the results of the simulation experiments for the original DSR protocol and for Optimized DSR (DSR Opt). In all figures below, Pause time varied between 0 seconds and 900 seconds. When pause time is 0 seconds this denotes high mobility, while 900 seconds pause time means no mobility. Each scenario is repeated five times and the average values of the results are chosen..

7.6.3.1 Broken Links

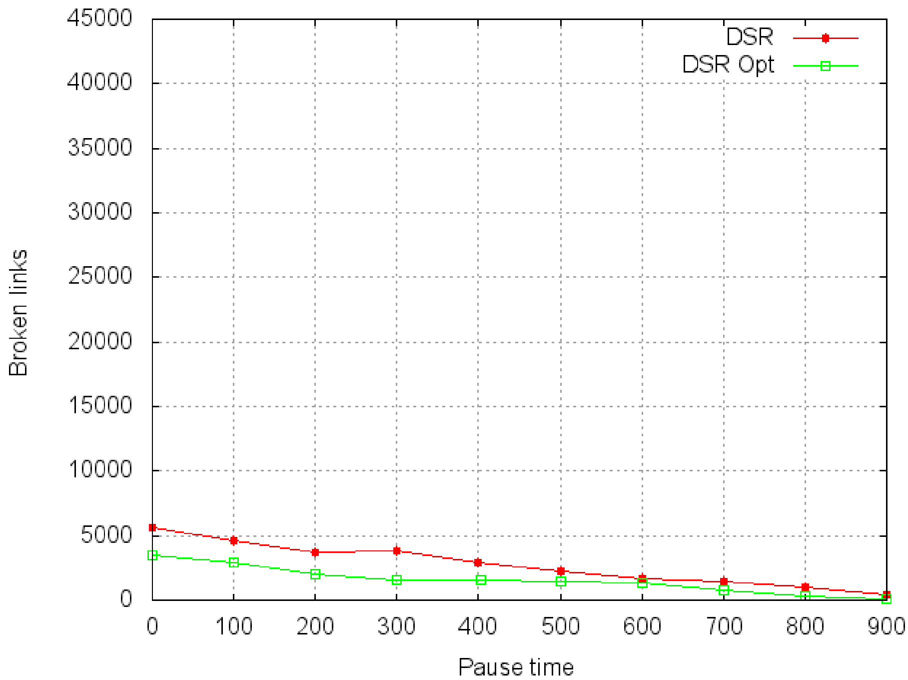

Figure 28: Number of Broken Links for 10 sources

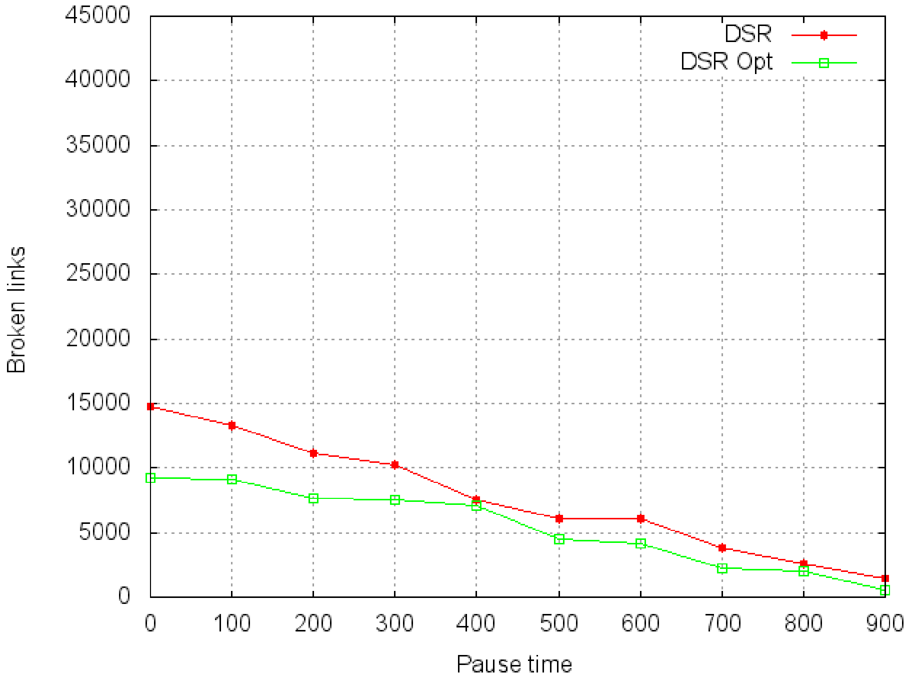

Figure 29: Number of Broken Links for 20 sources

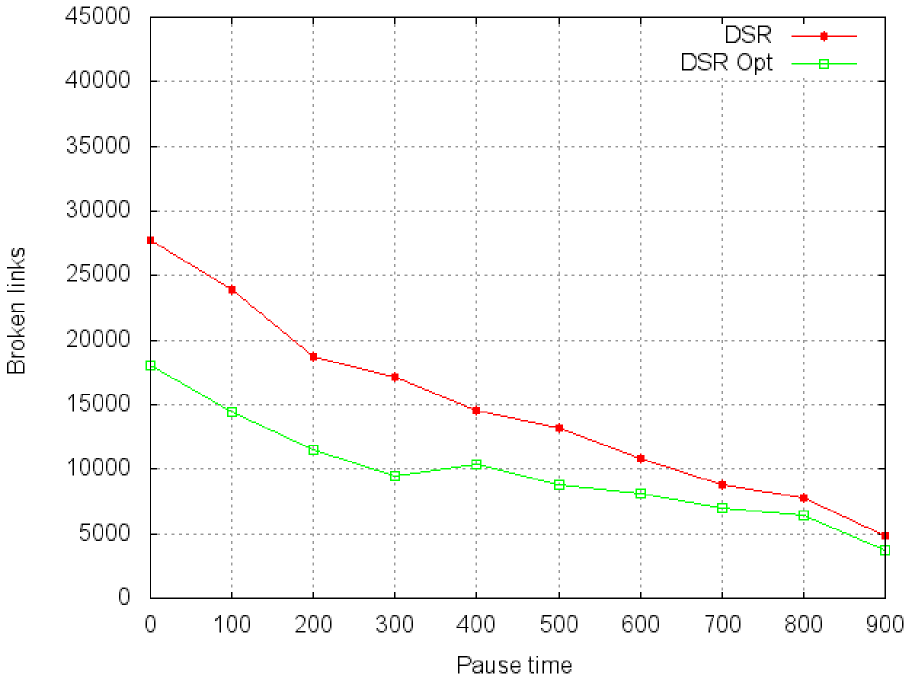

Figure 30: Number of Broken Links for 30 sources

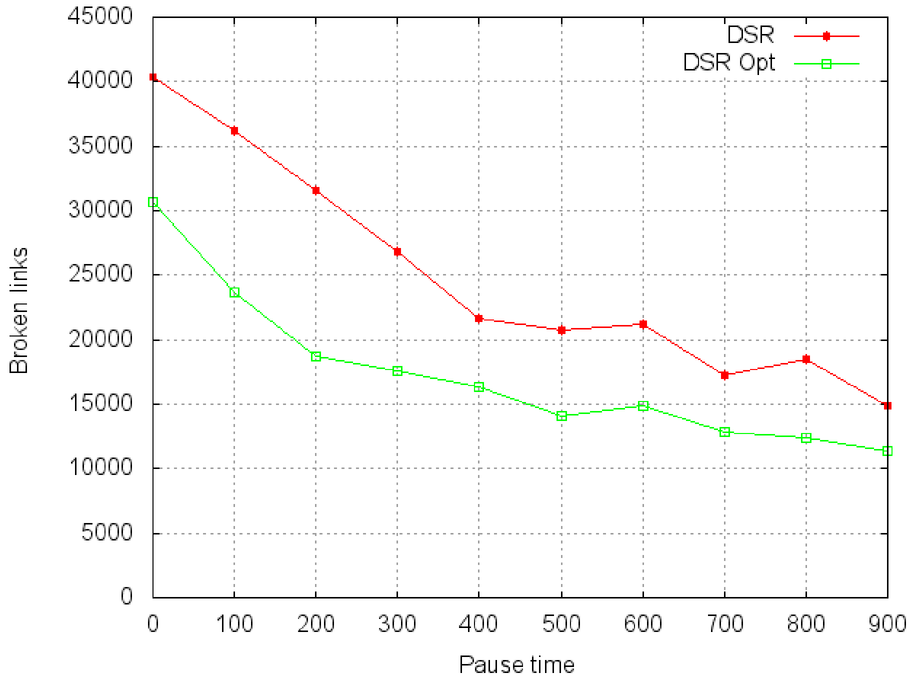

Figure 31: Number of Broken Links for 40 sources

In high mobility, the number of broken links is high (Fig. 28, 29, 30 and 31). This is due to constant changement in the network topology and the incapability to find a valid alternative link. The number of sources also affects the number of broken links. When the number of sources increases, the number of broken links also increases because the need of more routes to destinations and the failure of one link can induce a breach of several communications. It can be noticed from those figures that DSR Opt results in substantially fewer link breaks, especially when pause times are small (high mobility). This is due to the expiration time mechanism added to DSR and consequently, the probability of using a stale route is minimized (The protocol tends to use fresher valid routes).

7.6.3.2 Average End-to-End delay

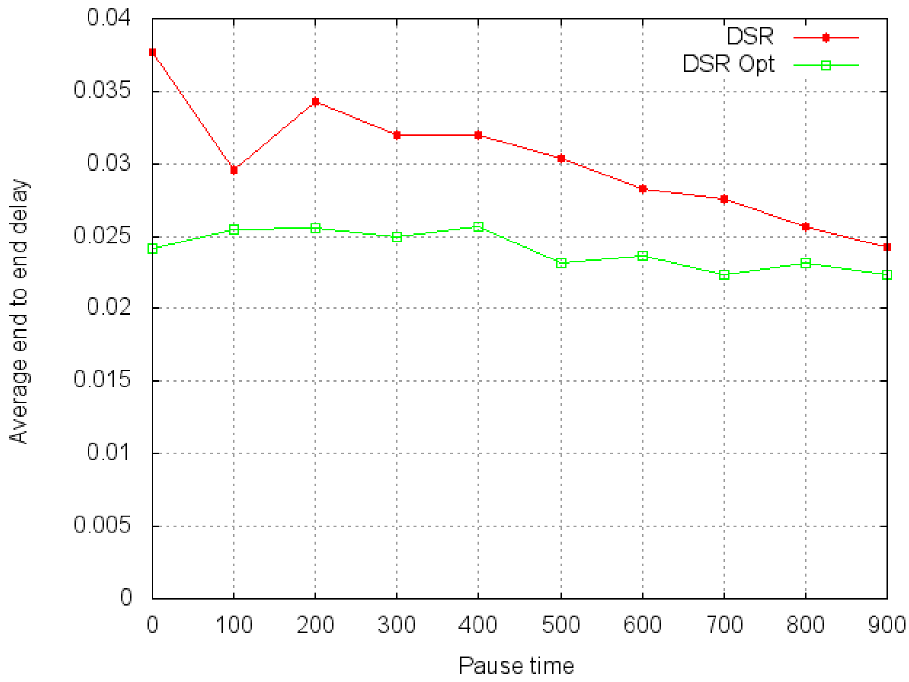

Figure 32: Average End-to-End delay for 10 sources

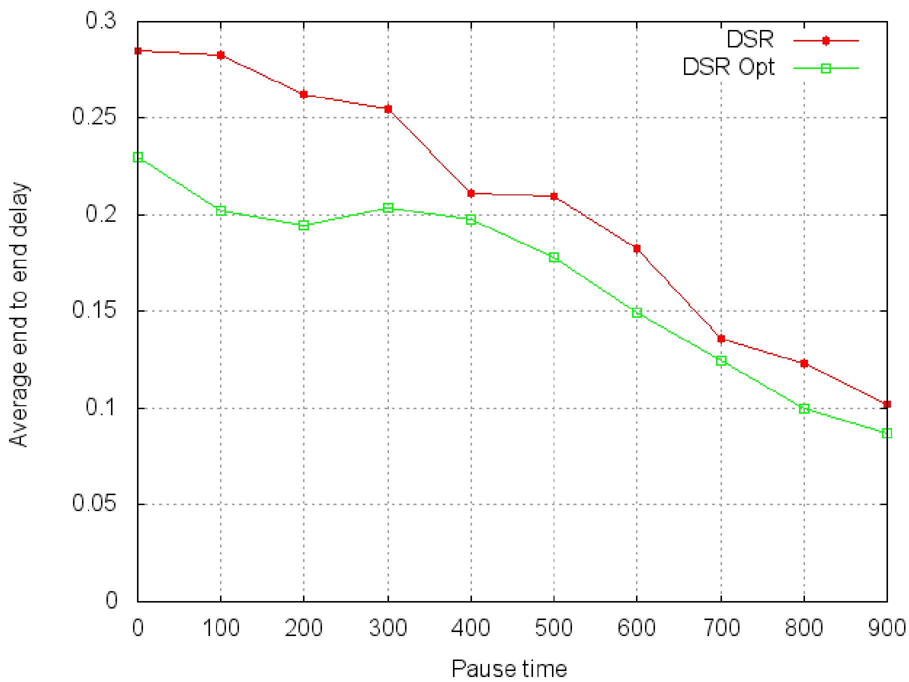

Figure 33: Average End-to-End delay for 20 sources

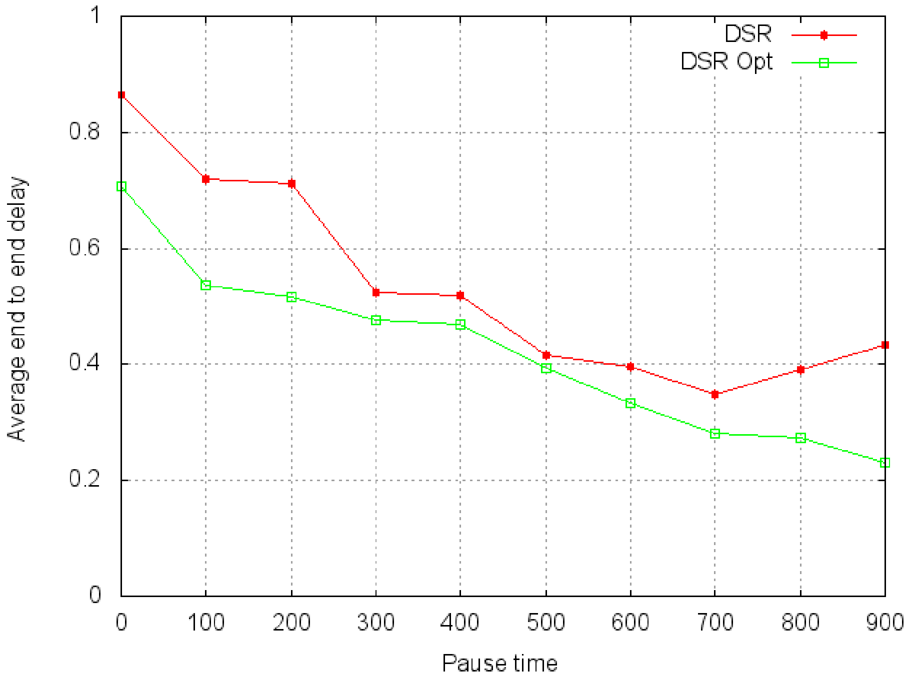

Figure 34:Average End-to-End delay for 30 sources

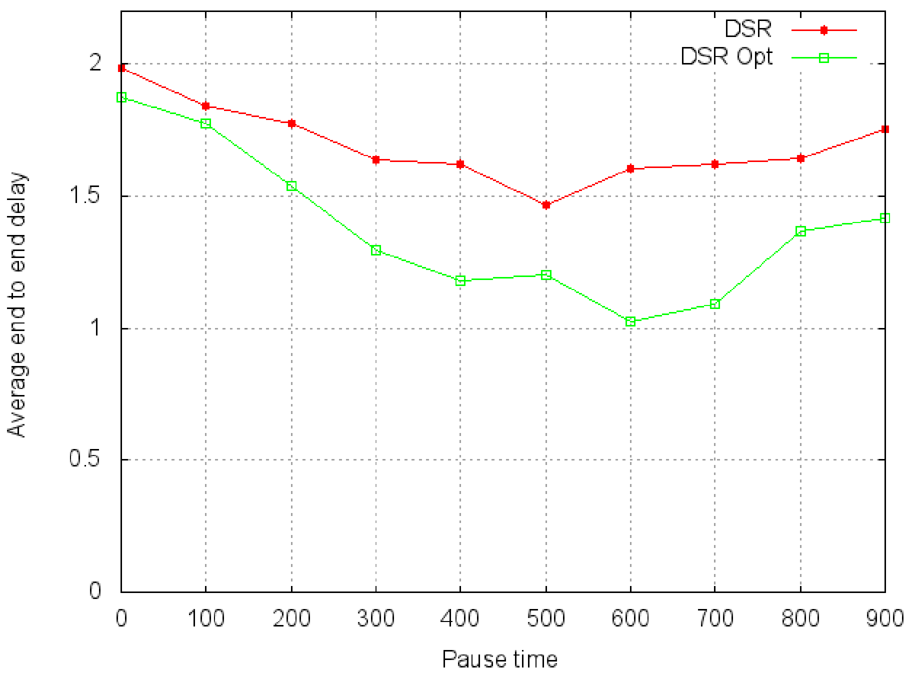

Figure 35: Average End-to-End delay for 40 sources

In Fig.32, 33, 34 and 35 the results obtained for the end-to-end delay metric are presented.
We observe that the end-to-end delay increases significantly when the number of sources increases, especially in high mobility because queues of nodes are almost full and nodes try to salvage many data packets. Minimizing stale routes contribute directly to minimizing end to end delay for data packets. When a broken link happens in DSR Opt, data packets experience a lower delay than in DSR because of the reduced number of cached route.

The results show that DSR Opt outperforms DSR significantly when the number of sources is low and motion of nodes is high. This enhancement of DSR is suitable for Multimedia flows which cannot tolerate higher delays.

7.6.3.3 Communication Overhead

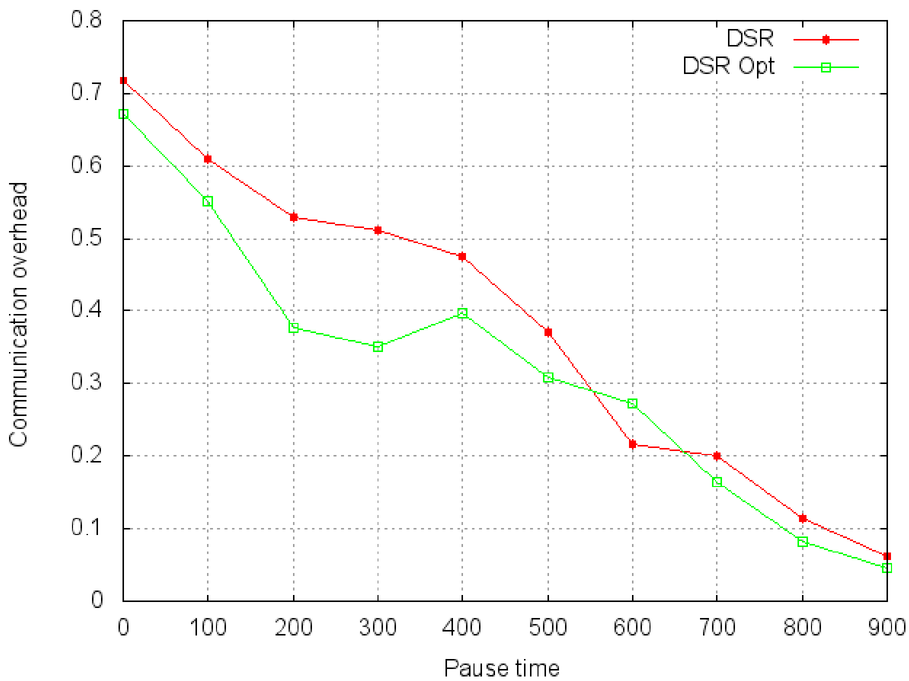

Figure 36: Communication Overhead for 10 sources

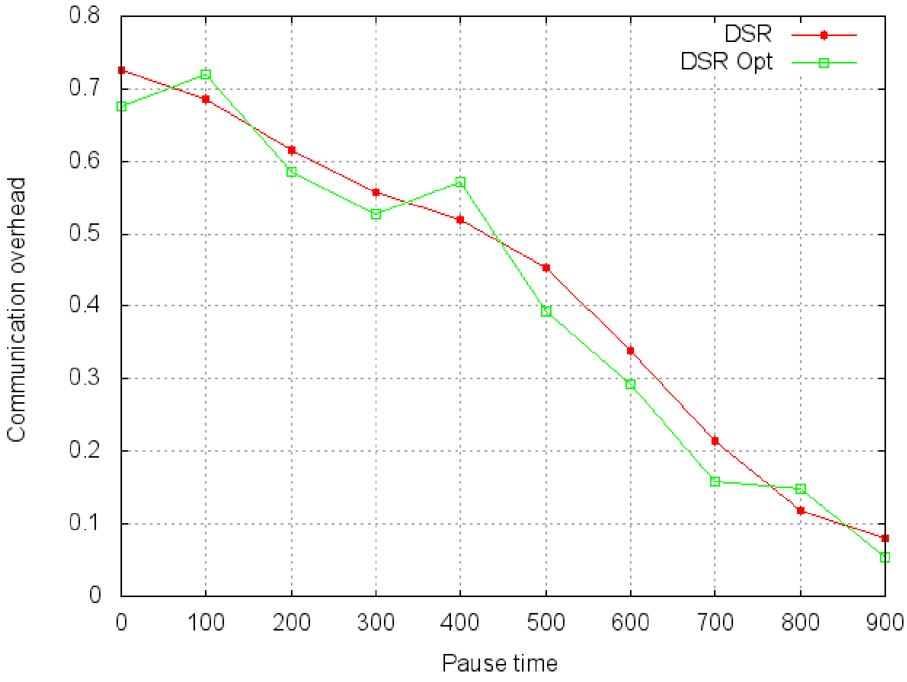

Figure 37: Communication Overhead for 20 sources

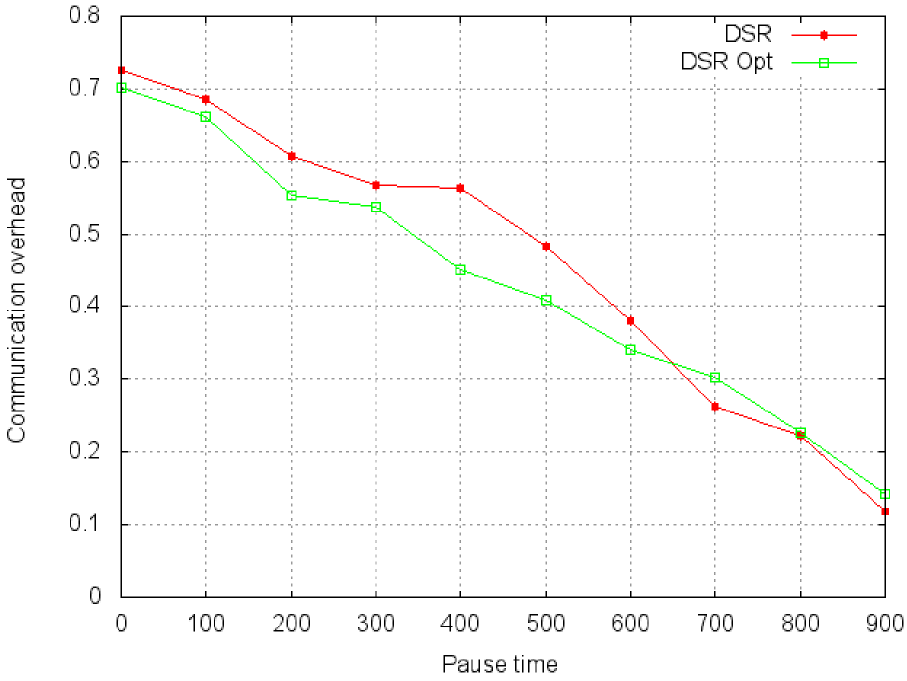

Figure 38:Communication Overhead for 30 sources

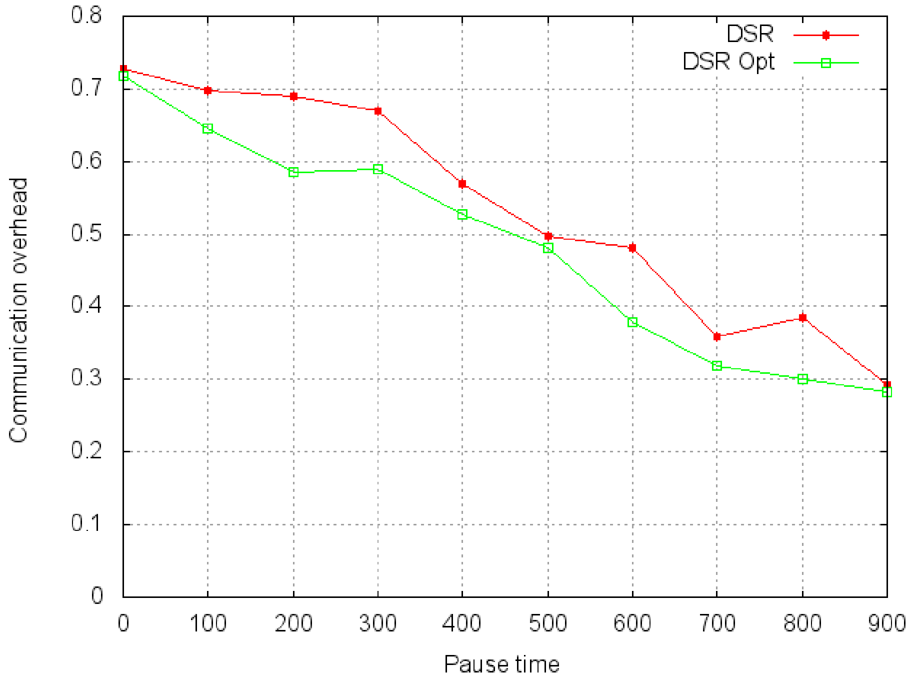

Figure 39: Communication Overhead for 40 sources

Fig. 36, 37, 38 and 39 show how mobility and number of sources affect the communication overhead. We notice that communication overhead is high when node mobility is high; this is due to the dynamic and constant change in network topology. It is also observed that the overhead is high when the number of sources is high. This results from the fact that many sources try to discover routes to destinations, which increase the number of control packets and so the communication overhead.

The results show that DSR Opt results in substantially less overhead when the mobility is moderate (100s to 400s); this has a good impact on energy consumption because the number of control packets generated is low. Sometimes, DSR Opt generates higher overhead than DSR, this can be explained by the fact that when using the expiration time technique, some valid routes may be removed from the cache, which generates a new route discovery.

7.7 Conclusion

In this chapter, we have improved the promising DSR routing protocol for ad hoc networks. We have equipped DSR with expiration time technique for routes in route cache. This technique has been inspired from route management in the routing table of AODV routing protocol, in order to avoid the use of stale route in routing.

The performance of the proposed technique was evaluated and compared with DSR using detailed simulations. Several common performance metrics were considered. The simulation results show that the proposed algorithm performs well; it can overall generate lower communication overhead, fewer broken links and lower Average end-to-end delay.

CHAPTER 8 :

CONCLUSION AND PERSPECTIVE

8 Conclusion and Perspective

Mobile ad hoc networks (MANETs) allow rapid deployment because they do not depend on a fixed infrastructure. MANETs nodes move freely, participate as a source of communication, a destination, or an intermediate router and cooperate to deliver data to the intended destination relying on a routing protocol. This flexibility is attractive to military applications, disaster-response situations, and academic environments where fixed networking infrastructures might not be available. However, this flexibility cause numerous problems, the most important problems are route failure and inaccurate routing information. These problems have a degenerative effect on the performance of the existing routing protocols.

Several techniques have been proposed to anticipate a link break and ameliorate routing protocols QoS capabilities. Those techniques are categorized into predictive and preemptive route maintenance. Predictive and preemptive techniques present many advantages and some inconvenient. In order to benefit from the advantages of those techniques and reduce the impact of the inconvenient, we proposed to combine them. Our approach has been added to the most promising reactive routing protocol AODV. The performance of the proposed Predictive Preemptive Ad hoc On-demand Distance Vector protocol has been evaluated and compared with the original AODV using detailed simulations on GlomoSim Simulator. Several performance metrics have been considered. The simulation results show that the proposed approach overall outperforms the original version of AODV.

To remedy the problem of information inconsistency in the route cache of DSR protocol, we proposed an enhancement on route cache management by adding an expiration time for each route inserted into the cache. This technique has been inspired from route management in the routing table of AODV. Detailed simulations have been done to evaluate and compare the proposed technique with DSR using GlomoSim Simulator. The simulation results show that the proposed technique performs well in terms of the end-to-end delay and link break.

As perspective, we propose to improve this first approach by adding information about neighbouring nodes, a confidence function to get an accurate prediction, implement it in a multi-path and in a multicast routing protocol and evaluate it. For the second approach, we propose to compute a dynamic expiration time for learned routes only.

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