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Performance Analysis of New Algorithms for Routing in Mobile Ad-hoc Networks

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Performance Analysis of New Algorithms for Routing in Mobile Ad-hoc Networks

The development and performance evaluation of some new routing algorithms for mobile ad-hoc networks based on the concepts of angle direction and node density

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Abstract

Mobile Ad hoc Networks (MANETs) are of great interest to researchers and have become very popular in the last few years. One of the great challenges is to provide a routing protocol that is capable of offering the shortest and most reliable path in a MANET in which users are moving continuously and have no base station to be used as a reference for their position. This thesis proposes some new routing protocols based on the angles (directions) of the adjacent mobile nodes and also the node density.

In choosing the next node in forming a route, the neighbour node with the closest heading angle to that of the node of interest is selected, so the connection between the source and the destination consists of a series of nodes that are moving in approximately the same direction. The rationale behind this concept is to maintain the connection between the nodes as long as possible. This is in contrast to the well known hop count method, which does not consider the connection lifetime.

We propose three enhancements and modifications of the Ad-hoc on demand distance vector (AODV) protocol that can find a suitable path between source and destination using combinations and prioritization of angle direction and hop count. Firstly, we consider that if there are multiple routing paths available, the path with the minimum hop count is selected and when the hop counts are the same the path with the best angle direction is selected.

Secondly, if multiple routing paths are available the paths with the best angle direction are chosen but if the angles are the same (fall within the same specified segment), the path with minimum hop count is chosen.

Thirdly, if there is more than one path available, we calculate the average of all the heading angles in every path and find the best one (lowest average) from the source to the destination.

In MANETs, flooding is a popular message broadcasting technique so we also propose a new scheme for MANETS where the value of the rebroadcast packets for every host node is dynamically adjusted according to the number of its neighbouring nodes. A fixed probabilistic scheme algorithm that can dynamically adjust the rebroadcasting probability at a given node according to its ID is also proposed; Fixed probabilistic schemes are one of the solutions to reduce rebroadcasts and so alleviate the broadcast storm problem.

Performance evaluation of the proposed schemes is conducted using the Global Mobile Information System (GloMoSim) network simulator and varying a number of important MANET parameters, including node speed, node density, number of nodes and number of packets, all using a Random Waypoint (RWP) mobility model.

Finally, we measure and compare the performance of all the proposed approaches by evaluating them against the standard AODV routing protocol. The simulation results reveal that the proposed approaches give relatively comparable overall performance but which is better than AODV for almost all performance measures and scenarios examined.

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DEDICATION

I dedicate this work
to my friend,
Othman.A.Al-Amoudi

Publications

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- O. Al-Amoudi, M. El-Azhari, M. Woodward, and I. Awan, "An Efficient Routing Mechanism based on Heading Angle " WAINA, International Conference on Advanced Information Networking and Applications Workshops: IEEE Computer Society, 2009, pp. 199-204.
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- M. El-Azhari, O. Al-Amoudi, M. Woodward, and I. Awan, "Performance analysis of angle direction routing in AODV protocols for MANETs", Sixteenth IEEE Telecommunications Forum TELFOR,pp.85-88, 2008.
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List of Abbreviations

ABAM	**On-Demand Associativity-Based Multicast Routing for Mobile Ad hoc Networks**
ABR	**Associativity Based Routing protocol**
MRIS	**Ad hoc multicast routing protocol utilizing increasing id-numberS**
AMRoute	**Ad hoc multicast routing protocol**
AODV	**Ad hoc On-Demand Distance Vector routing protocol**
BEMRP	**Bandwidth Efficient Multicast Routing Protocol**
CBR	**Constant Bit Rate**
CGSR	**Clusterhead Gateway Switch Routing algorithm**
DCM|P	**Distributed Cycle Minimization Protocol**
DDM	**Differential Destination Multicast**
DSDV	**Destination-Sequenced Distance Vector**
DSR	**Dynamic Source Routing protocol**
FGMP-RA	**Forwarding Group Multicasting Protocol for via Receiver Advertising**

FIFO	**First-In, First-Out**
FSR	**Fisheye State Routing protocol**
GloMoSim	**Global Mobile Information System Simulator**
GSR	**Global State Routing algorithm**
HARP	**Hybrid Ad hoc Routing Protocol**
HSR	**Hierarchical State Routing protocol**
IEEE	**Institute of Electrical and Electronics Engineers**
IETF	**Internet Engineering Task Force**
LAR	**Location-Aided Routing protocol**
LBM	**Location Based Multicast**
MAC	**Medium Access Control**
MANETs	**Mobile Ad hoc Networks**
MAODV	**Multicast Ad hoc On-Demand Distance Vector**
MCEDAR	**Multicast core-extraction distributed ad hoc routing**
MG	**Manhattan Grid mobility**
MZRP	**Multicast Zone Routing Protocol**
NSMP	**Neighbour-Supporting Multicast Protocol**
ODMRP	**On-Demand Multicast Routing Protocol**
OLSR	**Optimised Link State Routing protocol**
PLBM	**Preferred Link-Based Multicast Protocols**
Q o S	**Quality of Service**
RREP	**Route Reply**
RREQ	**Route Request**

RWP	**Random Waypoint**
SRB	**Saved Rebroadcast**
TORA	**Temporally Ordered Routing Algorithm**
WLANs	**Wireless Local Area Networks**
WRP	**Wireless Routing Protocol**
ZHLS	**Zone-based Hierarchical Link State routing algorithm**
ZRP	**Zone Routing Protocol**

Chapter 1 Introduction

1.1 Background

Wireless networks can be classified into two categories [1-3]. The first and most common category is a wireless network built on top of a wired network and this creates a reliable infrastructure wireless network. The wireless nodes are connected to the wired network and are able to act as bridges in a network of this type. They are usually called base stations or access points. An example of this is the mobile phone network where a phone connects to the base station. When the phone moves out of range of a base station it does a hand-off and switches to a new base station within reach. The hand-off should be fast enough to be seamless for the network users. Other more recent networks of this type are Wireless Local Area Networks (WLANs), where transmissions are typically in the 2.4 GHz or 5 GHz frequency bands and do not require line-of-sight between sender and receiver. Wireless base stations (access points) are often wired to an Ethernet LAN and transmit a radio frequency over an area of several hundred feet through walls and other non-metal barriers. Roaming users can be handed-off from one access point to another as in a mobile phone system [1, 2, 4-6].

The second category is Mobile Ad hoc Networks (or MANETs for short) [1-3, 7, 8], which are created by wireless devices that communicate without necessarily using a pre-existing network infrastructure such as that provided by access points. In such networks, each mobile node operates not only as a host where applications can reside, but also as a router so that it can send and receive packets as well as forward packets for other nodes in the network. MANETs are also called multi-hop packet radio networks [1-3, 9, 10], compared to the one-hop station-based mobile phone networks. The self-configuring nature of MANETs makes them suitable for a wide variety of applications [1, 2, 6]. One of the applications of these networks is communication within groups of people with laptops and other hand-held devices. MANETs could be useful to deploy in areas such as disaster sites, battlefields, temporary conference meetings and uninhabited field searching. In such environments, where there is often little or no communication infrastructure or the existing infrastructure is inconvenient to use, wireless mobile users can communicate through the fast formation of a MANET [1-3]. The communication capabilities of the mobile nodes in MANETs are bounded by their wireless transmission ranges; that is, two nodes can communicate directly with each other only if they are within their transmission ranges. When two nodes are out of one another's transmission ranges, their communication needs the support of some intermediate nodes, which set up a communication between the two nodes to relay packets between the source and destination. For example, in the network shown in Figure 1.1 node C is outside the range of node A's transmission range and this node is outside the range of node C’s transmission range, therefore they cannot communicate directly. If A and C wish to exchange a packet, node B has to forward the packet for them, since B is inside both A's and C’s transmission ranges.

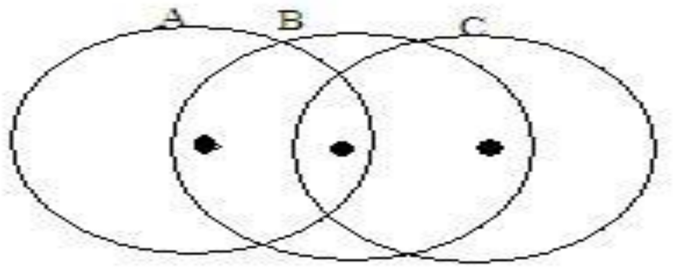


Figure1.1A sample MANET

Each mobile node is independent of the others in a MANET, and may function as a host that generates and consumes packets and also as a router that relays packets along network paths.

All nodes in the network dynamically establish routing among themselves as they move about, forming their own network connectivity. Furthermore, since the nodes are mobile, the network topology may change quickly and randomly and the connectivity among the nodes may vary with tim**e.**

Nodes in a MANET suffer constrained resources compared to their wired counterparts [1, 2, 11]. These constrained resources include the bandwidth capacity of the wireless links, which is significantly lower than that of the wired links. Moreover, mobile devices rely on batteries for their energy [12-16].

1.2 Proactive Routing

The basic routing problem is that of finding an ordered series of intermediate nodes that can transport a packet across a network from its source to its destination by forwarding the packet along this series of intermediate nodes. In traditional hop-by-hop solutions, each node in the network maintains a routing table; for each known destination, the routing table lists the next node to which a packet for that destination should be sent.

In proactive routing, each node maintains routes to all reachable destinations at all times. The routing information is usually kept in a table. These tables are periodically updated if the network topology changes. The differences between the different routing protocols are in the way the routing information is updated and detected and in the type of information data kept at each routing table. Furthermore, each routing protocol may maintain a different number of tables. Optimised Link State Routing (OLSR) [17] and Destination-Sequenced Distance Vector (DSDV) [18] are examples of proactive protocols.

1.3 Reactive Routing

In this type of routing, only the routes required are explored and maintained. In contrast to table-driven routing protocols all up-to-date routes are not maintained at every node; instead the routes are created as and when required. When a source wants to send to a destination, it invokes the route discovery mechanism to find a path to the destination.

The route remains valid while the destination remains reachable or until the route is no longer needed.

The existing reactive protocols differ in the way the route discovery and route maintenance is conducted. The Ad hoc On-demand Distance Vector routing protocol (AODV) [19, 20], the Dynamic Source Routing protocol (DSR) [21] and the Temporally Ordered Routing Algorithm (TORA) [22] are examples of reactive protocols.

1.4 Routing Principles in MANETs

Flooding was one of the earliest broadcast mechanisms used in wired and wireless networks. Upon receiving the message for the first time, each node in the network rebroadcasts a message to its neighbours. While flooding is simple and easy to implement, it can affect the performance of a network, and may lead to a serious problem, often known as the “broadcast storm problem”[23, 24] which is characterised by a large number of redundant rebroadcast packets, collisions and network bandwidth contention.

Ni et al.[23] have studied the flooding protocol experimentally and analytically, and they have classified existing broadcasting techniques into five classes. A brief description of each is provided below.

1. In the probabilistic scheme, a host node rebroadcasts messages according to a certain probability.

2. The distance-based scheme uses the relational distance between a host node and the previous sender to decide whether or not to rebroadcast a message.

3. In the counter-based scheme, a node determines whether or not to rebroadcast a message by counting the number of messages that are the same and that it has received during a random period of time. The counter-based scheme assumes that the expected additional coverage is so small that rebroadcasts would be ineffective when the number of received broadcast messages exceeds a certain threshold value.

4. The cluster-based scheme divides the ad hoc network into several clusters of mobile nodes. Every cluster has one cluster head and a number of gateways. The cluster head is a representative of the cluster and its rebroadcast can cover all hosts in this cluster. Only gateways can communicate with other clusters, with responsibilities to disseminate the broadcast message to other clusters.

5. The location-based scheme rebroadcasts the message if the additional coverage due to a new transmission is larger than a certain pre-determined threshold value.

1.5 Broadcasting in MANETs

Broadcasting is a fundamental operation in MANETs whereby a source node sends the same packet to all the nodes in the network. In the one-to-all model, a transmission by each node can reach all nodes that are within its transmission radius, while in the one-to-one model, each transmission is directed toward only one neighbour (using narrow beam directional antennas or separate frequencies for each node)[24]. Broadcasting has been studied in the literature, mainly for the one-to-all model, and most of this study is devoted to this model. The one-to-many model can also be considered, where fixed or variable angular beam antennas can be used to reach several neighbours at once[23].

1.6 Motivations

The broadcasting operation has extensive applications in MANETs; for example, it is used in the route-discovery technique of several well-known routing protocols [19, 22, 25-27], such as Route Request (RREQ) and Route Reply (RREP) [28-30].

In wireless communication, a channel is shared by all users in that when a sender transmits a packet all nodes within the sender's transmission range can receive this packet. This is usually referred to as the promiscuous receive mode [31]. The advantage is that one packet can be received by all the neighbours’ nodes. The disadvantage is that it interferes with the other concurrent transmissions, resulting in the exposed terminal problem [8]; that is, an outgoing transmission collides with an incoming transmission. This can also result in the hidden terminal problem; that is, a node simultaneously receiving packets from two other nodes that are not aware of each other's transmission [8].

Blind flooding is very simple to implement, but often leads to the broadcast storm problem. One solution for improving the deleterious performance effects of this is to provide well-organised probabilistic broadcast algorithms that aim to reduce the number of nodes that retransmit the broadcast packet while guaranteeing that most or all nodes receive the packet. Although probabilistic flooding schemes have been around for a relatively long time, so far there has not been any major attempt to analyse their performance behaviour in a MANET environment. The fixed probabilities control the number of rebroadcasts and might thus save network resources without affecting reachability. In order to achieve both high-saved broadcast and high reachability when network topology changes frequently, the rebroadcast probability should be set low for nodes located in sparse areas and high for nodes located in dense areas. These issues motivate the investigation of techniques for enhancing the performance of MANET routing protocols.

Also, in most MANET routing protocols it would seem sensible to choose the next node in forming a route as a neighbour node moving in a similar direction, so the connection between the source and the destination will consist of a series of nodes that have approximately the same direction of movement. Thus, in this way the stability of the link lifetime is implicitly considered in the route construction phase. So far, this idea does not appear to have been explored to any great extent.

1.7 Research Aims

The main aim of this research is to design and implement new routing algorithms incorporated within the AODV, one of the better-known and better-studied algorithms over recent years; our goal is to investigate new improved algorithms that can be used by MANETs to find a path between a source and a destination. Most of the new algorithms are to use the heading angle, defined as the angle of direction of movement of a node from some specified datum.

To achieve this aim this specific study is to explore routing techniques based on the following:

1) Angle direction.
2) Hop count and angle direction.
3) Angle direction and hop count.
4) Mean of all angle directions in the route**.**

Another aim is to attempt to reduce overhead due to excessive rebroadcasts by considering the node density within the transmission range of each of the nodes of a MANET and also investigate some aspects of probabilistic flooding. To this end we aim to explore the following:

5) Dynamic flooding schemes (node density).
6) Fixed probabilistic schemes.

In all of the above aims a key common task is to find a path between a source and a destination, while reducing the number of broken links, collisions, rebroadcast packets and hops counts as far as possible.

To achieve this, the objectives are as follows.

- To investigate and improve the AODV routing protocol in MANETs by incorporating heading angle information into the route discovery process.

- To investigate the performance impact of a number of important parameters in MANETs, including node speed, number of packets and network density, using extensive simulations.

- To study and analyse the topological characteristics of a MANET when nodes move according to the widely adopted Random Waypoint (RWP) mobility model using a short HELLO interval so as to keep up-to-date neighbourhood information in the dynamic network environment.

- To develop a dynamic flooding scheme for MANETs in order to reduce the number of redundant rebroadcasts and collisions.

- To evaluate the performance of a fixed probabilistic scheme in MANETs using the RWP mobility model.

- To compare the performance of the proposed schemes and use the performance of AODV as a benchmark throughout.

1.8 Original Contributions

The original contributions are as follows.

- New algorithms for routing in MANETs have been proposed using the [heading angle direction+hop count, hop count+angle direction and the mean of all angle directions in the route] and their performance has been compared with the basic AODV algorithm. The proposed algorithms have been embedded in the AODV protocol. The metrics for comparisons include the average number of collisions and the number of broken links.
- An assessment has been made of the impact of dynamic probabilistic flooding on the performance of AODV. The newly proposed algorithms are incorporated into AODV and compared against the traditional AODV version that employs simple flooding.

- A new dynamic flooding scheme has been proposed where each node dynamically sets the rebroadcast probability according to information about the number of its neighbouring nodes in order to reduce redundancy, the number of broken links and collisions. This is done based on the proactive exchange of HELLO packets between neighbouring nodes and without the need for the assistance of distance measurements or exact location-determination devices. The rebroadcast probability is made high when the number of neighbouring nodes is high, that is the host is in a dense area, and the probability is set low when the number of neighbouring nodes is low, that is the host is in a sparse area. The proposed algorithm is referred to as the dynamic flooding scheme.

1.9 Outline of the Thesis

The rest of the thesis is organised as follows.

Chapter 2 describes current routing protocols and types in MANETs. The chapter gives an overview of multicast routing protocols in MANETs and provides an overview of present and future MANET applications. Chapter 2 also describes the AODV, DSDV and DSR, existing protocols in MANETs.

Chapter 3 describes the important mobility models of MANETs, including the Manhattan mobility model and the Random Waypoint Mobility model (RWM), and also presents simulations using the GLoMoSim, NS2 and OPNET, and then goes on to give a comparison of the simulations.

Chapter 4 describes the angle direction algorithms with an explanation of how to calculate the node angle, and also describes the experimental scenarios and the setting of the simulation parameters. Additionally, this chapter presents and analyses the performance results of the angle direction algorithm for mobile nodes when nodes move according to the RWP mobility model and also introduces the modified (EAODV) algorithms [hop count and angle direction, angle direction and hop count and the mean of all angle directions in the route] and presents the simulation scenarios and parameters.

Chapter 5 presents a new dynamic flooding scheme where the rebroadcasting at the nodes is dynamically adjusted using neighbourhood information and presents the simulation scenarios and parameters.

Chapter 6 starts with an overview of the broadcast storm problem, which causes a serious degradation in network performance due to extreme redundant retransmissions, collisions and contention. This is then followed by a classification of the existing fixed probabilistic schemes suggested for MANETs and analyses the performance of the fixed probabilistic scheme behaviour in MANETs when nodes move according to the RWM model.

Chapter 7 gives a comparative analysis of the angle direction, node density and fixed probabilistic schemes.

Chapter 8 summarises the results presented in this thesis and points to potential areas for future research.

Chapter 2 Related Work

2.1 Introduction

The history of wireless networks started during the 1970s and interest has been growing ever since. During the last decade, and especially at its end, the interest had almost exploded, probably because of the fast growing Internet. Ad hoc networks are emerging as the next generation of wireless networks and are defined as a collection of mobile nodes forming a temporary network without the aid of any centralised administration or standard support services. In Latin, ad hoc literally means “for this”; a further meaning is “for this purpose only” and thus is usually temporary.

Ad hoc networks are basically peer-to-peer multi-hop mobile wireless networks where information packets are transmitted in a store-and-forward manner from a source to an arbitrary destination via intermediate nodes.

2.2 Mobile Ad Hoc Networks

Mobile networks can be classified into infrastructure networks and mobile ad hoc networks [32] according to their dependence on fixed infrastructures. To compare and analyse mobile ad hoc network routing protocols, appropriate classification methods are important. Classification methods help researchers and designers to understand the distinct characteristics of a routing protocol and find its relationship with others. One of the most popular methods to distinguish mobile ad hoc network routing protocols is based on how routing information is acquired and maintained by mobile nodes. Using this method, mobile ad hoc network routing protocols can be divided into proactive routing, reactive routing and hybrid routing. The DSR [21, 25], AODV [19, 20], Associativity Based Routing protocol (ABR) [33] and TORA [22]are examples of reactive routing protocols for mobile ad hoc networks. The DSDV [2, 3, 18], Wireless Routing Protocol WRP [34], OLSR [17] and Hierarchical State Routing protocol (HSR) [35] are examples of proactive routing protocols for mobile ad hoc networks. Hybrid routing protocols are proposed to combine the merits of both proactive and reactive routing protocols and overcome their shortcomings. Normally, hybrid routing protocols for mobile ad hoc networks exploit hierarchical network architectures.

Proper proactive routing approaches and reactive routing approaches are exploited at different hierarchical levels, respectively. In this thesis, examples of hybrid routing protocols for mobile ad hoc networks are the Zone Routing protocol (ZRP) [36], Zone-based Hierarchical Link State routing algorithm (ZHLS) [37], HARP [38], Fisheye State Routing protocol (FSR) [39] and GSR [40].

2.3 Applications

There are many applications of ad hoc networks, such as home networks, group discussions and vehicle communications. The nodes may be located in or on airplanes, ships, trucks or cars or perhaps even on people or very small devices, for communication using several portable devices and in emergency situations. In fact, any day-to-day application such as electronic email and file transfer can be considered to be easily deployable within an ad hoc network environment. Web services are also possible in case any node in the network may be able to serve as a gateway to the Internet. The technology was initially developed keeping in mind the military applications, such as a battlefield in an unknown territory where an infrastructure network is almost impossible to have or maintain. Table 2.1 shows some well-known ad hoc network applications.[41]

2.1 Mobile ad hoc network applications

Applications	**Possible scenarios/services**
Tactical networks	• Military communication and operations • Automated battlefields
Sensor networks	• Home applications: smart sensor nods actuators embedded in consumer electronics to allow end users to manage home devices locally and remotely. • Environmental applications include tracking the movements of animals (e.g., birds and insects). Chemical/biological detection, precision agriculture, etc. • Tracking data highly correlated in time and space, e.g, remote sensors for weather, earth activities. • Body area networks (BAN).
Emergency services	• Search and rescue operations. • Disaster recovery. • Replacement of a fixed infrastructure in case of environmental disasters (e.g., earthquakes, hurricanes). • Policing and fire fighting. • Supporting doctors and nurses in hospitals, e.g., early retrieval and transmission of patient data (record, status, diagnosis) from/to the hospital.
Commercial and civilian environments	• E-Commerce: e.g., Electronic payments anytime and anywhere. • Business: dynamic database access to customer files, mobile offices. • Vehicular Services: road or accident guidance, transmission of road and weather conditions, taxi cab network, inter-vehicle networks, Local ad hoc network with nearby vehicles for road/accident guidance. • Sports stadiums, trade fairs, shopping malls. • Networks of visitors at airports.
Home and enterprise Networking	• Home/Office Wireless Networking (WLAN) e.g., shared white-board application: use PDA to print anywhere: trade shows. • Personal Area Network (PAN). • Conferences, meeting rooms. • Networks at construction sites.
Educational	• Setup virtual classrooms or conference rooms.

applications	• Setup ad hoc communication during conferences, meetings or lectures. • Universities and campus settings.
Entertainment	• Multi-user games. • Robotic pets. • Outdoor Internet access. • Wireless P2P networking. • Theme parks.
Location aware services	• Follow-on services, e.g., automatic call-forwarding, transmission of the actual workspace to the current location. • Information services: push, e.g., advertise location specific service, like gas stations, pull. e.g., location dependent travel guide; services (printer, fax, phone, server, gas stations) availability information. • Touristic information.
Coverage extension	• Extending cellular network access. • Linking up with the Internet ,intranets, etc.

2.4 MANETs

A MANET is a kind of wireless ad hoc network and is a self-configuring network of mobile routers (and associated hosts) connected by wireless links — the union of which form an arbitrary topology.

The highly dynamic nature of mobile ad hoc networks results in frequent changes and unpredictability in network topologies. These make the routing area perhaps the most active research area within the MANET domain. Because the mobile nodes are free to move randomly, a dynamic topology is formed, with links between nodes exposed to potential breakages. Therefore, discovering and maintaining routes between nodes is one of the biggest challenges in MANETs.

There are many routing metrics available. The most widely used metric is hop count. It is used in both static and dynamic networks. The term “hop count” is used to represent the number of legs (or hops) traversed by a packet between the source and destination. The minimum hop count between a specific source and destination is called the shortest path, at least in the context of the hop count metric. It is generally accepted that one of the best metrics to use in a static network is hop count in which, if there are multiple routing paths available, the path with the minimum hop count is selected. This is because with a shorter path fewer resources will be consumed. There are many varieties of ad hoc routing protocols and no matter how different they may be, in every routing protocol it is a key common task to find a “good” path between a source and a destination. To answer the question as to which path is good enough is the major problem since the evaluation depends not only on a path metric such as hop count, but also expected delay, expected lifetime, or others. However, simply discovering and maintaining routes can be achieved by flooding specific packets, for example request packets, through the whole network.

2.4.1 Routing Protocols for Wireless Ad Hoc Networks

The protocols used in traditional wired networks to find a path from a source node to a destination node cannot be directly used in wireless ad hoc networks. This is because of the significant differences between the normal wired networks and wireless mobile ad hoc networks (MANETs) in terms of connection and movement. This has led to many routing protocols for ad hoc networks being developed in the recent past.

Routing in ad hoc networks is a difficult and interesting research area that has been growing in recent years. Its difficulty is mainly generated because of the continuous changes in the network topology. As an overview of ad hoc routing protocols we have compiled a list of every routing protocol we have found. It is far from certain that we have mentioned every currently existing protocol because there are so many new and different variations of protocols being developed all the time. The list of protocols is shown in Figure 2.1. We have divided the protocols into different categories according to their characteristics [41].

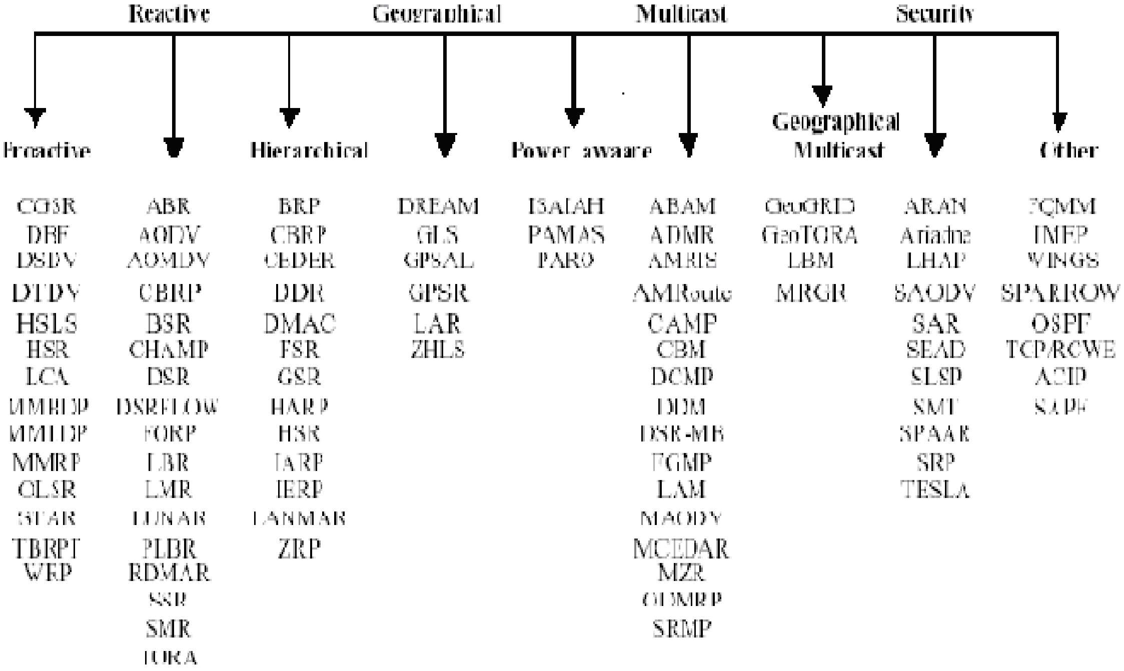


Figure 2.1 List of routing protocols

2.4.2 Discussion of Routing Protocols

We can categorise the routing protocols for ad hoc networks according to different criteria. They are routing protocols based on the following criteria.

2.4.2.1 Routing information update mechanism

These protocols can be driven either by a routing table or on demand. In the first case, every node stores the information in a routing table, which is updated regularly. In order to get the path to the destination the node uses the closest path. The typical protocols in this case are the DSDV [18], WRP [34], OLSR [17] and HSR [35]. In the second case the nodes do not need to maintain the network topology. They get the path when they need it, by using a connection establishment process. The advantage is that nodes do not need to exchange routing information frequently. The typical protocols of this case are the DSR [21, 25], AODV [19, 20] and ABR [33].

Some protocols, such as the ZRP [36], ZHLS [37], FSR [39] and GSR [40] combine both features. These are the previously mentioned hybrid routing protocols.

2.4.2.2 Use of temporal information for routing

This classification is based on the use of temporal information used for the routing process. Because ad hoc networks are very dynamic, it is very important to use the temporal information for routing. According to the time of the information, we get two more classifications in this category.

a) Routing protocols using post-temporal information, which is information about the past position of the node or the position of node at the time of routing to make routing decisions; protocols belonging to this class are, for example, DSDV [18], WRP [34], AODV [19, 20], FSR [39], HSR [35] and GSR [40].

b) Routing protocols using future temporal information, which is information about the expected future position of the node to make routing decisions; protocols in this class are, for example, FORP [42] and LBR [43].

2.4.2.3 Topology information organisation

Since the number of nodes in ad hoc networks is, in general, small, it is possible to use either a flat topology or a hierarchical topology for routing. In the first case, the availability of a globally unique addressing of nodes in ad hoc wireless networks should be assumed. Examples of such protocols are DSR [18, 21], AODV [19, 20] and ABR [33]. Protocols of the second case use a logical hierarchy in the network and an associated addressing scheme; Clusterhead Gateway Switch Routing (CGSR)[44], FSR [39] and HSR [35] are examples of this case.

2.4.2.4 Utilisation of specific resources

The protocols of this category are of two types.

a) Power-aware routing protocols: protocols in this class attempt to minimise the battery power. A typical protocol is PAR[45].

b) Geographical information assisted routing protocols: protocols in this class attempt to improve the performance of routing and reduce the control overhead by utilising the geographical information. A typical protocol is the Location-Aided Routing protocol (LAR) [46].

2.4.3 Multicast Routing

Due to the very dynamic topology, limited bandwidth and other limited resources of ad hoc networks, it is a challenge to adapt existing multicast routing protocols of wired networks, or to develop new protocols for ad hoc networks.

2.4.3.1 Requirements

A good multicast routing protocol for ad hoc networks should satisfy the following requirements.

- Robustness: it should be robust enough to sustain the mobility of the nodes and get a high packet delivery percentage.
- Efficiency: multicast efficiency is defined as the percentage of the number of sent data packets received by the receivers.
- Control overhead: it is necessary to exchange the control packets. Due to the limited bandwidth in ad hoc networks, the number of the control packets should be minimal.
- Quality of service (QoS): the main parameters for QoS in ad hoc networks are throughput, delay, broken links and reliability.
- Independence of the unicast routing protocol: a multicast routing protocol should be independent of any specific unicast routing protocol.
- Resource management: a multicast routing protocol should use minimum power and memory.

2.4.3.2 Classifications of multicast routing protocols

According to the dependency of the applications, we can classify the multicast routing protocols generally into two types.

2.4.3.2.1 Application-independent/generic multicast protocols

Most multicast routing protocols are of this class. They can be further classified along the following lines.

a) Based on topology

i-Tree-based: only one path exists between a source-receiver pair. Compared to mesh-based protocols, the tree-based are more efficient. Protocols falling into this class are Multicast CEDAR (MCEDAR)[47], BEMRP [48], MZRP [49], ABAM[50], Differential Destination Multicast (DDM) [51], and WBM [52].

ii- Mesh-based: there may be more than one path between a source-receiver pair; for this reason protocols of this type are more stable than the tree-based type. Protocols falling into this class are AMRoute [53], MAODV [54], and Ad hoc Multicast Routing utilising increasing ID-numbers (AMRIS)[55].

b) Based on initialisation of the multicast session

i- Source-initiated: in protocols of this class, the source initialises the multicast formation. Protocols falling into this class are MZRP [49], ABAM[50], AMRIS[55], On-Demand Multicast Routing Protocol (ODMRP) [56, 57], DCMP [58] and NSMP [59].

ii- Receiver-initiated: in protocols of this class, the receiver initialises the multicast formation. Protocols falling into this class are BEMRP [48], DDM [51], WBM [52], PLBM [60], FGMP-RA [61] and NSMP [59].

c) Based on the topology maintenance mechanism

i- Soft state approach: protocols falling into this class send control packets regularly to refresh the route. Protocols of this class are MZRP [49], DDM [51], ODMRP [56], DCMP [58], FGMP-RA [61] and NSMP [59].

ii- Hard state approach: protocols falling into this class send control packets to refresh the route only when a link breaks. Protocols of this class are BEMRP [48], ABAM[50], WBM [52], PLBM [60], AMRIS[55] and CAMP [62].

2.4.3.2.2 Application dependent multicast protocols

Protocols of this class are used for specific applications for which they are designed. The protocols that have been developed are, for example, RBM [63], CBM [64] and LBM [65].

2.5 Aims of Protocols

The features desired for a routing protocol in ad hoc networks are as follows.

1. The protocol should adapt quickly to topology (mobility) changes.
2. The protocol should provide loop-free routing.
3. The protocol should provide multiple routes from the source to the destination and this will solve the problems of congestion to some extent.
4. The protocol should have minimum control message overhead due to exchange of routing information when topology changes occur.
5. The protocol should aim to maintain the connection between the nodes for the longest possible time.
6. The protocol should allow quick establishment of routes so that they can be used before they become invalid.

2.6 Destination-Sequenced Distance Vector (DSDV)

DSDV is a proactive unicast mobile ad hoc network routing protocol [2, 3]. Sequence numbers are used in DSDV to differentiate old routes from fresh ones and avoid the structure of route loops. The route updates of DSDV can be either time driven or event driven. Every node regularly transmits updates, including its routing information, to its immediate neighbours. Packets are transmitted between the nodes of the network by using routing tables that are stored at each node of the network. Each routing table, at each of the nodes lists all available destinations and the number of hops to each. Each route table entry is tagged with a sequence number, which originates from the destination node. Each node regularly transmits updates, and transmits updates immediately when important new information is available.

These packets indicate which nodes are available from each node and the number of hops necessary to reach these reachable nodes, as is often done in distance-vector routing algorithms.

The DSDV protocol requires each mobile node to broadcast to each of its current neighbours its own routing table (for example, by broadcasting its entry) [18]. The entry in this list may change fairly dynamically over time, so the advertisement must be made often enough to ensure that every mobile node can almost always locate every other mobile node of the collection. In addition, each mobile node agrees to send data packets to other nodes on request. This agreement places a premium on the ability to determine the shortest number of hops for a route to a destination. All the nodes that need to create data paths between themselves broadcast the necessary data regularly, once every few seconds. In a wireless medium, the data broadcast by each mobile node will contain its new sequence number and the following information for each new route.

- The destination’s address.
- The number of hops required to reach the destination.
- The sequence number of the information received regarding that destination, as originally stamped by the destination.

- The transmitted routing tables will also contain the hardware address.
- The routing table will also include a sequence number created by the transmitter.

Routes with more recent sequence numbers are always preferred as the basis for making forwarding decisions because they use more recent information. A mobile host could possibly always receive two routes to the same destination.

Each new metric is broadcast to every mobile host in the neighbourhood, which broadcast to their neighbours, and so on. The route with the later sequence number must be available for use, but it does not have to be present immediately unless it is a route to a destination that was previously unreachable.

There will be two routing tables kept at each mobile host: one for use with forwarding packets, and another to be broadcast via incremental routing information packets. The sequence number is sent to all mobile nodes, which may each decide to maintain a routing entry for that mobile node.

One of the most important parameters to be selected is the time between broadcasting the routing information packets. However, when any new or significantly modified route information is received by a mobile node the new information will be retransmitted.

Mobile nodes cause broken links as they move from place to place. The broken link may be noticed by the protocol. When a link to a next hop has broken, any route through that next hop is immediately assigned a metric and an updated sequence number.

To reduce the amount of information carried in these packets, two types are defined. One carries all the available routing information, called a full dump. The other type carries only information changed since the last full dump and this is called an incremental dump. If a new sequence number for a route is received, but the metric stays the same, it is unlikely this would be considered a significant change. When a mobile node receives new routing information, this information is compared to the information already available from previous routing information packets. Any route with a new fresh sequence number is used. Routes with older sequence numbers are unused.

A route with a sequence number equal to an existing route is chosen if it has a “better” metric and the existing route is discarded or stored as less preferable. The metrics for routes chosen from the newly received broadcast information are each incremented by one hop. The broadcasts of routing information by the mobile nodes are to be regarded as somewhat asynchronous events.

2.7 Ad Hoc On-Demand Distance Vector (AODV).

The AODV routing protocol is a reactive protocol designed for wireless ad hoc networks. AODV is based on a hop-by-hop routing approach and is designed to improve upon the performance characteristics of DSDV in the creation and maintenance of routes.

The primary objectives of the AODV protocol are as follows.

1. To broadcast discovery packets only when necessary.

2. To distinguish between local connectivity management (neighbourhood detection) and general topology maintenance.

3. To disseminate information about changes in local connectivity to those neighbouring mobile nodes that are likely to need the information. In AODV, each node maintains two separate counters.

a- ***Sequence Number***: a monotonically increasing counter used to maintain freshness of information about the reverse route to the source (relating to movement).

b- ***Broadcast-ID***: this is incremented whenever the source issues a new RREQ message. Each node also maintains information about its reachable neighbours with bi-directional connectivity. Whenever a node (router) receives a request to send a message, it checks its routing table to see if a route exists. Each routing table entry consists of the following fields.

- Destination address
- Next hop address
- Destination sequence number
- Hop count.

2.7.1 AODV Route Discovery

When a node needs to determine a route to a destination node, it floods the network with RREQ messages. If a route exists, the originating node broadcasts a RREQ message to its neighbouring nodes, which broadcast the message to their neighbours, and so on. Otherwise, it saves the message in a *message queue*, and then it initiates an RREQ to determine a route. Figure 2.2 shows a flowchart to illustrate this process. To prevent cycles, each node remembers recently forwarded RREQs in a RREQ buffer.

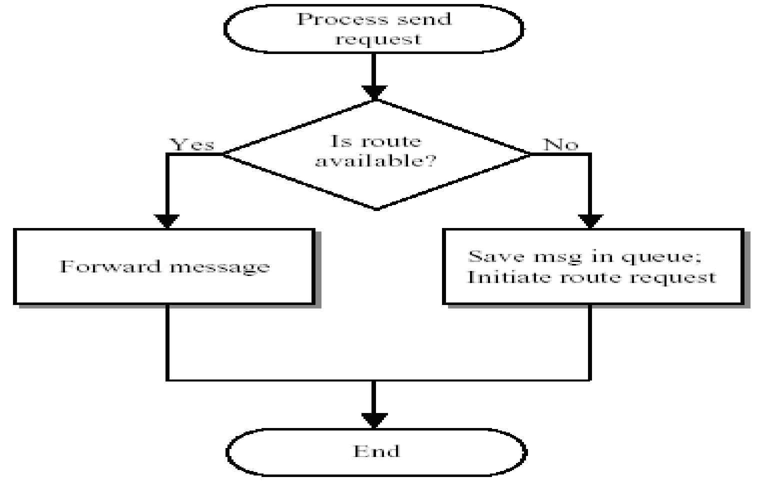


Figure 2.2 Flowchart for broadcasting an RREQ message

2.7.1.1 Generating RREQs

A node disseminates an RREQ when it determines that it needs a route to a destination and does not have one available. This can happen if the destination is previously unknown to the node or if a previously valid route to the destination expires or is marked as invalid. The destination sequence number field in the RREQ message is the last known destination sequence number for this destination and is copied from the destination sequence number field in the routing table. If no sequence number is known, the unknown sequence number flag MUST be set. The originator sequence number in the RREQ message is the node’s own sequence number, which is incremented prior to insertion in a RREQ. The RREQ ID field is incremented by one from the last RREQ ID used by the current node. Each node maintains only one RREQ ID. The hop count field is set to zero. Before broadcasting the RREQ, the originating node buffers the RREQ ID and the originator IP address (its own address) of the RREQ for PATH_DISCOVERY_TIME. In this way, when the node receives the packet again from its neighbours, it will not reprocess and re-forward the packet. An originating node often expects to have bidirectional communications with a destination node. In such cases, it is not sufficient for the originating node to have a route to the destination node; the destination must also have a route back to the originating node. In order for this to happen as efficiently as possible, any generation of an RREP by an intermediate node for delivery to the originating node should be accompanied by some action that notifies the destination about a route back to the originating node.

Data packets waiting for a route (that is, waiting for an RREP after an RREQ has been sent) should be buffered. The buffering should be "First-in, First-out" (FIFO).

2.7.1.2 **Generating an RREP message**

A node copies the destination IP address and the originator sequence number from the RREQ message into the corresponding fields in the RREP message. Processing is slightly different, depending on whether the node is itself the requested destination or instead whether it is an intermediate node with a fresh enough route to the destination. Once created, the RREP is unicast to the next hop toward the originator of the RREQ, as indicated by the route table entry for that originator. As the RREP is forwarded back towards the node that originated the RREQ message, the hop count field is incremented by one at each hop. Thus, when the RREP reaches the originator, the hop count represents the distance, in hops, of the destination from the originator. A node generates an RREP if either:

(i) it is itself the destination, or

(ii) it has an active route to the destination.

2.7.1.3 RREP generation by the destination

If the generating node is the destination itself, it MUST increment its own sequence number by one if the sequence number in the RREQ packet is equal to this incremented value. Otherwise, the destination does not change its sequence number before generating the RREP message. The destination node places its (perhaps newly incremented) sequence number into the destination sequence number field of the RREP, and enters the value zero in the hop count field of the RREP.

2.7.1.4 RREP generation by an intermediate node

If the node generating the RREP is not the destination node, but instead is an intermediate hop along the path from the originator to the destination, it copies its known sequence number for the destination into the destination sequence number field in the RREP message. The intermediate node updates the forward route entry by placing the last hop node (from which it received the RREQ, as indicated by the source IP address field in the IP header) into the precursor list for the forward route entry.

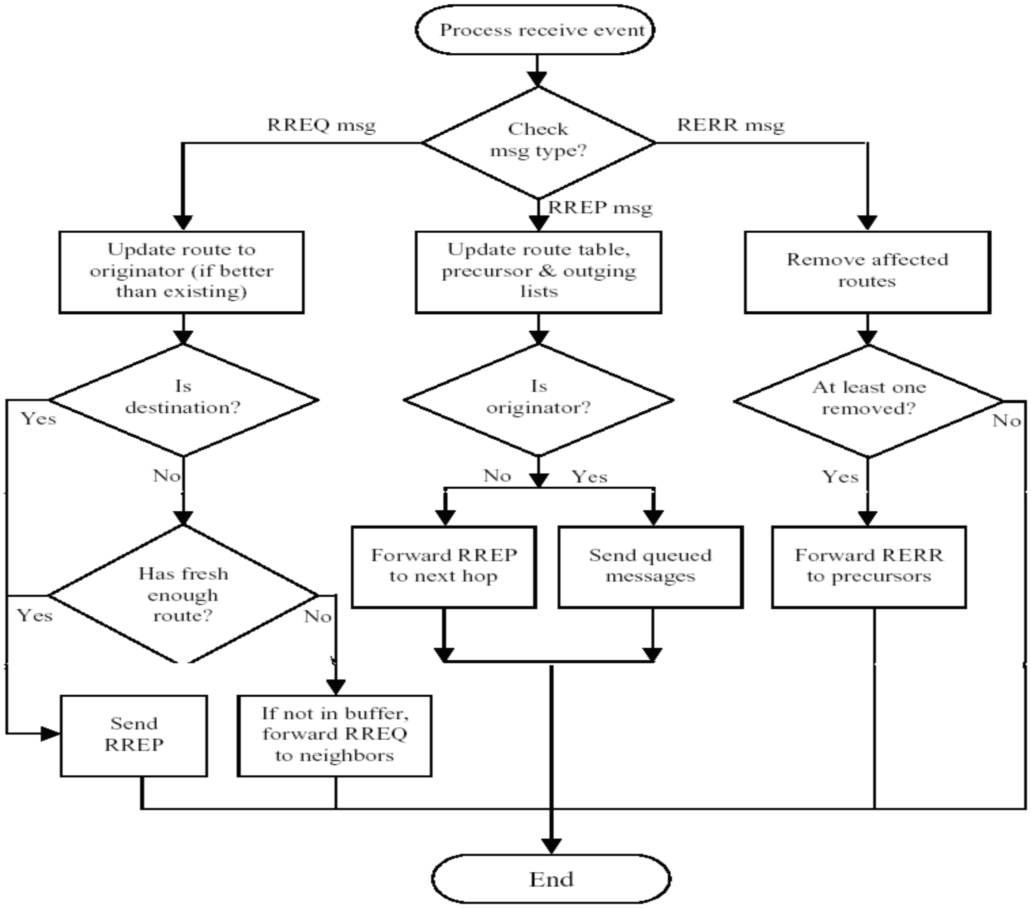


Figure 2.3 Flow chart for an AODV node when processing an incoming message [41]

2.8 AODV Example [41].

Figure 2.4 shows a set up of five nodes on a wireless network. The circles show the range of communication for each node. Because of the limited range, each node is able to communicate only with the nodes within range, which in this case are the directly adjacent nodes.

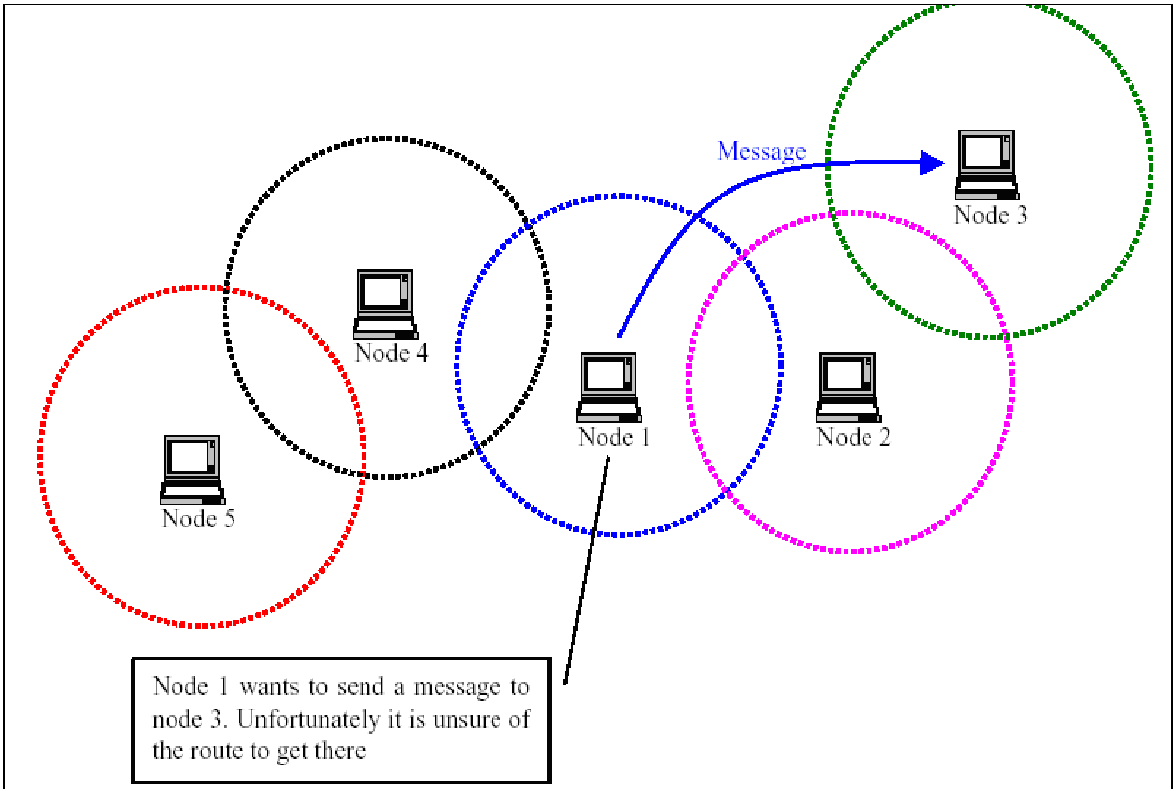


Figure 2.4 Set up of a mobile ad hoc network consisting of five nodes[41]

Nodes that can communicate with the other nodes directly are considered to be neighbours.

A node keeps track of its neighbours by listening for a HELLO message that each node broadcasts at set intervals. When one node needs to send a message to another node that is not its neighbour, it broadcasts an RREQ message. The RREQ message contains several key bits of information: the source, the destination, the lifetime of the message and a *sequence number*, which serves as a unique ID. If node 1 wishes to send a message to node 3, node 1’s neighbours are nodes 2 and 4. Since node 1 cannot directly communicate with node 3, node 1 sends out an RREQ. The RREQ is heard by nodes 4 and 2 as shown in Figure 2.5.

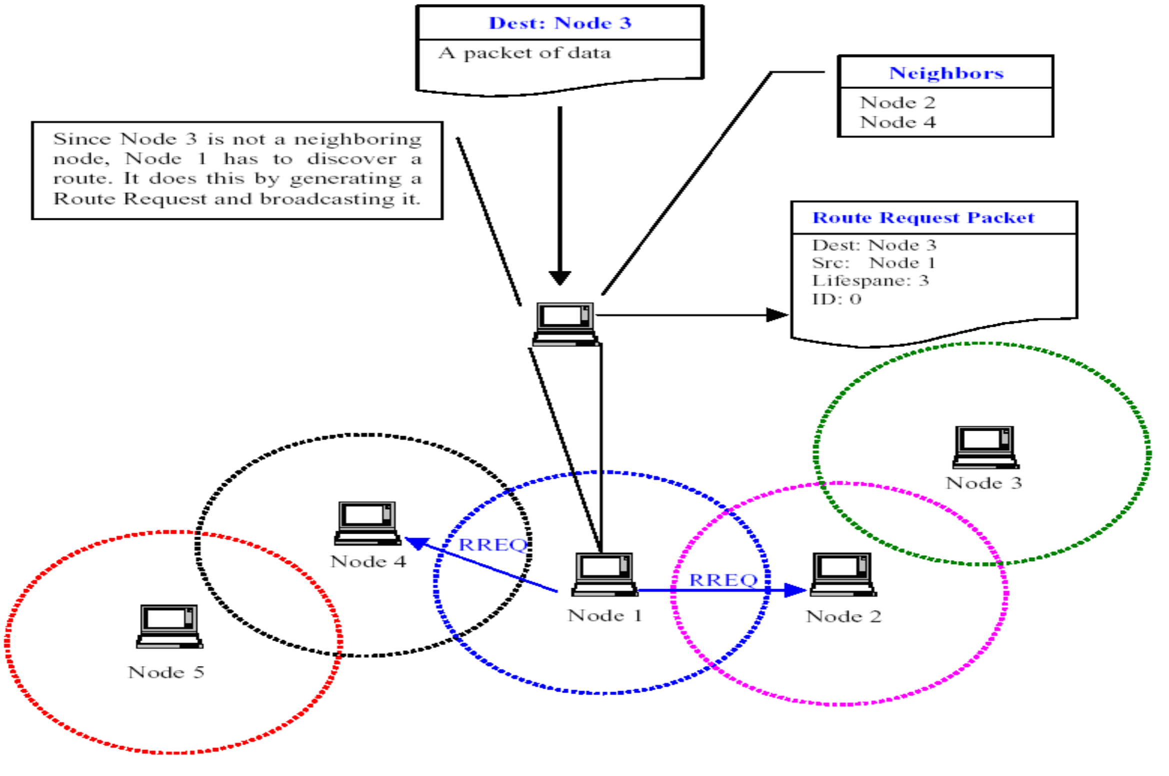
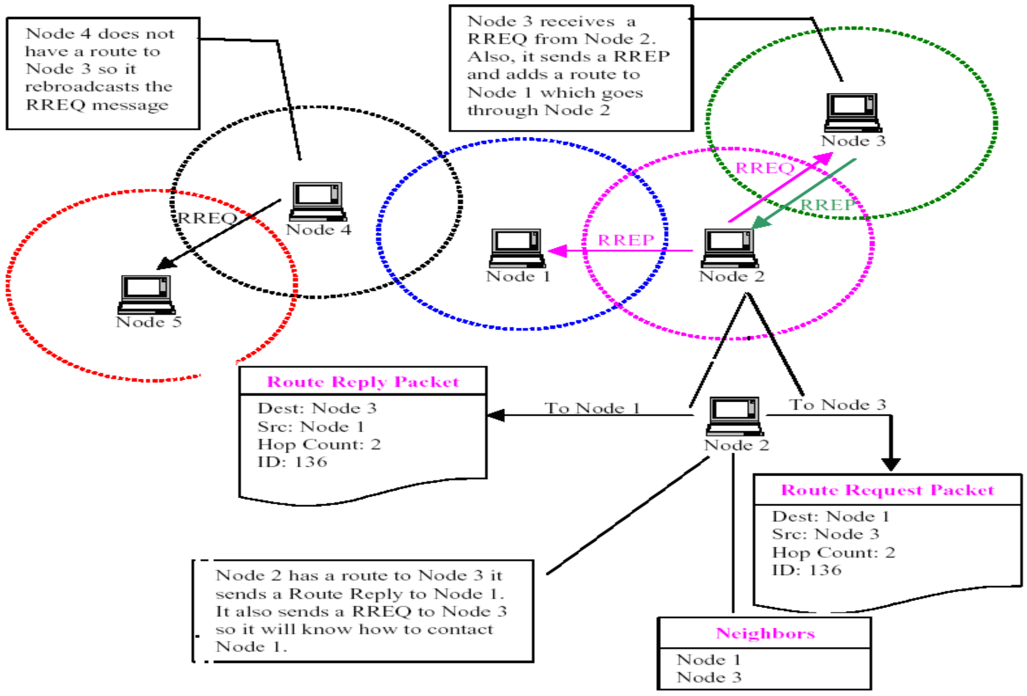


Figure 2.5 Node 1 sends out an RREQ to its neighbour nodes[41]

When node 1's neighbours receive the RREQ message they have two choices: if they know a route to the destination or if they are the destination they can send an RREP message back to node 1; otherwise they will rebroadcast the RREQ to their set of neighbours.



Node 4 does not have a route to Node 3 so it rebroadcasts the RREQ message

Node 3 receives a RREQ from Node 2. Also, it sends a RREP and adds a route to Node 1 which goes through Node 2

Route Reply Packet
Dest: Node 3
Src: Node 1
Hop Count: 2
ID: 136

Route Request Packet
Dest: Node 1
Src: Node 3
Hop Count: 2
ID: 136

Node 2 has a route to Node 3 it sends a Route Reply to Node 1. It also sends a RREQ to Node 3 so it will know how to contact Node 1.

Neighbors
Node 1
Node 3

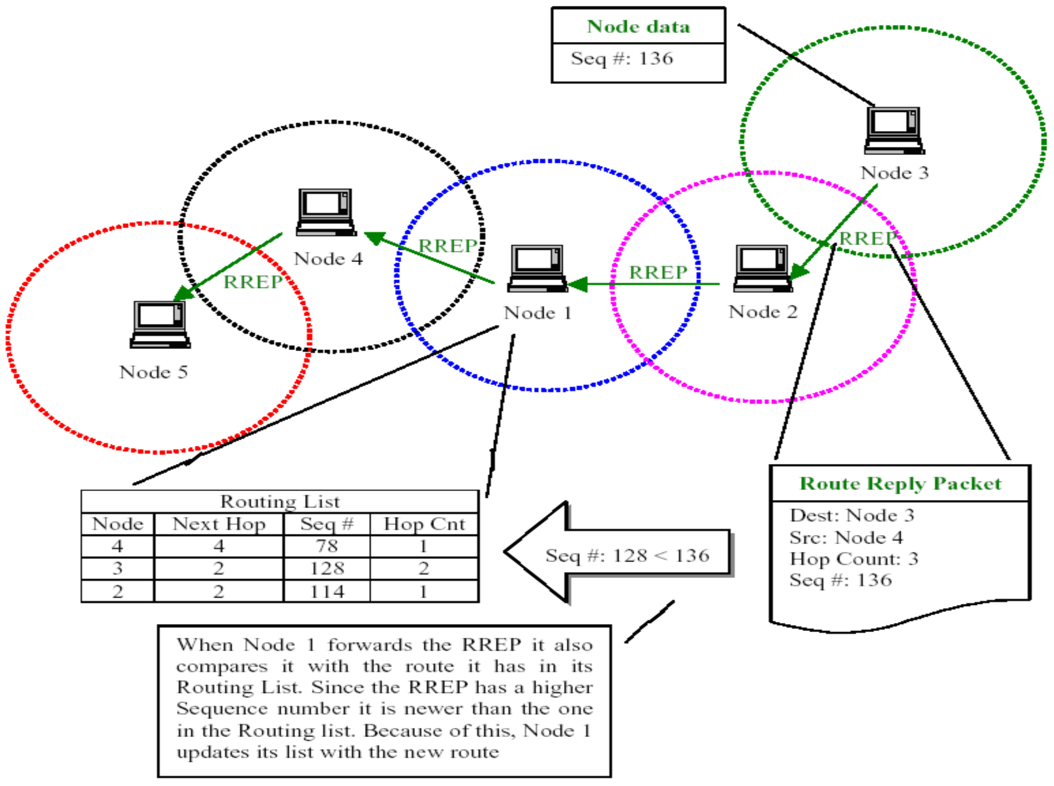
Figure 2.6 Node 2 has a route to node 3 and sends out an RREP[41]

The message keeps getting rebroadcast until its lifespan is up. If node 1 does not receive a reply in a set amount of time, it will rebroadcast the request but this time the RREQ message will have a longer lifespan and a new ID number. All of the nodes use the sequence number in the RREQ to ensure that they do not rebroadcast the same RREQ. In Figure 2.6, node 2 has a route to node 3 and replies to the RREQ by sending out an RREP. Node 4, on the other hand, does not have a route to node 3 so it rebroadcasts the RREQ.

Sequence numbers serve as time stamps. They allow nodes to compare how “fresh” their information on other nodes is. Every time a node sends out any type of message it increases its own sequence number. Each node records the sequence number of all the other nodes it talks to. A higher sequence number signifies a fresher route. Thus, it is possible for other nodes to figure out which one has more accurate information. In Figure 2.7, node 1 is forwarding an RREP to node 4. It notices that the route in the RREP has a better sequence number than the route in its routing list. Node 1 then replaces the route it currently has with the route in the RREP.

The Route Error Message (RERR) allows AODV to adjust routes when nodes move around.

Whenever a node receives an RERR, it looks at the routing table and removes all the routes that contain the bad nodes. Figures 2.7 illustrate the three cases under which a node would broadcast an RERR to its neighbours.



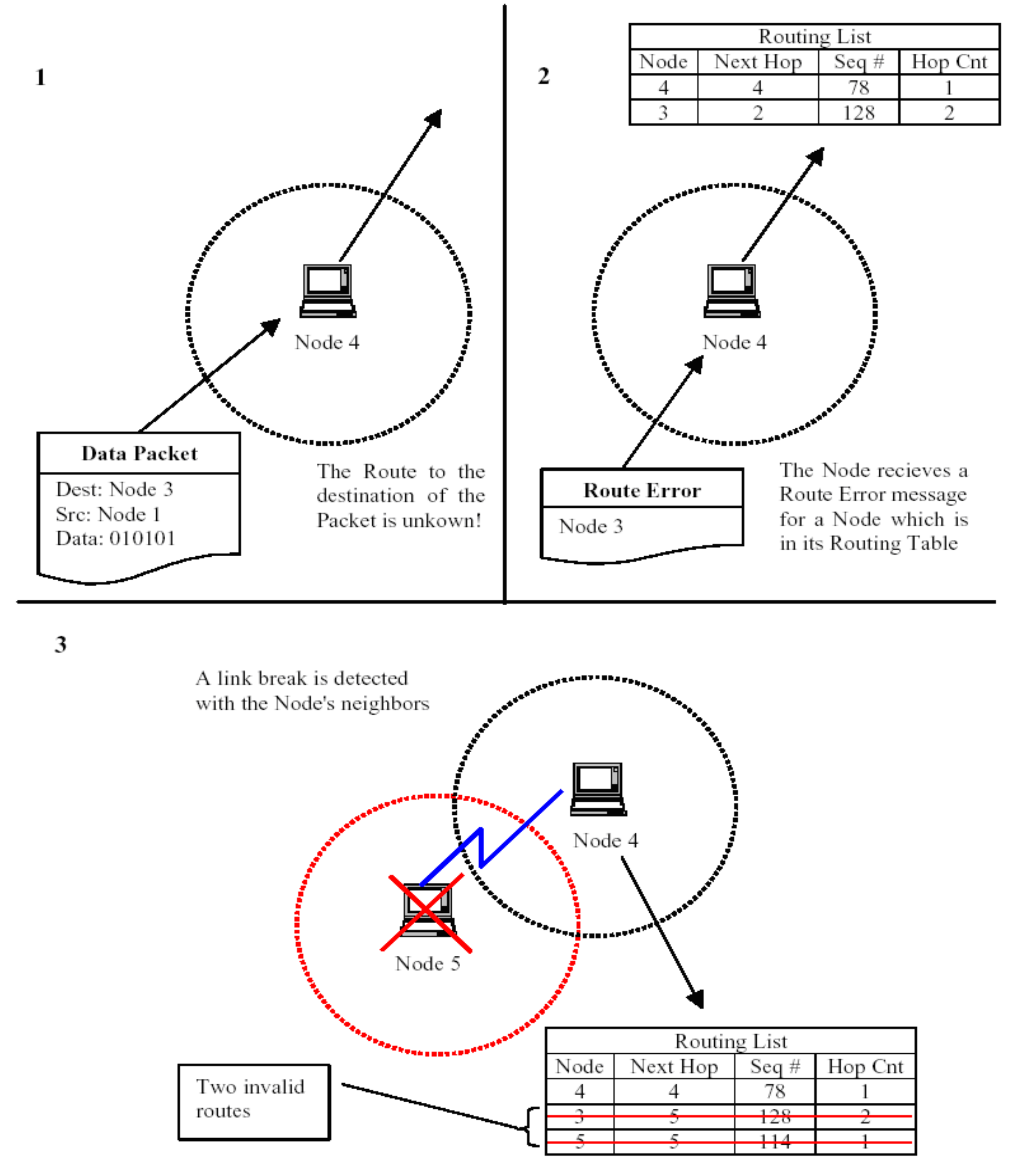
Routing List			
Node	Next Hop	Seq #	Hop Cnt
4	4	78	1
3	2	128	2
2	2	114	1

Dest: Node 3
Src: Node 4
Hop Count: 3
Seq #: 136

When Node 1 forwards the RREP it also compares it with the route it has in its Routing List. Since the RREP has a higher Sequence number it is newer than the one in the Routing list. Because of this, Node 1 updates its list with the new route

Figure 2.7 Node 1 is forwarding an RREP to node 4[41]

In the first scenario, the node receives a data packet that it is supposed to forward but it does not have a route to the destination.



Data Packet
Dest: Node 3
Src: Node 1
Data: 010101

Route Error
Node 3

Routing List

Node	Next Hop	Seq #	Hop Cnt
4	4	78	1
3	2	128	2

Routing List

Node	Next Hop	Seq #	Hop Cnt
4	4	78	1
~~3~~	~~5~~	~~128~~	~~2~~
~~5~~	~~5~~	~~114~~	~~1~~

Figure 2.8 Different cases of a node broadcasting an RERR to its neighbours[41]

The real problem is not that the node does not have a route; the problem is that some other nodes may assume that the correct route to the destination is through this node. In the second scenario, the node receives an RERR that causes at least one of its routes to become invalid. If this happens, the node then sends out an RERR with all the new nodes, which are now unreachable. In the third scenario, the node detects that it cannot communicate with one of its neighbours. When this happens, it looks at the routing table for routes that use the neighbour as a next hop and marks them as invalid. Then, it sends out an RERR for the neighbours with the invalid routes.

2.9 Summary

In order to provide a background to the performance evaluation of MANETs, this chapter has described MANETs, including their types, features and applications. The routing principles in MANETs and the characteristics of broadcast operations in MANETs have also been covered. The chapter has also provided a general overview of existing broadcasting algorithms in MANETs. Finally, the chapter has provided a description of the DSDV routing protocol and AODV.

What has been apparent in reviewing the MANET literature has been a notable lack of work involving the heading angle in any recent literature (apart from the publications by the present author [96-100]) since the paper by Alakaidi et al in 2004 [95]. The focus of the research in more recent literature appears to be in other areas such as security[66-71] and power level [72-77], with the seemingly fundamental concept of the heading angle largely ignored. The thesis therefore attempts to partly redress this situation.

Chapter 3 Mobility Models and Simulation

3.1 Introduction

Ad hoc networks can operate without a fixed infrastructure and survive quick changes in the network topology. Usually nodes are mobile and use wireless communication links. In recent years many routing algorithms for ad hoc networks have been proposed. The algorithms are often compared using simulation. There are three different ways to model and evaluate networks (formal analysis, real world measurements and simulation). The dynamic nature of ad hoc networks makes them hard to study using formal analysis. Since ad hoc networks are still mostly a research subject, all but the most common scenarios are still either unknown or not well understood.

Some of the most common scenarios that are known are in military networks and these are not generally available. Thus, the use of real-world measurement is currently almost impossible and certainly costly. A commonly used option is to study the behaviour of the protocols in a simulated environment. The purpose of simulation is to create an artificial environment, usually a computer program that captures the necessary characteristics of the phenomena that are being studied. Simulation is an economically practical way to create a statistically significant amount of test runs.

For these reasons, simulation is a much used tool for comparing ad hoc routing protocols. There are several network simulators that can be used for studying mobile ad hoc networks, such as GloMoSim and NS-2. The main goal of this chapter is to present a simulation model for routing in MANETs.

3.2 Mobility Models Used in Simulation

Ad hoc network researchers face a problem in that it is unknown how nodes will operate in real-life situations, especially how they will move. In order to create significant simulation results good understanding of mobility and its effects on ad hoc routing is necessary. Ad hoc mobility models are used to describe the movement of nodes, so they play a key part in simulating ad hoc networks. Every model includes an algorithm that is used to randomise the movements of nodes. Currently, there are two types of mobility models used in the simulation of networks: traces and synthetic models[78]. Traces are those mobility patterns that are observed in real-life systems. Traces provide accurate information, especially when they involve a large number of mobile nodes and an appropriately long observation period. On the other hand, synthetic models attempt to realistically represent the behaviour of mobile nodes without the use of traces. The synthetic models are divided into two categories: entity mobility models and group mobility models [79]. The entity mobility models randomise the movements of each individual node and represent mobile nodes whose movements are independent of each other. The group mobility models have groups of nodes that stay close to each other and then randomise the movements of the group and represent mobile nodes whose movements are dependent on each other. The node positions also vary randomly around the group reference point. In our simulation process, we will use one of these mobility models called the Random Waypoint (RWM) for reasons given later.

3.2.1 Random Waypoint Mobility (RWM)

Since not many MANETs are currently deployed, research in this area is mostly simulation based. One of the key points in the design of good simulations is the choice of realistic movement models. The most widely used models are based around random individual movement; the simplest, the random walk mobility model, is used to represent pure random movements of the entities of a system. A slight enhancement of this is the RWM model. The RWM model was first proposed by Johnson and Maltz[25]. The RWM model [80] is one of the most popular mobility models in MANET research and is in itself a main point of much research activity. The model defines a collection of nodes that are placed randomly within a confined simulation area. Then, each node selects a destination inside the simulation area and travels towards it with some speed (metres/s). Once it has reached the destination, the node pauses for some time (pause time) before it chooses another destination and repeats the process. The speed of each node is specified according to a uniform distribution between 0 and V max, where V max is the maximum speed parameter.

In the RWM, the velocity of a mobile node is a memoryless random process; that is, the velocity at the current time is independent of any previous time. Thus, some extreme mobility behaviour, such as unexpected stopping, unexpected accelerating and sharp turning, may frequently occur in the trace generated by the RWM. However, in many real-life scenarios, the speed of vehicles and pedestrians accelerate incrementally. In addition, the direction change is also smooth. In the RWM, the mobile node is considered to be an entity that moves independently of other nodes. This kind of mobility model is classified as an entity mobility model.

The RWM model has been the subject of many studies and a number of them claim that their results show that this mobility model is a good approximation for simulating the motion of vehicles on a road, but there are situations in which a different model is better suited [81].

Others claim the opposite. They demonstrate the utility of their test-suite by evaluating various MANET routing protocols, including AODV and DSDV. Their results show that the protocol performance may vary drastically across mobility models and performance rankings of protocols may vary with the mobility models used. The RWP is a simple model that may be applicable to many scenarios. However, it may not be sufficient to capture some mobility characteristics of scenarios in which some MANETs may be deployed[82]. Some graphical and tabular illustrations of a node's movement are shown in figures 3.1 and 3.2 and tables 3.1 and 3.2.

3.2.1.1 Some examples of a node's movement using the random waypoint model

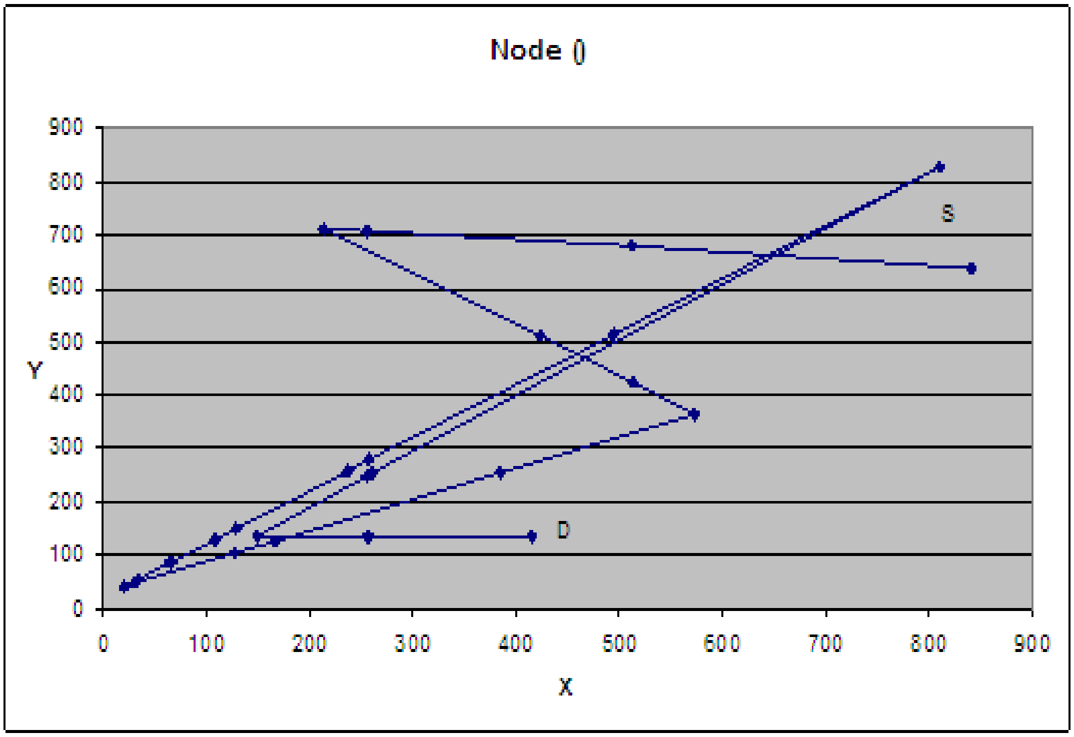


Figure 3.1 RWM mobility model node 0

Table 3.1 Node 0

	X	Y	Node angle
node0	839.927	638.7102	276.7621
node0	511.2354	677.6835	276.7621
node0	255.4211	708.0157	276.7621
node0	213.3705	712.0944	133.77
node0	423.0634	511.2171	133.77
node0	512.7774	425.2748	133.77
node0	513.8583	424.2393	133.77
node0	573.0951	365.4992	239.724
node0	384.3004	255.2825	239.724
node0	165.7641	127.7028	239.724
node0	126.9707	105.0555	239.724
node0	31.28025	49.19219	239.724

node0	20.70666	43.4541	45.22538
node0	33.47995	56.1273	45.22538
node0	65.41319	87.81028	45.22538
node0	107.9908	130.0543	45.22538
node0	129.2797	151.1763	45.22538
node0	235.7238	256.7862	45.22538
node0	258.077	278.9643	45.22538
node0	493.3185	512.3623	45.22538
node0	810.5468	827.0549	223.876
node0	260.5848	255.0814	223.876
node0	255.3867	249.6752	223.876
node0	148.7642	137.2121	90.55872
node0	256.6631	136.1599	90.55872
node0	258.1617	136.1453	90.55872
node0	415.9891	136.0328	18.46585

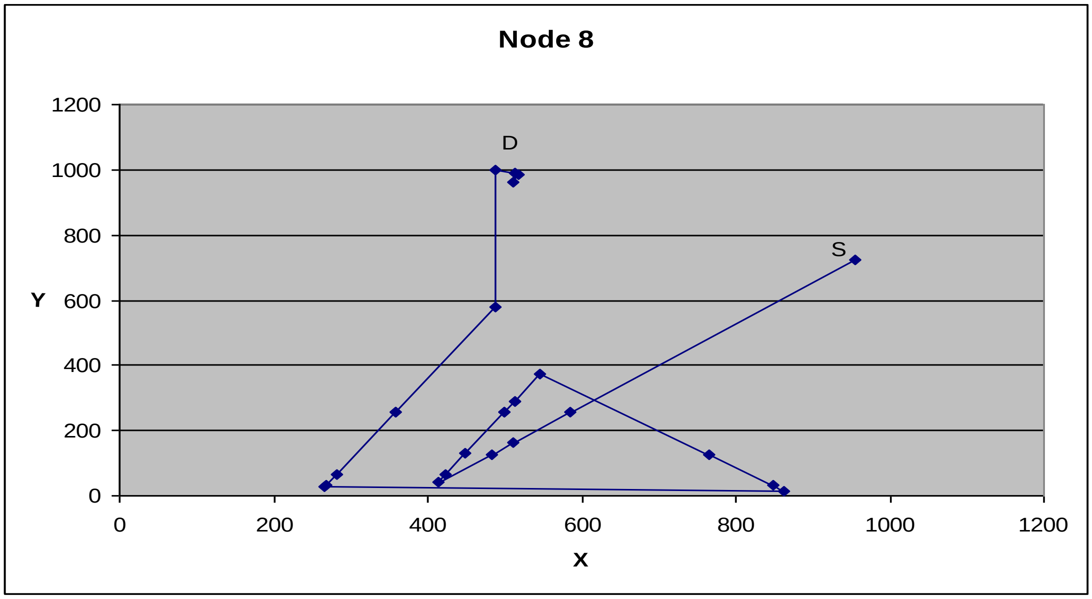


Figure 3.2 RWM model node 8

Table 3.2 Node 8

	X	Y	Node angle
Node8	955.2535	723.6917	218.3507
node8	585.1352	255.8919	218.3507
node8	511.6695	163.0371	218.3507
node8	483.7712	127.7759	218.3507
node8	413.6435	39.83834	21.50863
node8	423.5113	64.878	21.50863
node8	448.7288	128.8682	21.50863
node8	499.1639	256.8487	21.50863
node8	512.8691	291.626	21.50863
node8	546.2096	372.5801	138.3574
node8	764.3809	127.2151	138.3574
node8	849.0593	31.98214	138.3574
node8	862.5033	15.20348	271.0378
node8	266.3666	27.40192	21.82168
node8	281.9488	66.31744	21.82168
node8	358.7466	258.1153	21.82168
node8	486.7403	579.2739	359.8921
node8	487.2867	998.9244	112.5152
node8	512.7049	988.3879	112.5152
node8	517.6973	984.7161	193.8633
node8	511.9574	961.458	193.8633

3.3 Geographic Restriction Model

The limitation of the Random Waypoint model is the unconstrained movement of the mobile node. Mobile nodes in the Random Waypoint model are allowed to move freely and randomly anywhere in the simulation field. However in many real-life applications, we observe that a node’s movement is local streets in an urban area or on a campus and pedestrians may be blocked by buildings and other obstacles. Some recent work addresses this characteristic and integrates the paths and obstacles into mobility models.

This kind of mobility model is called a “mobility model with geographic restriction” [78].

3.3.1 Manhattan Mobility Model

The Manhattan mobility model is a popular, special case of a geographic restriction model[78]. The following section describes the Manhattan mobility model in detail. One simple way to integrate geographic constraints into the mobility model is to restrict the node movement to the pathways in the map. The map is predefined in the simulation field and utilises a random graph to model the map of the city. This graph can be either randomly generated or carefully defined based on a certain map of a real city. The vertices of the graph represent the buildings of the city, and the ends represent the streets and freeways between these buildings. Initially the nodes are placed randomly on the edges of the graph. Then for each node a destination is randomly chosen and the node moves toward this destination through the shortest path along the edges. Upon arrival, the node pauses for a short time and again chooses a new destination for the next movement. This procedure is repeated until the end of the simulation. Unlike the Random Waypoint model, where the nodes can move freely, the mobile nodes in this model are only allowed to travel on the pathways. However, because the destination of each action phase is randomly chosen, a certain level of randomness still exists for this model. So in this graph-based mobility model, the nodes are travelling in a pseudorandom fashion on the pathways. Similarly, in the Manhattan mobility model, the movement of a mobile node is also restricted to the pathways in the simulation field. Figure 3.3 illustrates the maps used for the Manhattan models.

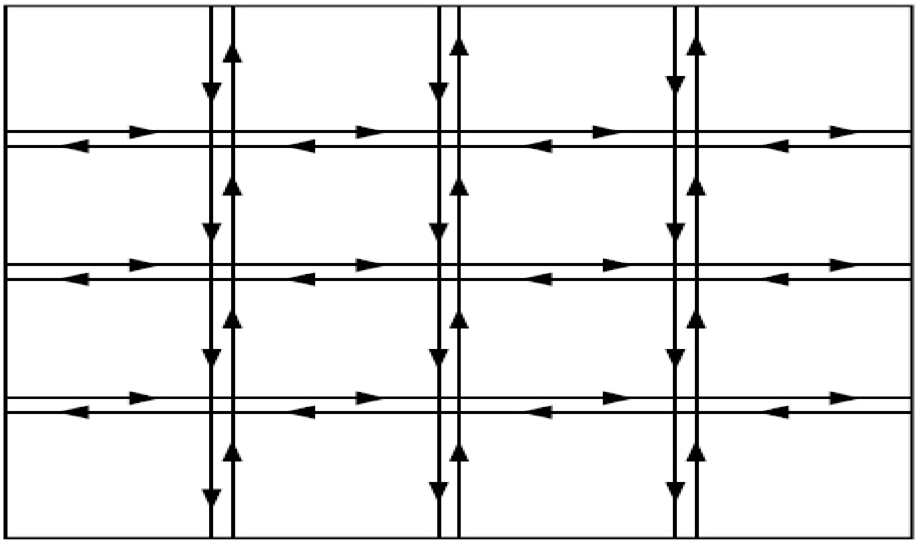


Figure 3.3 Example of mobile movement in the Manhattan mobility model

In the Manhattan model topology each line represents a single-lane road. Vehicular movement occurs in the direction shown by the arrows.

3.4 Performance Evaluation Techniques

Performance evaluation can be defined as forecasting system behaviour in a quantitative way. Evaluating and analysing a communication system before employing it in the real world is difficult and expensive due to the complex interaction between application characteristics and architectural features. Performance evaluation techniques can be classified into three major categories:

1) experimental measurement

2) theoretical/analytical modelling

3) simulation [83, 84].

In this section, these three techniques are introduced.

3.4.1 Experimental Measurement Technique

The experimental measurement technique is based upon direct measurements of the communication system under study using a software, hardware and/or hybrid monitor. The main characteristic of performance evaluation using this approach is the employment of real or synthetic workloads to measure their performance on actual hardware. Monitoring tools that are used in this measurement technique perform three main tasks: data acquisition, data analysis and result output. In general, monitoring tools can be classified into three major types: software, hardware and hybrid monitors. Software monitoring tools can be defined as programs that detect the state of the communication system [83, 84]. Hardware monitoring tools are electronic devices that are connected to specific communication system points in order to detect signals characterising specific phenomena.

3.4.2 Theoretical/Analytical Modelling Technique

The performance evaluation of any communication system is a hard task due to the various degrees of freedom exhibited. In order to abstract the details of a system that limit the degree of this freedom, analytical and theoretical models are widely used as performance evaluation techniques in many research studies of communication systems [83, 84]. The analytical model can be defined as a set of equations describing the performance of a communication system. These techniques try to hide hardware details to provide a simpler view of the communication devices. Moreover, analytical and theoretical models capture the complex system's features by simple mathematical formulae, parameterised by a limited number of degrees of freedom such that the model is tractable.

3.4.3 Simulation Techniques

In addition to measurement and analytical model techniques, simulation techniques have become one of the major performance evaluation techniques. Simulation techniques consist of implementing a computer-program-based model of a communication system for the purpose of studying system behaviour in order to further understand it [83, 84]. Simulation techniques can be classified into two main categories: continuous event and discrete event simulations. In the continuous event simulations, systems are studied in which the state continuously changes over time. In discrete event simulations, on the other hand, the state changes at discrete points in time.

3.5 Global Mobile Information System Simulator (GloMoSim)

GloMoSim [85] is a simulator written in Parsec [86], a highly-optimised C-like simulation language. GloMoSim has recently gained popularity within the wireless ad hoc networking community. It was designed specifically for scalable simulation and the sequential version of GloMoSim is freely available. With GloMoSim we can build a scalable simulation environment for wireless network systems. It uses a parallel discrete-event simulation capability provided by Parsec. GloMoSim has several nice features. It comes with a rich suite of models and it is the only simulator among the considered ones that seems able to scale up to thousands of nodes and its highly modular design is such that it appears quite straightforward to modify and/or extend the basic functionalities. GloMoSim is the second most used simulator, after NS-2 [87], in the ad hoc research community. Also, GloMoSim is a proven simulation tool and has recently gained popularity within the wireless ad-hoc networking community due to the fact that, unlike most other simulation packages such as NS-2 and OPNET (see later), it was designed specifically for scalable simulation in a wireless network environment. It is built using a layered approach that is similar to the OSI seven layer network architecture. Standard APIs are used between the different simulation layers. This not only allows sharing of memory areas but also allows for more efficient performance evaluation, better scalability and ease of programming use. GloMoSim is thus modular, easy to use and flexible while maintaining a high degree of detail and has additional implementations of layers/modules and features like GUI based analysis tools.

Therefore, it is widely accepted from a scientific point of view.

GloMoSim features

- Scalable simulation environment for wireless and wired networks, developed initially at UCLA computing laboratory
- Provides various applications (CBR, ftp, telnet), transport protocols (tcp, udp), routing protocols (AODV, flooding) and mobility schemes (RWP, random drunken, Manhattan mobility)
- User must define specific scenarios in text configuration files
  - app file—contains description of traffic to generate (for example, app type, bit rate, and so on)
  - config file—contains description of other (remaining) parameters.

3.6 NS-2

NS-2 is the most popular simulator used in the research field of mobile ad hoc networks [87]. NS-2 comes fully equipped with protocols, models, algorithms and accessory tools and it is free. Therefore, in terms of scientific acceptance and the number of tools/modules and cost NS-2 should be an ideal choice. On the other hand, some disadvantages of NS-2 from the description of its architecture, it is quite clear that NS-2 is rather complex software. Adding new components and/or modifying existing ones necessarily involves the writing of several software modules (in C++ and OTcl), taking into account several parameters and multi-step data flows. As a net result, with NS-2 it is not easy to use different protocols and study different scenarios at different levels of detail. Moreover, there is a lack of graphical tools that could greatly help code development. These tools are often written with scripting languages.

Unfortunately, the documentation provided does not help from this point of view. In fact, it is often limited and out of date in terms of the current release of the simulator. Most problems must be solved by consulting the highly dynamic newsgroups and browsing the source code. In general, it is admitted that the learning curve for NS-2 is steep and debugging is difficult due to the dual C++/OTcl nature of the simulator. In some sense, since NS-2 is the result of a rather long process of development, which has incorporated contributions from several different sources and the software design is considered quite poor with respect to current standards. If it is rather easy to use the simulator, it is it not that easy to learn how to add new components or modify existing ones. Moreover, in terms of (graphical) tools to describe simulation scenarios and analyse or visualise simulation trace files, NS-2 cannot compare positively with commercial tools like OPNET and also with GloMoSim. A more troublesome limitation of NS-2 is its large memory footprint and its lack of scalability as soon as simulations of a few hundred to a few thousand nodes are undertaken.

3.7 OPNET

OPNET is a well-established and very professional product [88, 89]. Support for mobile ad hoc networks is essential but of high quality and enough to carry out serious studies. The graphical interface simplifies most of the routine operations. OPNET [88] differs from NS-2 and GloMoSim in that it is quite easy to describe an application that bypasses part of the protocol stack. This aspect can be quite important to speed up and/or to reduce the level of unnecessary detail during the simulations. The performance seems to scale quite well, but there are not enough data in the current literature to make a more precise statement in this sense in the context of mobile ad hoc networks. Also it requires a licence to allow its use.

3.8 Comparison between Some Simulators

- This scenario depicts a critical factor that influences the success rate in MANETs: the effective transmission range
- Notice the apparent differences in trend between the simulators.

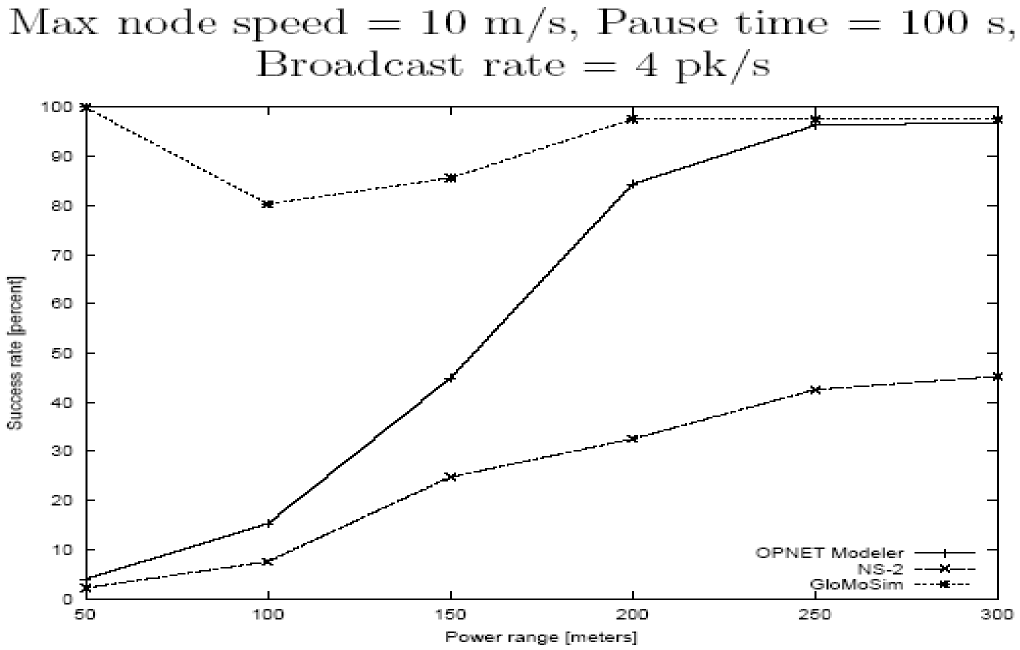


Figure 3.4 Success rate versus power range [90]

Overhead versus mobility

- This scenario presents the average overhead of messages flooded in the network for a single simulation run
- This metric is related to the mean number of reachable neighbours (that is, within transmission range).

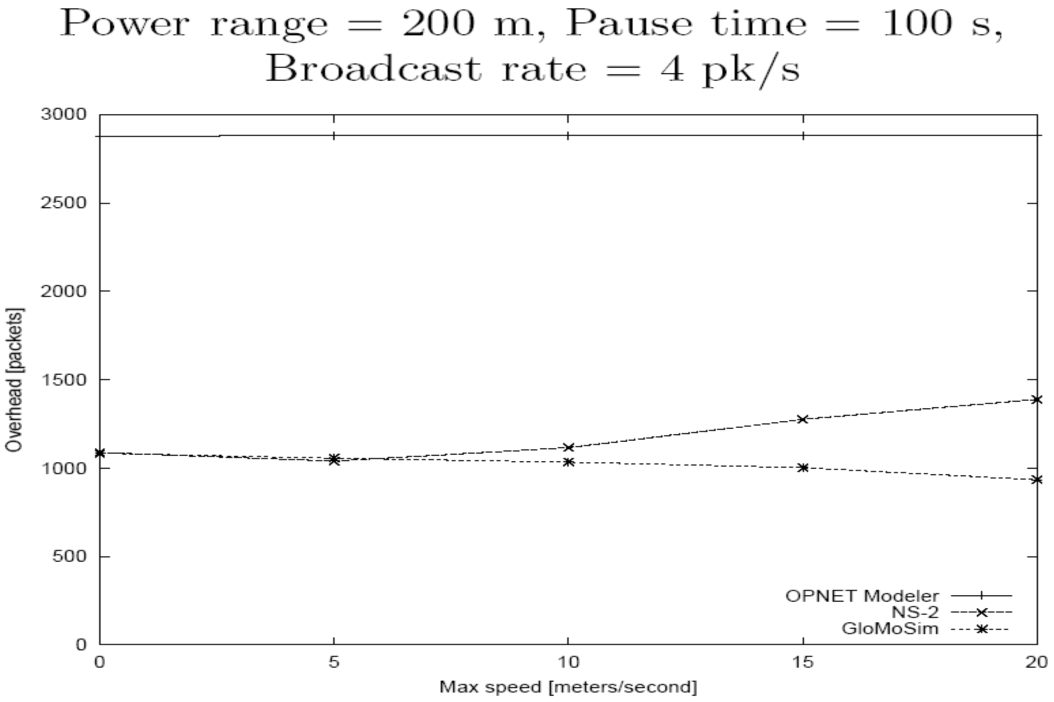


Figure 3.5 Overhead versus mobility[90]

Success rate versus mobility

- This scenario evaluates the effects of node mobility on the ability of flooding to deliver packets reliably
- Again, we see a significant difference in the success rate.

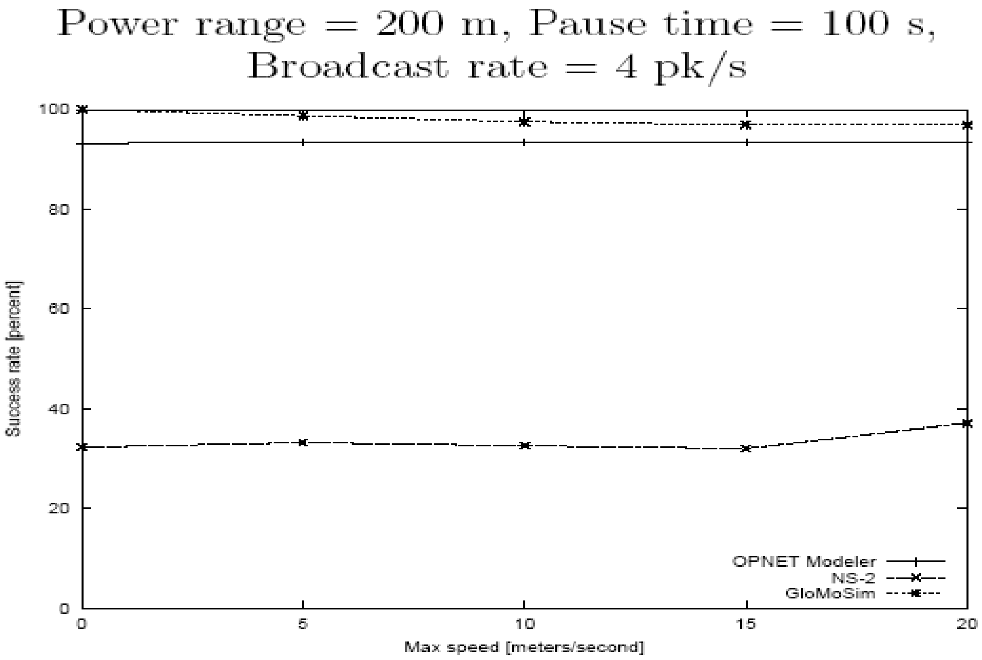


Figure 3.6 Success rate versus mobility [90]

Time delay versus mobility

- The final scenario compares the average time delay needed to flood a message throughout the whole network
- The metric increases in value with the number of hops from source to destination and also whenever collisions occur.

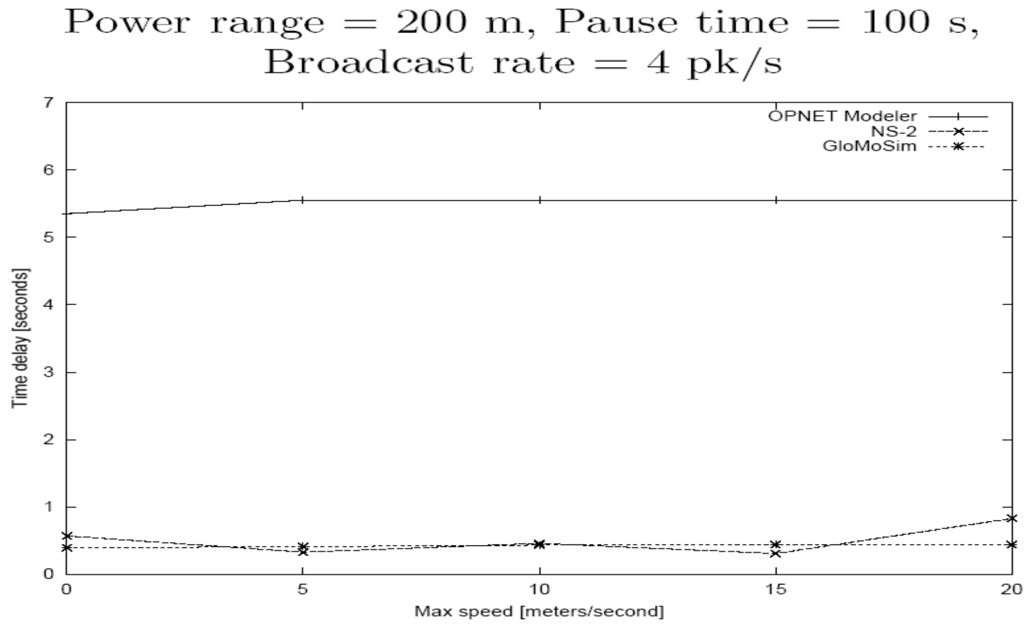


Figure 3.7 Time delay versus mobility [90]

3.9 Existing Alternatives

3.9.1 NS2

- C++ with Tcl bindings, O (n2)
- used extensively by community
- written for TCP simulation
- modified for ad hoc networks
- processor and memory intense
- sequential; max. ~500 nodes

3.9.2 OPNET – Popular Commercial Option

- good modelling capabilities
- poor scalability

3.9.3 GloMoSim

- implemented in Parsec, a custom C-like language
- entities are memory intensive
- requires “node aggregation”, which imposes conservative parallelism, loses Parsec benefits
- shown ~100,000 nodes.

3.10 Justification of the Method of Research

This section briefly discusses the choice of simulation as the preferred method of study for the purpose of this thesis, and further justifies the adoption of GloMoSim as the preferred simulator; it also further provides information on the techniques used to reduce the incidence of simulation errors. After some consideration, simulation has been chosen as the method of study for this thesis because when this research began, it was discovered that analytical models with respect to multi-hop MANETs were considerably coarse in nature, rendering them unsuitable as tools for the study of heading angle routing with any reasonable degree of accuracy. It should be noted however that the understanding of multi-hop wireless communications has improved in current years

[91]. Furthermore, since the scope of this study of broadcasting in MANETs involves several mobile nodes, even a moderate deployment of nodes as an experimental test bed could involve substantial and prohibitively expensive costs. As such, simulation has been chosen as it provides a reasonable exchange between the accuracy of observation involved in a test-bed implementation and the insight and holistic understanding provided by analytical modelling.

In order to conduct simulations, the popular GloMoSim (v2.23) [85] is used extensively in this work. The main contenders appeared to be GloMoSim and NS-2 and the drawbacks of the latter have already been documented in section 3.6. GloMoSim provides a scalable simulation environment for large wireless and wired communication networks [85] and is a proven simulation tool that has relatively recently gained popularity within the wireless ad hoc networking community due mainly to the fact that, unlike NS-2 which is more general purpose, it was designed specifically for scalable network simulation within a wireless environment [92, 93]. GloMoSim implements a technique called "node aggregation", where in multiple simulations nodes are multiplexed within a single Parsec entity [86], effectively reducing memory consumption. GloMoSim can simulate networks with up to ten thousand nodes linked by a heterogeneous communications capability that includes multicast, asymmetric communications using direct satellite broadcasts, multi-hop wireless communications using ad hoc networking and traditional Internet protocols. Furthermore, real-life implementations of routing agents such as AODV [20] have been used in some of the simulations conducted in this thesis in order to achieve a close approximation of real system behaviour.

3.11 Summary

This chapter has described mobility models used in MANET performance evaluation, including their types, simulation applications and advantages/disadvantages. The chapter has also briefly described performance evaluation techniques and has provided a justification for using the GloMoSim simulator as the method of study for this research. The comparisons between the simulators has highlighted some quite remarkable differences in the results obtained for similar scenarios and it is therefore difficult to conclude which of the simulators is the closest to reality without comparison with an actual (hardware implemented) MANET. However, GloMoSim provides a built-in implementation of AODV and since most of the work in the thesis centres on new enhancements to the basic AODV protocol, this is of considerable convenience in enabling us to provide an accurate assessment of the performance gain these various enhancements can provide. For example, in chapter 4 we modify the RREP phase in AODV by using the angle direction instead of using the hop count to take the best route from source to the destination and also introduce further modifications that involve both hop count and angle direction, angle direction and hop count and the mean of all angle directions in the route.

It appears that overhead in using the heading angle is linear in node density and so in the subsequent chapters 5 and 6 we modify the RREQ phase by using a new dynamic flooding scheme where the rebroadcasting at the nodes is dynamically adjusted using information related to node density and look at fixed probabilistic schemes with the aim of limiting the overhead as node density increases.

Chapter 4 Angle direction

4.1 Introduction

The ultimate goal of the MANET community is to provide a set of standardised protocols that can be both robust and scalable. Our goal is to investigate a relatively new concept that can be used by MANETs to find a "good" path between a source and a destination. Many different parameters have been used with the most common being the hop count, which is used in both static and dynamic networks. To recap, the term hop count represents the number of hops between nodes traversed by a packet between the source and destination. The smallest possible hop count is called the shortest path. Hop count is usually considered the best parameter to asses a route in a static network. If there are multiple routing paths available, the path with the minimum hop count is selected. The concept we examine in this chapter is the heading angle, defined as the angle of direction of movement of a node from some specified datum.

There are many varieties of ad hoc routing protocols but no matter how different they are, in every routing protocol it is a key common task to find a "good" path between a source and a destination. A big question is: Which path is good enough?

We select the AODV algorithm as a benchmark because this is a well known routing protocol designed specifically for ad hoc mobile networks. AODV is capable of both unicast and multicast routing. It is an on-demand algorithm meaning that it builds routes between nodes only as desired by source nodes. It maintains these routes as long as they are needed by the sources. Furthermore, AODV forms trees, which connect multicast group members. The trees are composed of the group members and the nodes needed to connect the members. AODV uses sequence numbers to ensure the freshness of routes. It is loop free, self-starting and scales to large numbers of mobile nodes.

4.2 Motivation

Surprisingly, the use of the heading angle has not been used to any great extent in current MANET routing protocols, despite the fact that maximising link lifetime would appear to be a crucial factor in ensuring that overhead incurred in re-establishing routes due to link breakages is minimised.

Related work in this context is that which directly or indirectly aims at using the heading angles to form a route that consists of a number of hops between the source and the destination. Because the proposed protocol is based on the heading angle, each node is assumed to be equipped with a digital compass. Moreover, each node classifies its neighbours into eight different zone ranges (d1-d8) according to their direction [94, 95].

Although the use of the RWP mobility model may not be suitable to capture some important mobility characteristics in scenarios in which MANETs can be deployed, it appears to be the most popular method used in MANET performance evaluation, thus giving a wider choice of potential comparisons with existing work than if other mobility models were used. The RWP model will therefore be used throughout. In this context, it should be noted that the randomness of the RWP model, with frequent and possibly abrupt changes in direction, would be likely to cancel out much of the gain that might be achieved compared to using a mobility model in which the directional changes are more incremental and smoother. As such, the use of the RWP mobility model might be viewed as providing a lower bound on any performance gain that might be achieved by the use of the heading angle in forming a route; that is, in most real-world situations the direction of movement would be likely to change less frequently than with the RWP mobility model which may thus result in a more substantial gain in performance over standard AODV than that achieved when using the RWP model [82]. In a similar context, various MANET routing protocols, including DSR, AODV and DSDV, have been evaluated and the results show that the protocol performance may vary drastically across mobility models and performance rankings of protocols may vary with the mobility models used. We therefore consider that it is important to stick with the RWP model in the interests of consistency.

4.3 Angle Direction Algorithms

In choosing the next node in forming a route, the neighbour node with the closest heading angle to that of the node is selected,[96-98] so the connection between the source and the destination consists of a series of nodes that have approximately the same direction (Figure 4.2). Thus, the stability of the link lifetime is considered in the route construction phase by this new concept. Figures 4.1 and 4.2 explain this.

The rationale behind this concept is to maintain the connection between the nodes as long as possible (Figure 4.2). This is in contrast to the hop count method which does not consider the connection lifetime (Figure 4.1).

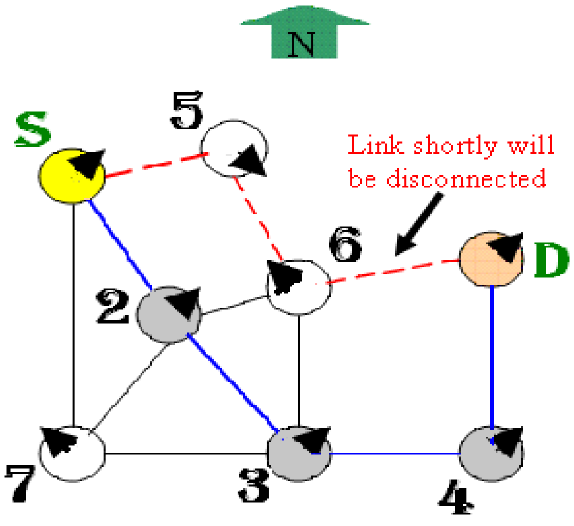


Figure 4.1 Hop count

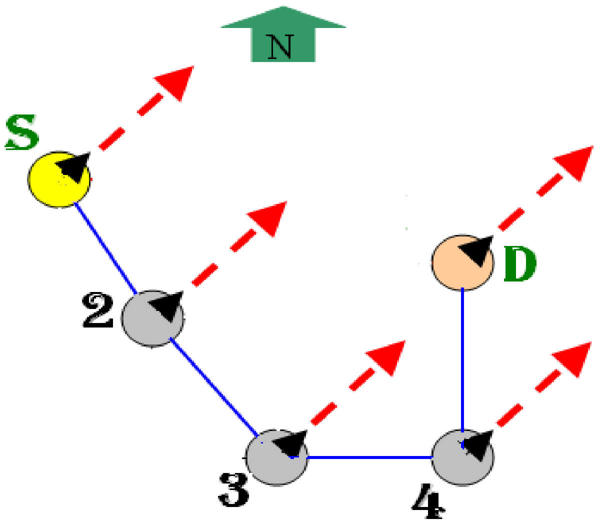


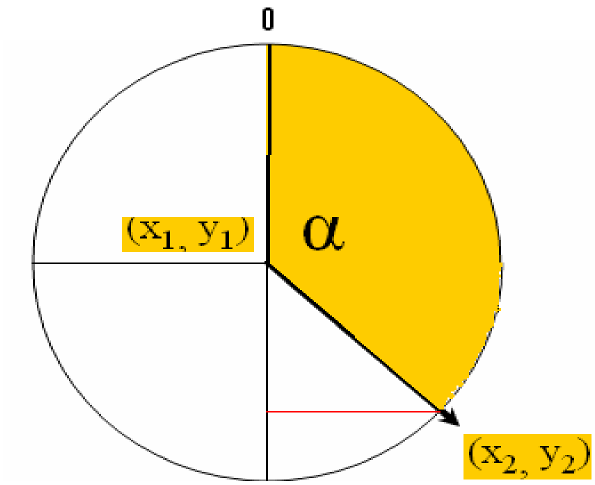
Figure 4.2 Direction angle

In figure 4.1, the series of nodes S, node 5, node 6 and node D represent a minimum hop route between the source and the destination. For forming this route, the hop count is used for routing path construction. The problem here is that since node 6 and node D are diverging, the connection between them will soon break and the route will have to be recomputed causing some disruption and increased overhead.

The series of nodes S, node 2, node 3, node 4 and node D represent the route between the source and the destination obtained using the heading angle. The directions of these nodes are very similar and this gives an expectation that the connection will remain as long as possible (Figure 4.2).

As dynamics cause the current network topology to change, new valid routes must be discovered and maintained in order to forward the packets to the desired destination. Discovering and maintaining these routes can be achieved by flooding specific packets (request packets, etc) through the whole network. The new suggested method can reduce the need for discovering and maintaining new routes, thus also reducing the corresponding overhead. There are varieties of ad hoc routing protocols and, no matter how different they may be, in every routing protocol it is a key common task to find a "good" path between a source and a destination. Evaluation depends on methods or the amount of overhead, such as expected delay or expected lifetime. As a result, we have to find a path that is optimal or at least nearly optimal with respect to the method used.

4.3.1 Calculation of the Node Angle

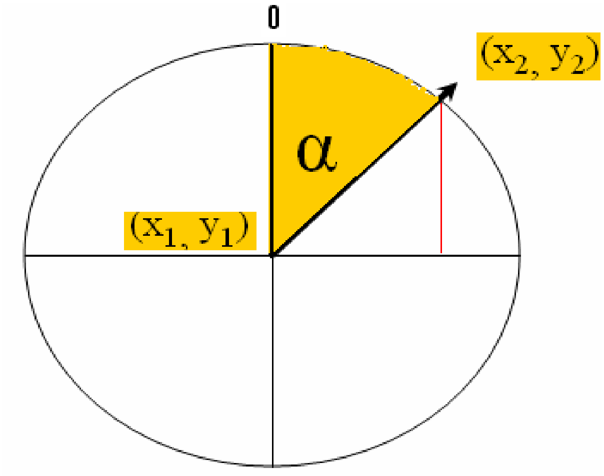


Y=Y2-Y1

X=Y1-Y2

angle=180-atan(y/x)*180/pi

Figure 4.4 Second quadrant

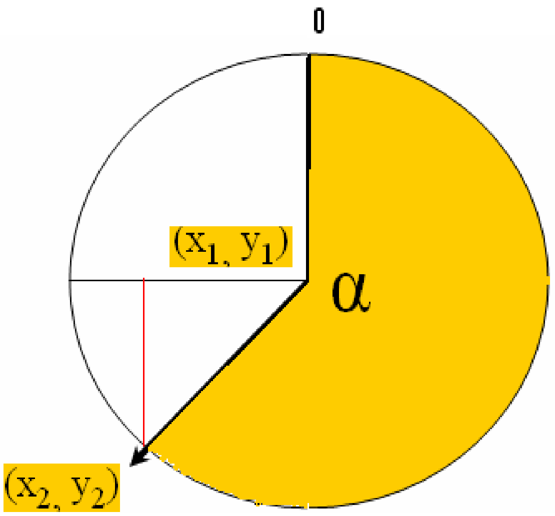


Y=X2-X1

X=X2-X1

angle=90-atan(y/x)*180/pi

Figure 4.3 First quadrant

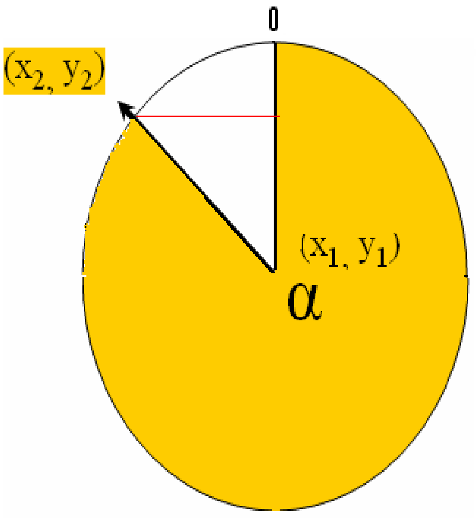


Y=Y1-Y2

X=X1-X2

angle=270-atan(y/x)*180/pi

Figure 4.5 Third quadrant



Y=X1-X2

X=Y2-Y1

angle=360-atan(y/x)*180/pi

Figure 4.6 Fourth quadrant

In the mobility procedure there are four quadrants as shown in figures 4.3, 4.4, 4.5 and 4.6. The algorithm proceeds according to the following steps.

We calculate the heading angle for all nodes depending on the node position and movement from position (x1, y1) to position (x2, y2); figures 4.3, 4.4, 4.5 and 4.6 show angles in different quadrants of the networks

Previous position x1, y1

Current position x2, y2

At the first quadrant

Angle=90-atan ((y2-y1)/(x2-x1)*180/3.14

At the second quadrant

Angle=180-atan ((x2-x1)/(y2-y1)*180/3.14

At the third quadrant

Angle=270-atan ((y1-y2)/(x1-x2)*180/3.14

At the fourth quadrant

Angle=360-atan ((x1-x2)/(y1-y2)*180/3.14

When a node receives a request packet:

Node 1: the sender node

Node 2: the receiver node

Calculate the angle difference between the two nodes

```
  Def=|Node 1 Angle-Node 2 Angle|
  If Def>180
  Angle=360-Def
Otherwise
  Angle=Def;
End if
  Return Angle.
```

4.3.2 Procedure: Handle Request (Angle Processing)

1: If packet is received for the first time

2: If the route is new add it to the routing table

3: Or else check if the angle of the last node is better than the angle in the table

Procedure: handle reply

1: If the new route (new angle) is better than the available route (current angle) update the routing table

2: After selecting the lowest angle difference, then we send the data to the corresponding node.

4.4 Performance Analysis

In this section, we evaluate the performance of the proposed angle direction algorithm and compare the algorithm with the basic AODV algorithm. We implement the proposed algorithm embedded in the AODV protocol, as previously explained. The metrics for comparison include the average number of collisions and the number of broken links.

4.5 Simulation Scenarios and Configuration

The well-known network simulator GloMoSim (version 2.03) is adopted to conduct the simulation experiments. This section will present the experimental scenarios and explain how the simulation parameters are configured. The simulation scenarios studied in this research are designed to investigate the performance of the routing protocols in MANETs under a range of conditions. We study the performance comparison using the hop count approach; that is, the AODV protocol [19, 20], which is included in the GloMoSim package. The original AODV protocol uses hop count for discovering and maintaining routes between source and destination nodes. We thus implement AODV additionally using angle direction, called EAODV (Enhanced AODV), the enhancement by using the heading angle. In our simulation, we use a 1000 m×1000 m area using the RWP mobility model with different numbers of mobile hosts. The network bandwidth is 2 Mbps and the Medium Access Control (MAC) layer protocol is IEEE 802.11. Other simulation parameters are shown in Table 4.1

Table 4.1 Summary of the parameters used in the simulation experiments

Parameter	**Value**
Network range	**1000 m×1000 m**
Transmission range	**250 m**
Number of mobile nodes	**100**
Number of connections	**40**
Bandwidth	**2 Mbps**
Traffic type	**Constant bit rate (CBR)**
Packets per unit time	**(50, 100, 150)**
Packet size	**512 bytes**
Simulation time	**900s**
Speed	**5, 7.5, 10 (m/s)**

The main idea behind the proposed approach is to reduce the number of broken links in the route discovery phase, thus reducing the network traffic and decreasing the probability of channel contention and packet collision. Since our algorithm is based on an angle approach, it may, of course, not fit every scenario.

4.5.1 Broken Links

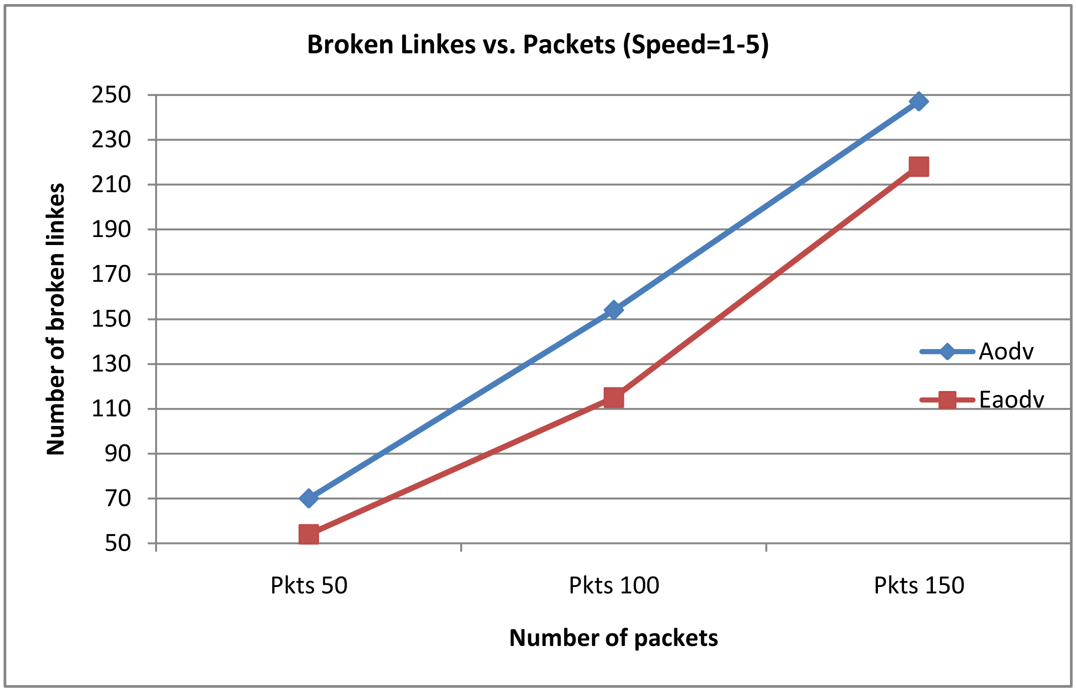


Figure 4.7 Broken links versus packets

Figure 4.7 shows that our improved algorithm can significantly reduce the number of broken links for a network of 100 nodes and a varying number of packets.

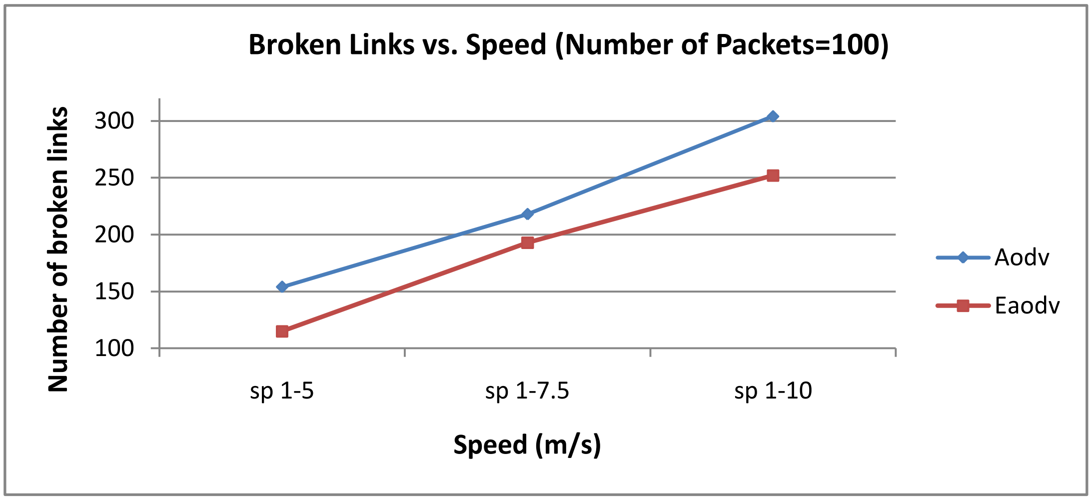


Figure 4.8 Broken links versus speed

Figure 4.8 illustrates the improvement in reducing the number of broken links when the EAODV is used with 100 nodes moving at different speeds.

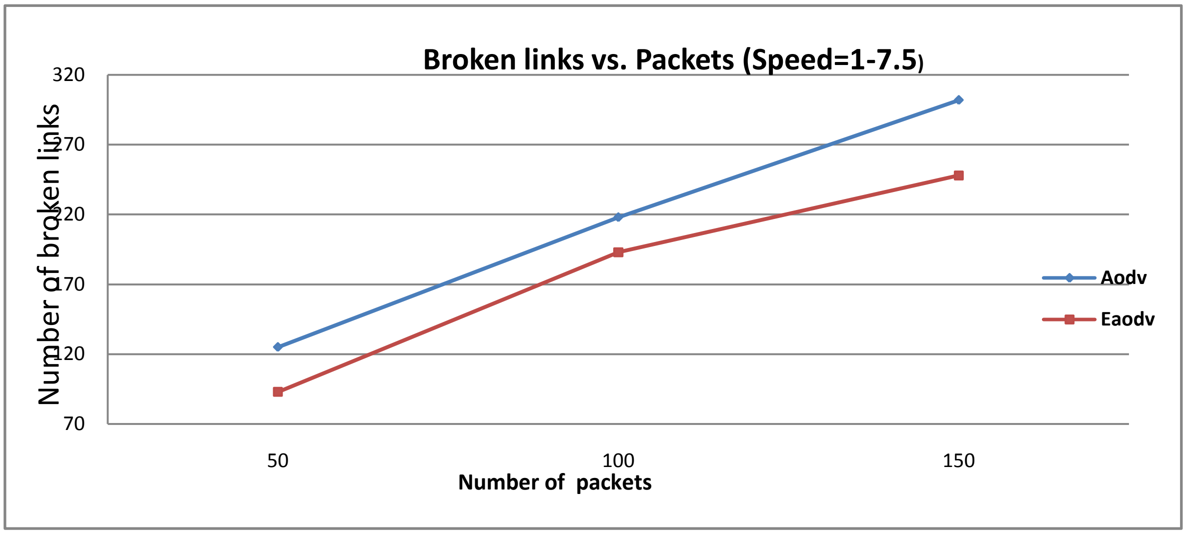


Figure 4.9 Broken links versus packets

Figure 4.9 shows the relationship between the numbers of broken links and different numbers of packets for a network with 100 nodes and (1-7.5) m/s maximum speed. As shown in the figure, the proposed algorithm has achieved fewer numbers of broken links than AODV. It also shows the number of broken links increasing when the number of packets increases, which is expected behaviour.

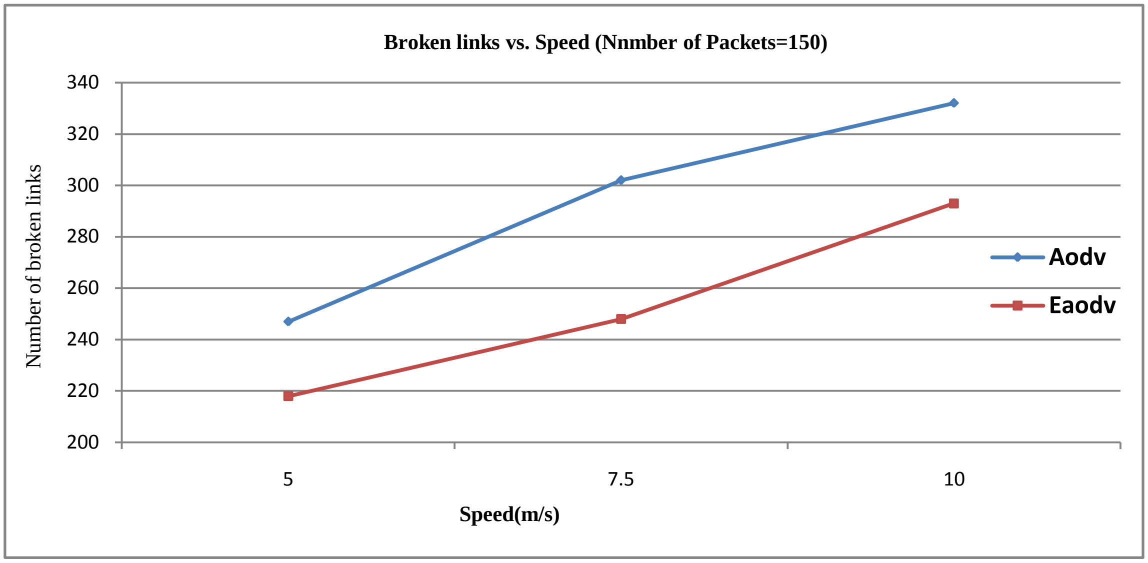


Figure 4.10 Broken links versus speed

Figure 4.10 shows the relationship between the numbers of broken links and different degrees of mobility (speed) for a network with 100 nodes and 150 packets. As shown in the figure, the proposed algorithm has achieved fewer of broken links than AODV. It also shows the number of broken links increasing when the speed increases. This is most likely due to the greater distances covered by the nodes in the same time period at higher speeds, thus giving more pronounced changes in the relative positions of the nodes than at lower speeds and so resulting in nodes moving out of range more quickly with subsequent link breakages increasing.

4.5.2 Collisions

We also measure the number of collisions at the physical layer for these schemes. Since data packets and control packets share the same physical channel, the collision probability is high when there are a large number of control packets.

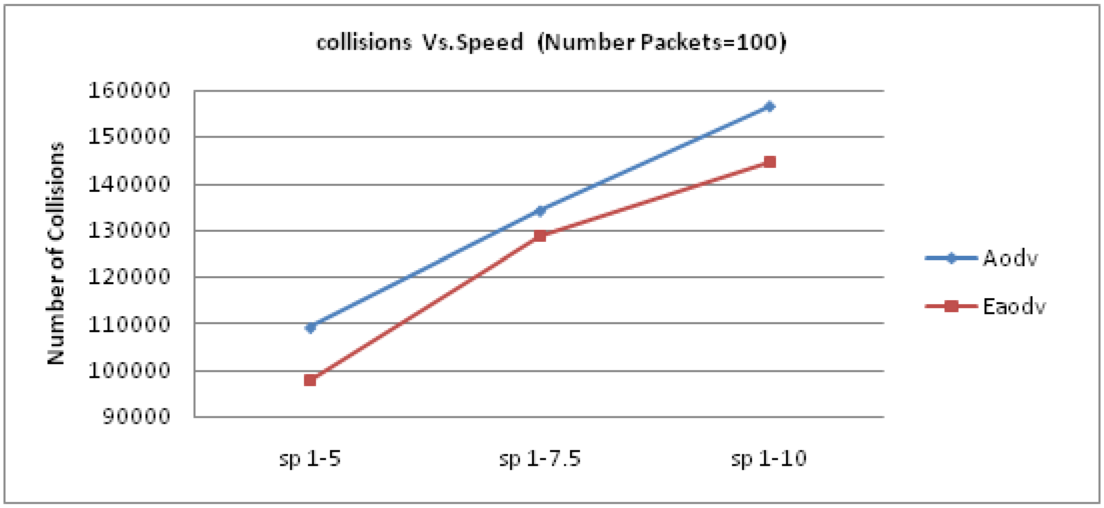


Figure 4.11 Collisions versus speed

Fig. 4.11 shows the number of collisions for networks with 100 nodes, 100 packets and different speeds. As shown in Figure 4.11 our algorithm incurs fewer collisions than AODV and although the number of collisions increases with speed as expected, the improvement over AODV is not significantly affected by speed.

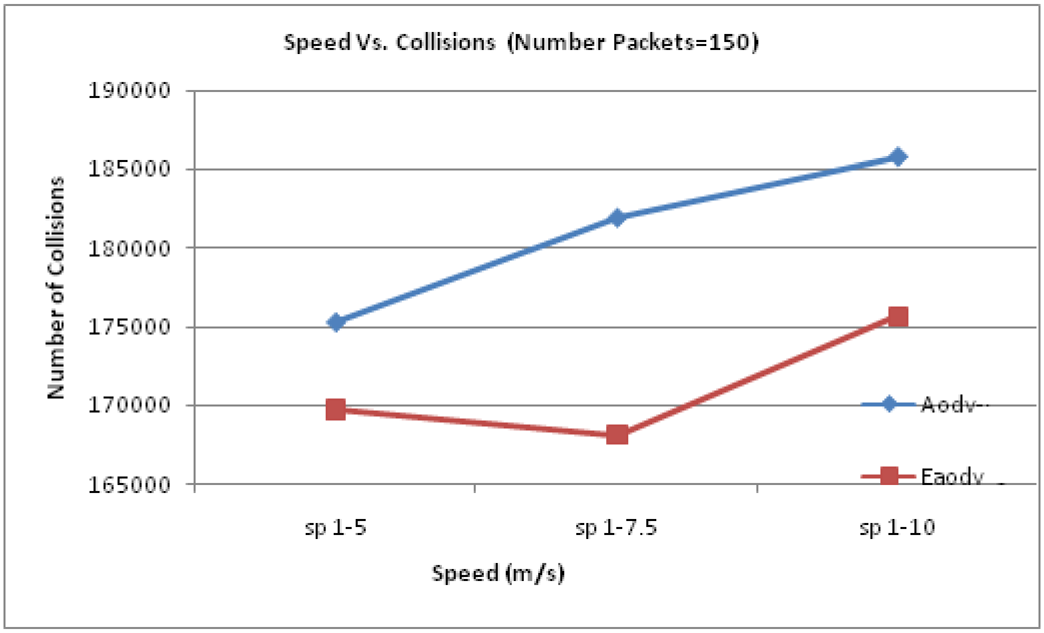


Figure 4.12 Collisions versus speed

Figure 4.12 shows the number of collisions for a network with 100 nodes, 150 packets and different speeds. There are now more collisions with a larger number of packets and this result is obviously expected because of the larger number of simultaneous transmissions taking place. However the improvement over AODV in reducing collisions is not more significant with a larger number of packets, although the greater divergence at speeds of 1-7.5 m/s than at the other speeds is unexpected and somewhat difficult to explain but may be due to the specific combination of the settings of the various parameters at this speed range rather than any specific single factor.

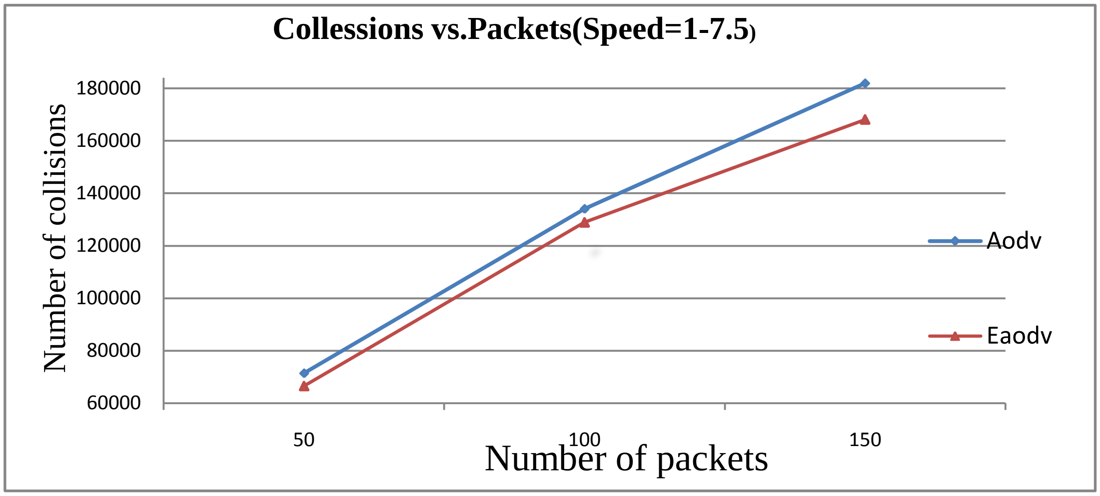


Figure 4.13 Collisions versus packets

Figure 4.13 shows the proposed algorithm (EAODV) incurs fewer collisions than simple AODV. It also shows the number of collisions increasing as number of packets (packet transmission rate) increases. This is because when the number of packets increases; more route requests are generated, leading to more collisions as a result of the increase in control packets.

4.5.3 RREQs

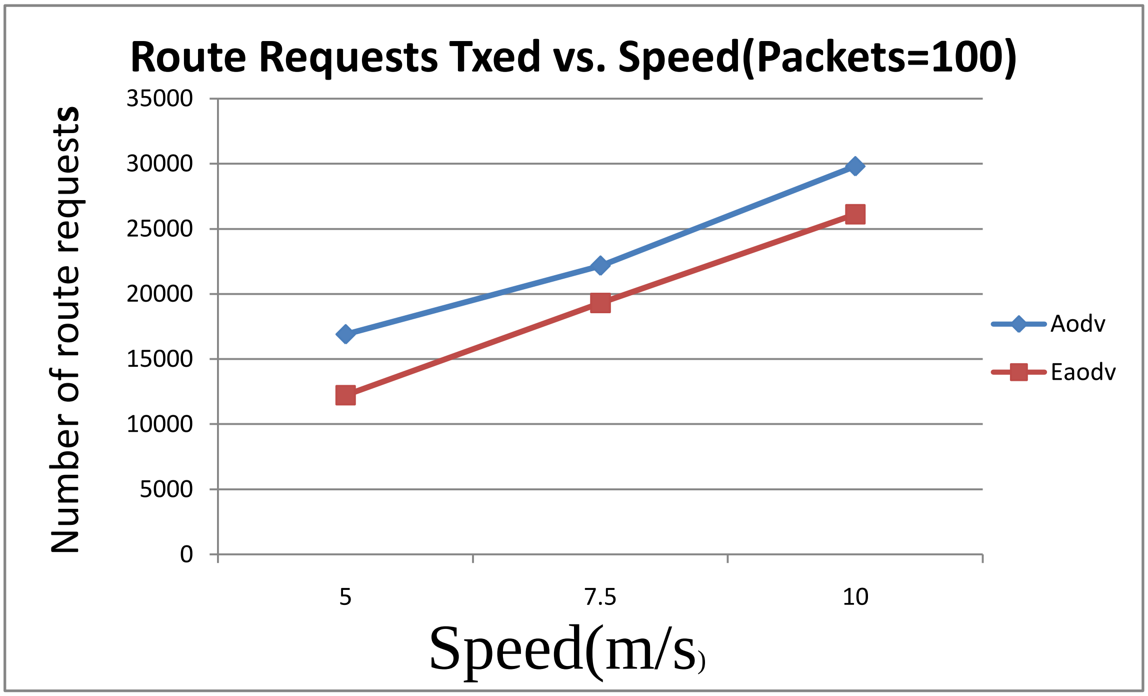


Figure 4.14 Route requests txed versus speed

The main aim of the EAODV algorithm is to decrease the number of broken links in the transmission phase during the simulation time for all nodes. Figure 4.8 and Figure 4.9 show that the EAODV algorithm can significantly reduce the number of broken links for the network with various speeds (5, 7.5 and 10 m/s) and different numbers of packets sent to the destinations (50, 100 and 150 packets). As a result of reducing the broken links the collisions and the number of RREQs are reduced too. Figure 4.14 shows the results for this latter performance measure, with different speeds.

4.6 Conclusions

This section has presented an angle direction approach to routing for MANETs. The proposed algorithm calculates the heading angle direction for every neighbour node and selects the neighbour with the lowest difference between the heading angle and the host. The simulation results demonstrate that this approach can generate fewer broken links than the AODV. It also results in fewer collisions than the existing AODV approach. Performance improvements are obtained for all the scenarios tested and greater improvements might be expected in many real life scenarios because of the suggested lower bound feature of the RWP model.

These improvements, as with most routing algorithms when a new feature is introduced, come at a cost of an increase in overhead. Because each node is assumed to be equipped with a digital compass, then a node's heading angle would be available to the node directly at any time. Any node that wishes to make a transmission would therefore need to broadcast a request for the current heading angle of each of its neighbour nodes. Each neighbour would therefore respond by sending a packet indicating its heading angle. The number of additional control packets required would therefore depend on the node density, with the overhead generally increasing linearly with node density. A simple calculation to identify the neighbour node with the least difference in heading angle to the host would then be required. Because these overhead increases are linear with node density, it is suggested that they should be comfortably scalable. This also would indicate that overhead limitation as node density increases might be a useful avenue to explore and so this is addressed in the next chapter.

4.7 Modified EAODV Algorithms

In this section we propose some modifications of EAODV that can find a suitable path between source and destination using both angle direction and hop count. Firstly, we consider that if there are multiple routing paths available the path with the minimum hop count is selected and when the hop counts are the same the path with the best angle direction is selected. Secondly, if there are many routing paths available the paths with the best angle direction are chosen such that when the angles are classed as the same (within the same segment) the path with minimum hop count is chosen. Thirdly, if there is more than one path available, we calculate the average of all heading direction angles in every path and find the best one (lowest average) from the source to the destination. We evaluate our proposed approaches with respect to the simple AODV hop count approach by implementing the described modified versions of the EAODV protocol.

4.7.1 First Suggested Method:

Figure 4.15 explains the first suggested method.[99] The source node S1, node 2, node3 and node D4 represent a minimum hop count route between the source S and the destination D. In the normal AODV the protocol ignores any new route with the same or more hops. The first modified method if the new route has the same number of hops the protocol compares the new route angle with the old route angle and if it is in a direction similar to that of the source angle the protocol takes the new route. If it is in a direction worse than the old one it is ignored. In Figure 4.15 node S1, node 5, node 6 and node D4 represent a route between the source and the destination. To form this route, the directions of these nodes are the same or almost the same. This method gives an expectation that the connection will remain as long as possible.

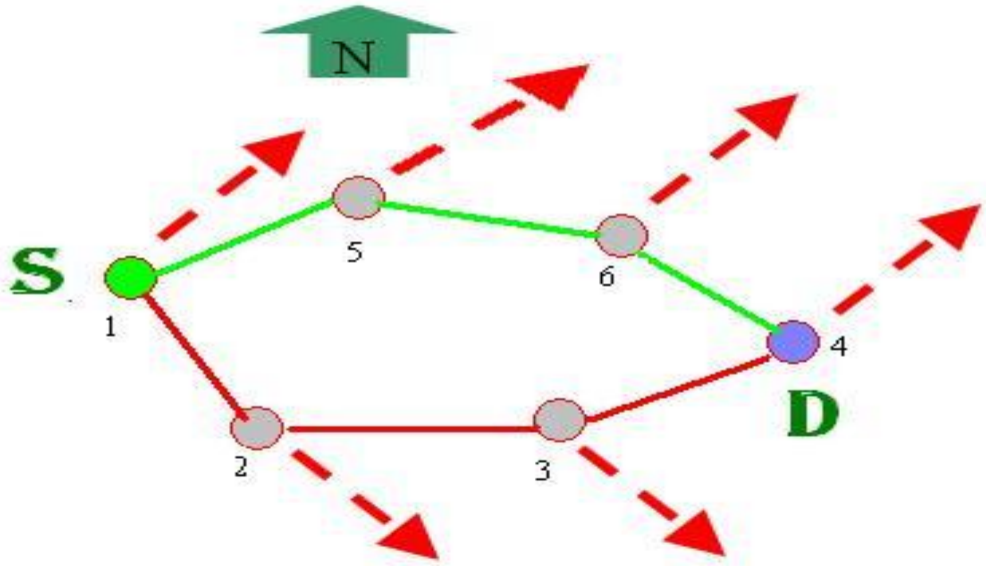


Figure 4.15 Hop count and direction angle

The algorithm proceeds according to the following steps.

1- Calculate the heading angle for all nodes in the network.

Calculate the least hop count route between the source and the destination.

2- If the new route has the same number of hops, compare the angles and if the new route angle is better than the available angle (current angle) update the routing table.

Calculate the angle between the two nodes:

Node 1: the sender node

Node 2: the receiver node

Def=|Node 1 Angle-Node 2 Angle|

```
        If Def>180
    Angle=360-Def
        Else
    Angle=def
        End if
        Return Angle
```

3- Check if the angle of the last node is better than the angle in the table.

4- Select the node with the lowest node angle difference to the source angle.

4.7.2 Second Suggested Method

Figure 4.16 explains the second suggested method [99] .The source node S1, node 2, node 3, node 4 and node D7 represent the best route based on the angles between the source S and the destination D. In our suggested method, if the new route has the same angle for the first hop (the angles fall within the same segment considered) the protocol compares the new route’s number of hops with the old route’s number of hops and if there are fewer new route hops the protocol takes the new route. If not the route is ignored. In Figure 4.16 the new route is node S1, node 5, node 6 and node D7.

The algorithm proceeds according to the following steps.

1- Calculate the heading angle for all nodes in the network.

2- Calculate the route with the least difference in the heading angle between the source and the destination.

3- If the new route has the same angle compare the number of hops and if the new route number of hops is less than current route number of hops, update the routing table and take the new route.

Or else ignore the new route.

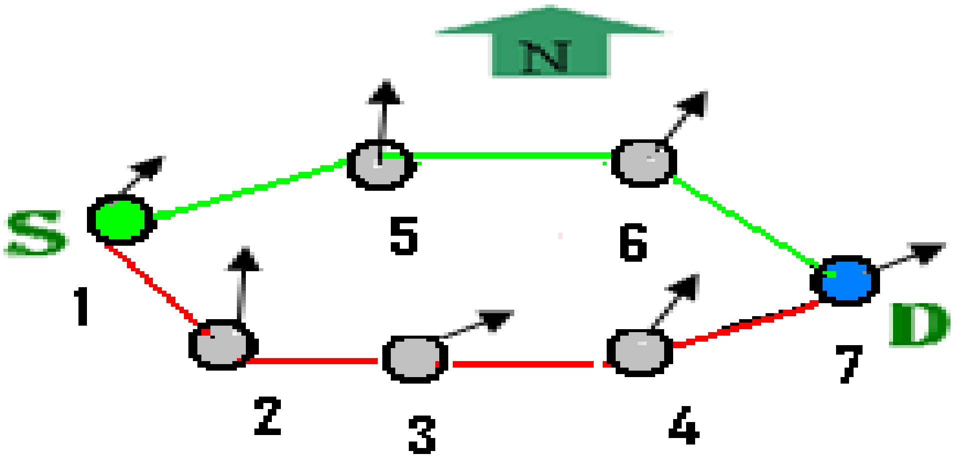


Figure 4.16: Direction angle and hop count

4.7.3 Third Suggested Method

Figure 4.17 explains the third suggested method [100]. If there is more than one path available the average of all the heading direction angles in every path is calculated and the best average from the source to the destination is found. In the figure we can compare the paths, node S1, node 2, node 3, node 4 and node D5, and path from node S1 through node 6, node 7, node 8 and node D5.

The algorithm proceeds according to the following steps.

1- Calculate the heading angle for all nodes in the network.

2- Calculate the average of all heading direction angles in every path and take the best average from all routes between the source and the destination.

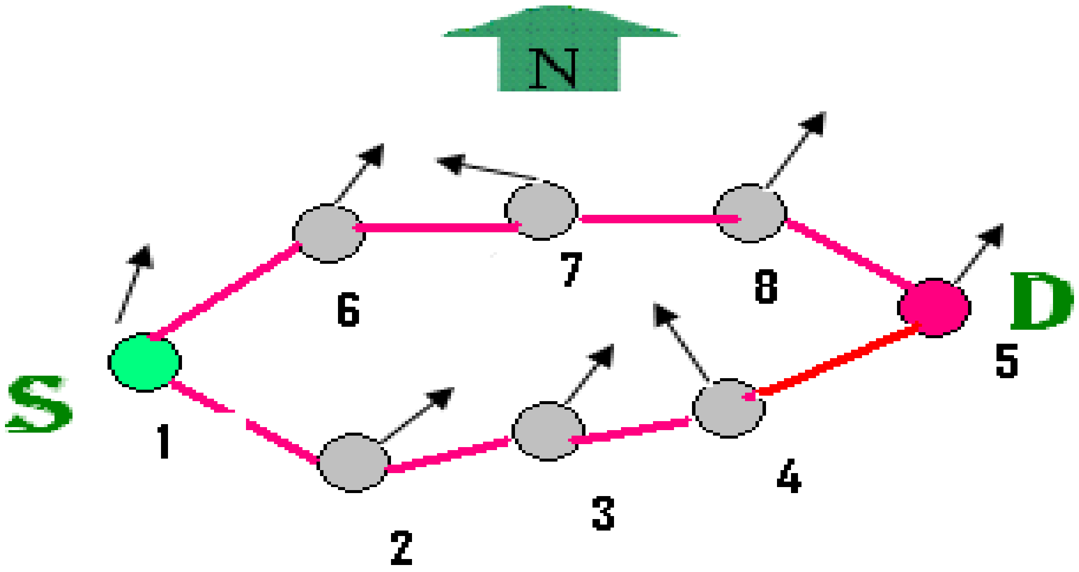


Figure 4.17 Mean of all direction angles in the route.

4.8 Performance Analysis

We evaluate our proposed algorithms by a comparison with the AODV protocol.

4.9 Simulation Setup

We use the GloMoSim network simulator (version 2.03) to conduct extensive experiments to evaluate the behaviour of the proposed algorithm. We study the performance comparison with the hop count approach, that is the AODV protocol [19, 20], which is included in the GloMoSim package. The MAC layer protocol is IEEE

802.11. The original AODV protocol uses hop count for discovering and maintaining routes between source and destination nodes. We thus implement AODV additionally using angle direction; we use a 1000 m×1000 m area and the parameters used in the simulation experiments are shown in Table 4.2.

4.10 Parameters

Table 4.2 Simulation parameters

Simulation Parameter	**Value**
Simulator	**GloMoSim v2.03**
Network Range	**1000 mx1000 m**
Transmission Range	**250 m**
No. of Connections	**40**
Mobile Nodes	**100,120,140**
Traffic Generator	**Constant Bit Rate(CBR)**
Bandwidth	**2 Mbps**
Packet Size	**512 bytes**
Simulation Time	**900s**
Speed	**30(m/s)**
No. of Packets	**25, 50, 75, 100**

4.10.1 Collisions

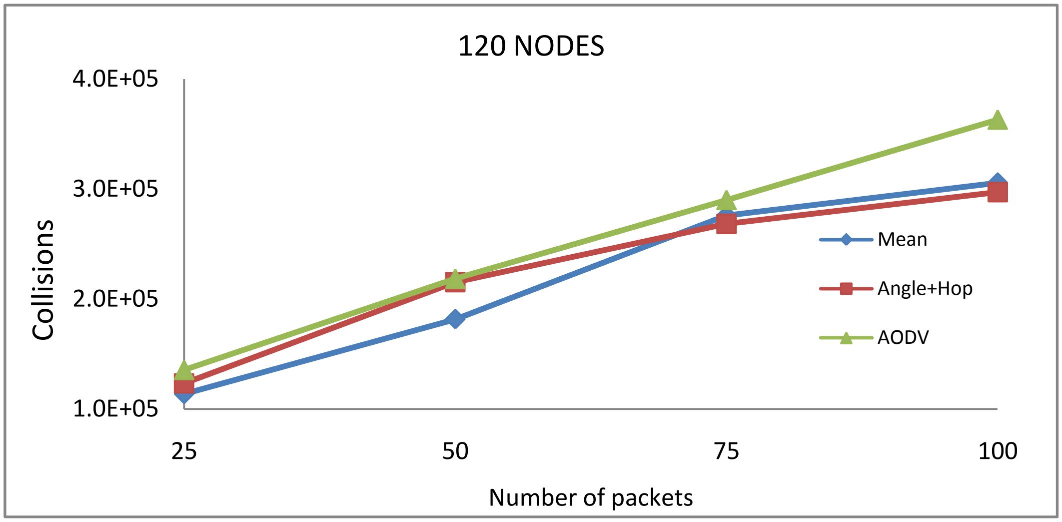


Figure 4.18 Collisions versus packets

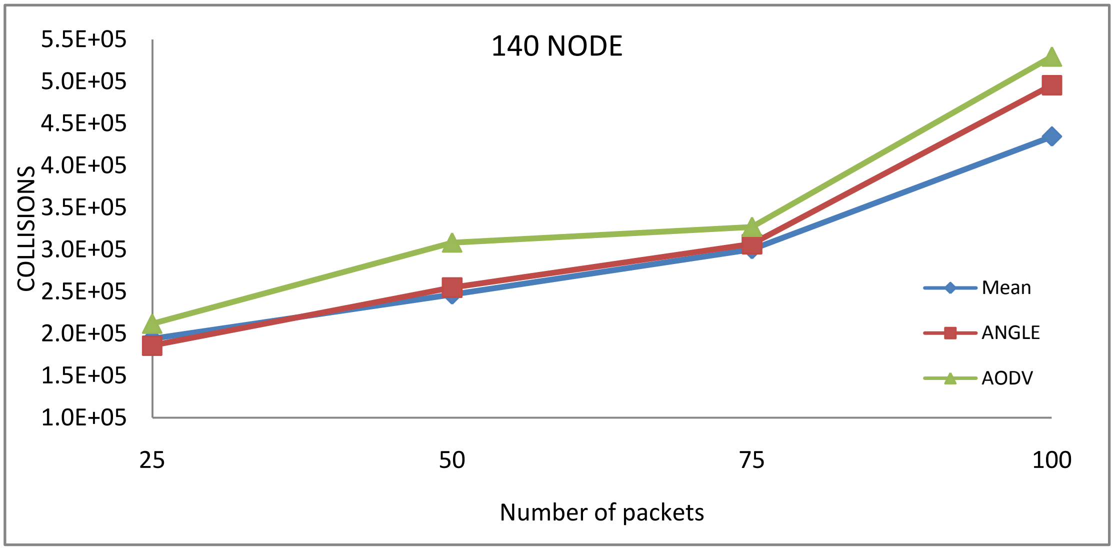


Figure 4.19 Number of collisions versus packets

Figures 4.18 and 4.19 show the number of collisions for networks with 120 and 140 nodes and different numbers of packets (25, 50, 75 and 100). In such cases, more route requests are generated, leading to more collisions as a result of the increasing number of control packets. It is evident that the proposed algorithms all incur a lower number of collisions than AODV.

4.10.2 Broken Links

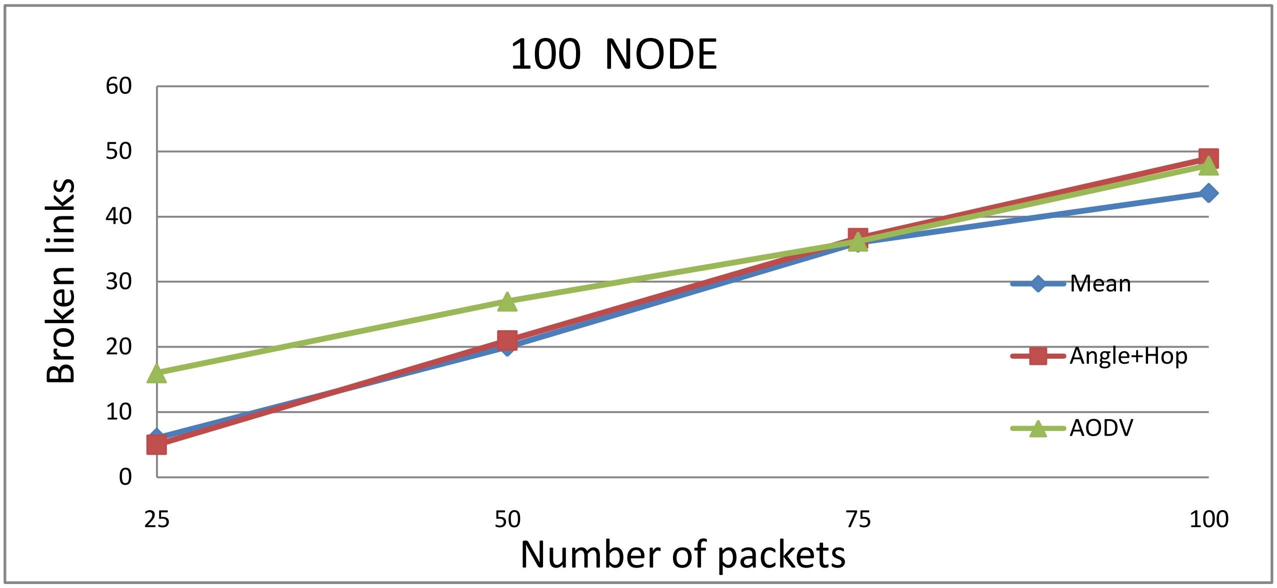
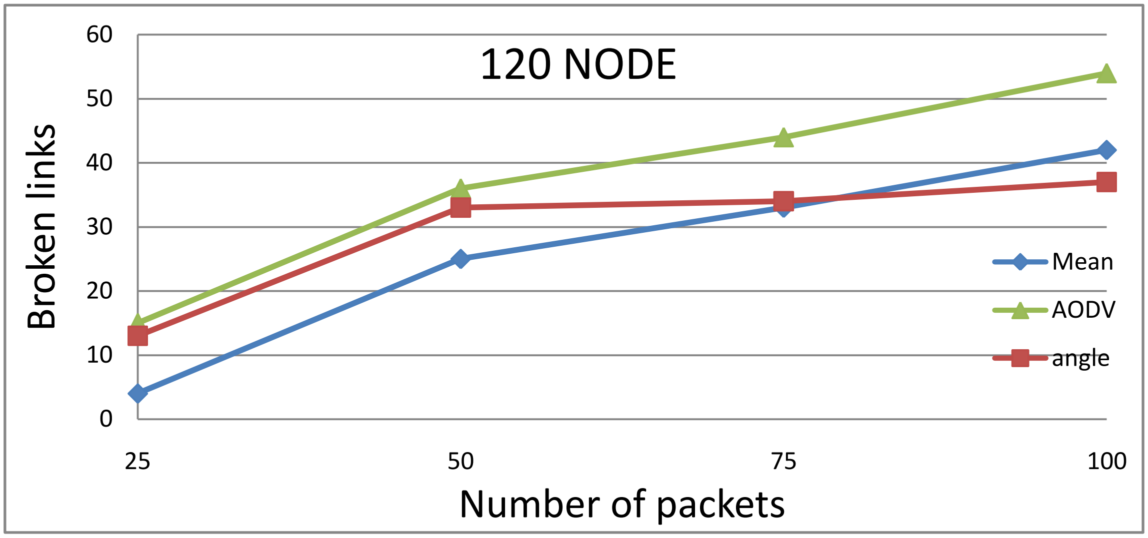
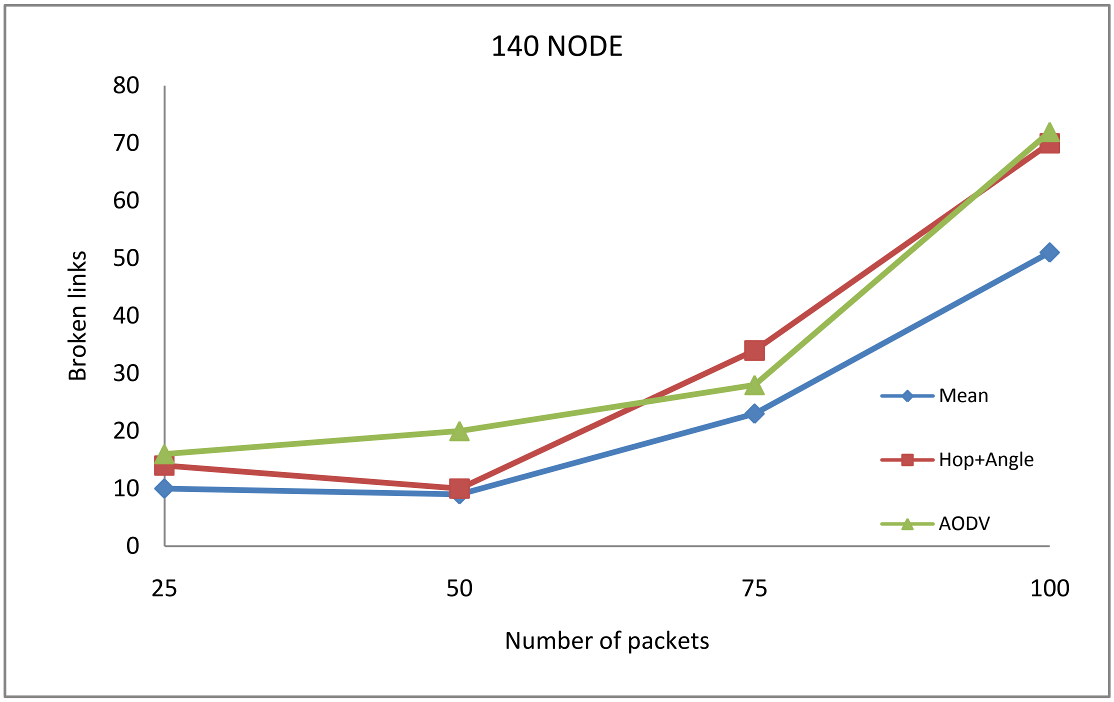


Figure 4.20 Broken links versus packets



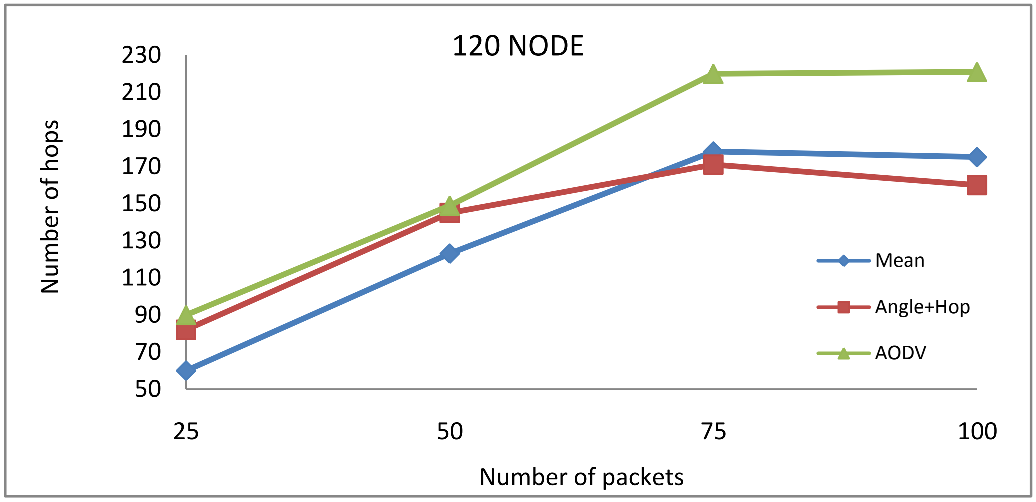
4.21 Broken links versus packets



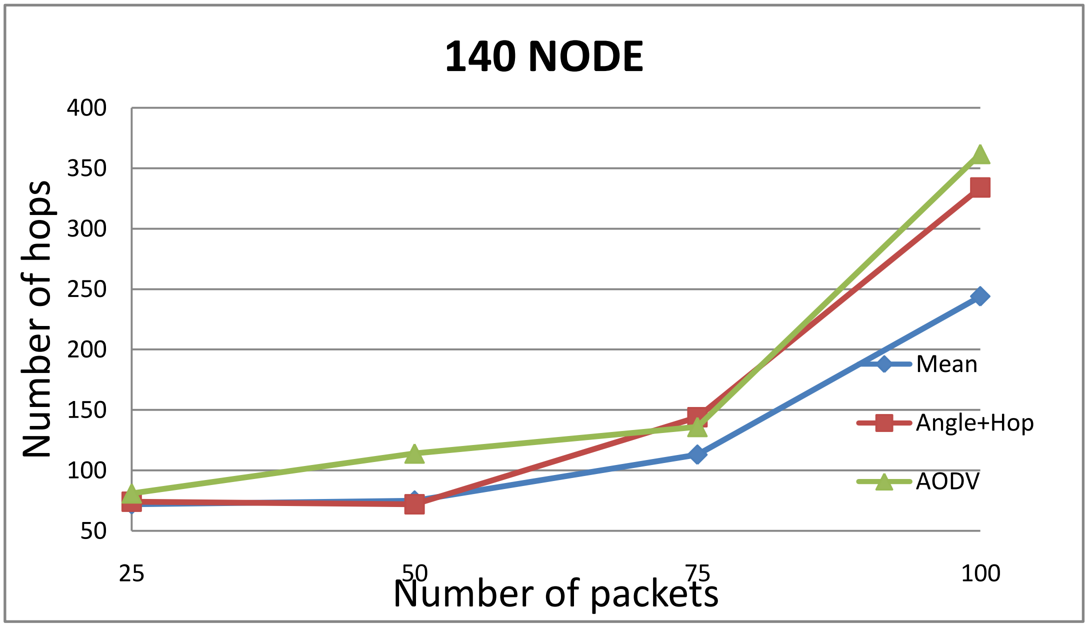
4.22 Broken links versus packets

Figures 4.20, 4.21 and 4.22 show that the modified algorithms can significantly reduce the number of broken links for networks of 100, 120 and 140 nodes and varying numbers of packets. Generally speaking, the method based on the mean of the angle directions gives the lowest broken links, with the performance difference becoming more significant as the number of packets increases. This could possibly be due to the RWP mobility model which, as its name implies, changes direction in a random fashion. Thus, because of the frequent changes in direction, this is not likely to result in much improvement for a protocol that tracks each change. Using the mean of heading angles would tend to give a better indication of the general trend in direction of the nodes involved which clearly gives a better result. How much better is likely to depend on multiple factors, such as the segment size used to classify the angle directions (resolution), with a smaller segment size (better resolution) possibly giving a better result at a cost of increased overhead. Another factor which might have a bearing on this is the length of the route, with shorter routes giving a better result for the mean of the heading angles due to the random changes in direction tending to cancel each other out when averaged over many hops and thus nullify any indications of a general trend in direction.

4.10.3 Number of Hops



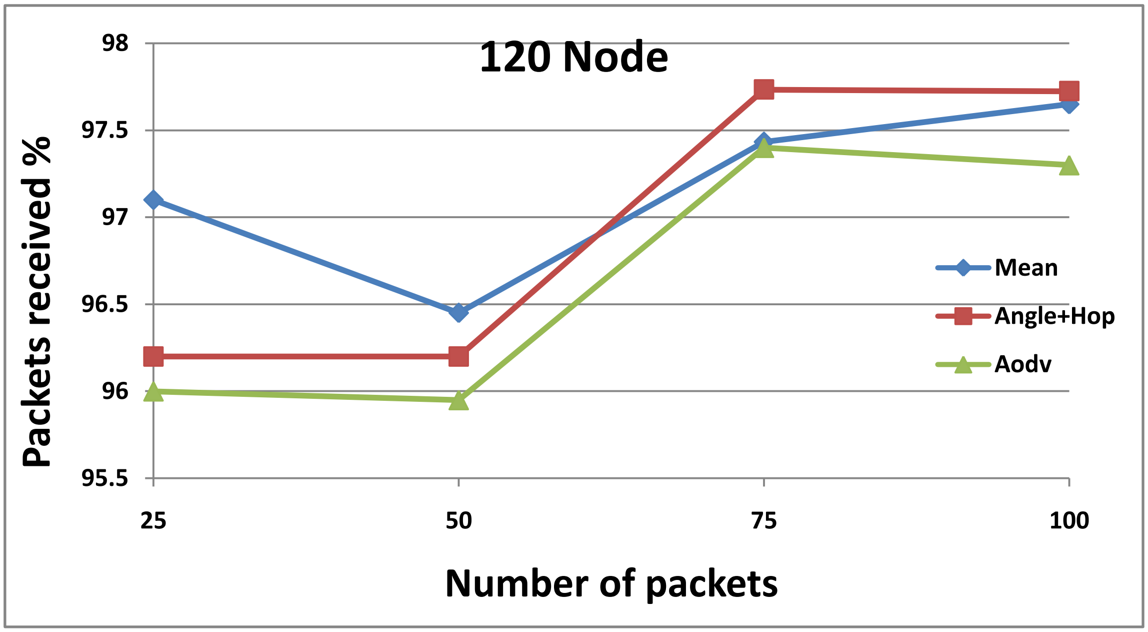
4.23 Number of hops versus packets



4.24 Number of hops versus packets

Figures 4.23 and 4.24 show the number of hops for a network with 120 and 140 nodes and 25, 50, 75 and 100 packets. The improvement in reducing hops is now more significant with a large number of packets and this again specifically applies to the algorithm based on the mean of the angles, which tends to establish routes having fewer hops. This also supports the conclusion drawn at the end of the previous section that shorter routes are likely to give a better result for the algorithm based on the mean of the angles. The better results are likely to be a consequence of the lower overhead due to fewer routes having to be re-established when using the mean of the angles. Packets therefore don't waste so many hops due to routes breaking down before the packets reach their destinations.

4.10.4 Packets Received



4.25 Percentage of packets received versus packets

Figure 4.25 shows the percentage of packets received for a network with 120 nodes and 25, 50, 75, and 100 packets. The improvement over AODV in the percentage received is more significant with a small number of packets, although the absolute number of packets received increases for all algorithms with a larger number of packets, as expected. The diminishing percentage improvement as the number of packets increases is likely due to the corresponding increase in broken links and collisions, which are likely to make the improvements self limiting, thus reducing the percentage.

4.11 Summary

New algorithms have been presented for routing in MANETs using the heading angle direction+hop counts, hop counts+angle direction and the mean of all angle directions in the route. The simulation results show the new algorithms generally generate a smaller number of broken links, smaller number of hops and fewer collisions than the AODV protocol.

Although the results show improved preference for the presented algorithms over AODV, in some cases the improvements are not that significant. This is again very likely due to the mobility model used (RWP) which causes the nodes to frequently change direction in a random way, which to some extent nullifies the effects of using the heading angle. A mobility model that moves in the same direction for longer periods, such as the Manhattan model, is likely to give better results. Because, the Manhattan mobility model is proposed to model movement in an urban area, a mobile node is allowed to move along the horizontal or vertical streets on the urban map. At a junction of a horizontal and a vertical street, the mobile node can turn left or right or go straight ahead. The probability of moving on the same street is 0.5, the probability of turning left is 0.25 and the probability of turning right is 0.25. The speed of a mobile node at a time period is dependent on its speed at the previous time period. Also a node's speed is restricted by the speed of the node preceding it on the same lane of the street.

Such models would thus be more representative than the RWP model to represent vehicles moving in an urban area and thus be more realistic for this and similar situations. In some respects, therefore, this supports the previous suggestion that of all the mobility models that might be used, the RWP model is the most likely to give a lower bound on the performance of protocols based on the heading angle. It is therefore argued that a model that gives a lower bound, which is the equivalent of giving the least amount of improvement in the context of using the heading angle over protocols that don't use the heading angle, is far better than using some other model such as the Manhattan model, that would be biased towards a specific scenario or situation. It is therefore suggested that the performance gains achieved by our algorithms are the least that might be expected and we may look forward to more significant improvements than those indicated in many real world situations.

As discussed at the end of section 4.6, the overhead involved using the heading angle increases linearly with node density. In the next chapter we therefore propose to examine ways to limit this overhead by developing features that can be incorporated in the AODV protocol to take account of node density.

Chapter 5 Node density

5.1 Introduction

Network-wide dissemination is used widely in MANETs [101, 102] for the process of route invention, address resolution and other network-layer tasks. For example, on-demand routing protocols such as AODV [19, 20] and DSR use broadcast information in route-request packets to construct routing tables at every mobile node. The dynamic nature of MANETs, however, requires routing protocols to refresh routing tables regularly, which could generate a large number of broadcast packets at different nodes. Since not every node in a MANET can communicate directly with nodes outside its communication range, a broadcast packet may have to be rebroadcast several times at relaying nodes in order to guarantee that the packet can reach all nodes. Consequently, an inefficient broadcast approach may generate many redundant rebroadcast packets [103].

There are many proposed approaches for dissemination in MANETs. The simplest one is flooding. In this technique, each mobile host rebroadcasts the broadcast packets when they are received for the first time. Packets that have already been received are just discarded. Though flooding is simple, it consumes many network resources as it introduces a large number of duplicate messages. It leads to serious redundancy, contention and collision in mobile wireless networks, commonly referred to as the broadcast storm problem.

In the last chapter, it was indicated that the use of the heading angle is achieved at the cost of a linear increase in overhead (control packets) with node density. Thus limiting overhead as node density increases is likely to be a useful avenue to explore. In order to enhance the performance of dynamic routing protocols, a dynamic broadcast approach is therefore proposed that can efficiently reduce broadcast redundancy in mobile wireless networks. The proposed algorithm dynamically calculates the host rebroadcast packets according to the information about the number of neighbouring nodes. The rebroadcast would be when the number of neighbouring nodes is high; that is, the host is in a dense area, and no rebroadcast would be when the number of neighbouring nodes is low, that is the host is in a sparse area.

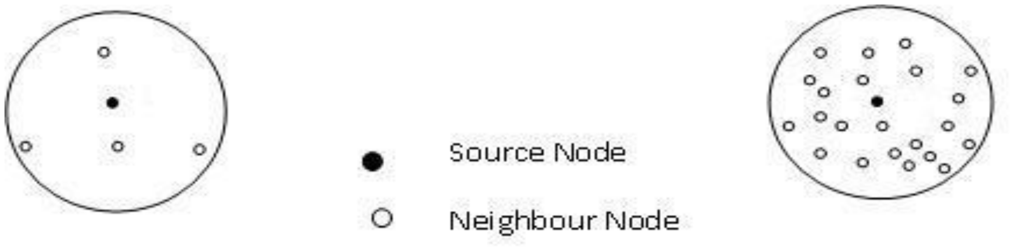
The remainder of this chapter is organised as follows. Section 5.2 presents the ideas and algorithm of the dynamic flooding scheme. Section 5.3 describes the experimental scenarios and the setting of simulation parameters. Section 5.4 presents and analyses the performance results obtained from simulation experiments. Finally, section 5.5 summarises this chapter.

5.2 Proposed Broadcasting Scheme

As explained above, traditional flooding [104] suffers from the problem of redundant message reception. The same message is received multiple times by every node, which is inefficient, wastes valuable resources and can cause high contention in the transmission medium.

In dense networks, multiple nodes share similar transmission ranges. Therefore, this algorithm controls the number of rebroadcasts and might thus save network resources without affecting delivery ratios. Note that in sparse networks there is substantially less shared coverage; thus some nodes will not receive all the broadcast packets.

The proposed algorithm dynamically calculates the number of its neighbouring nodes.



B. Dense Region

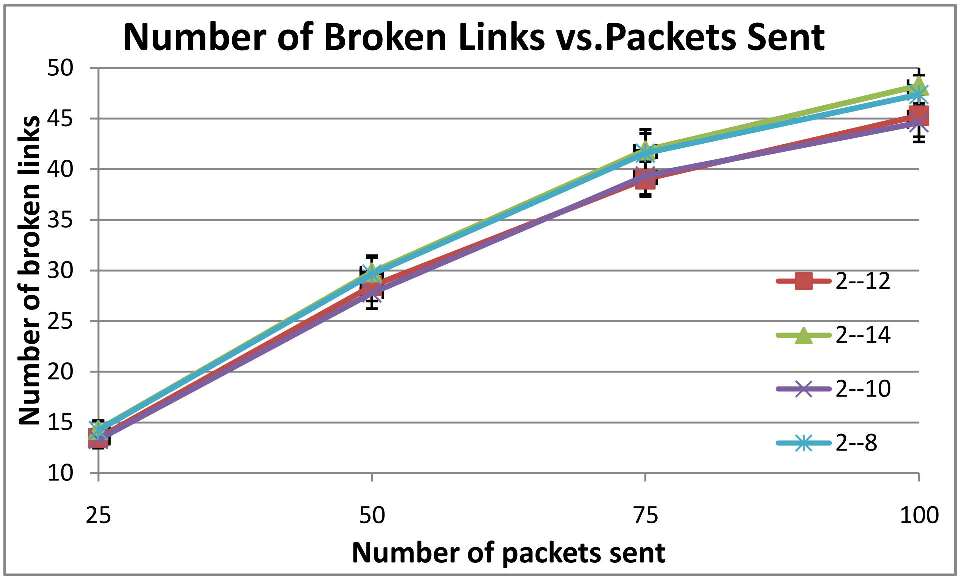
A. Sparse Region

Figure 5.1 A. sparse region and B. dense region

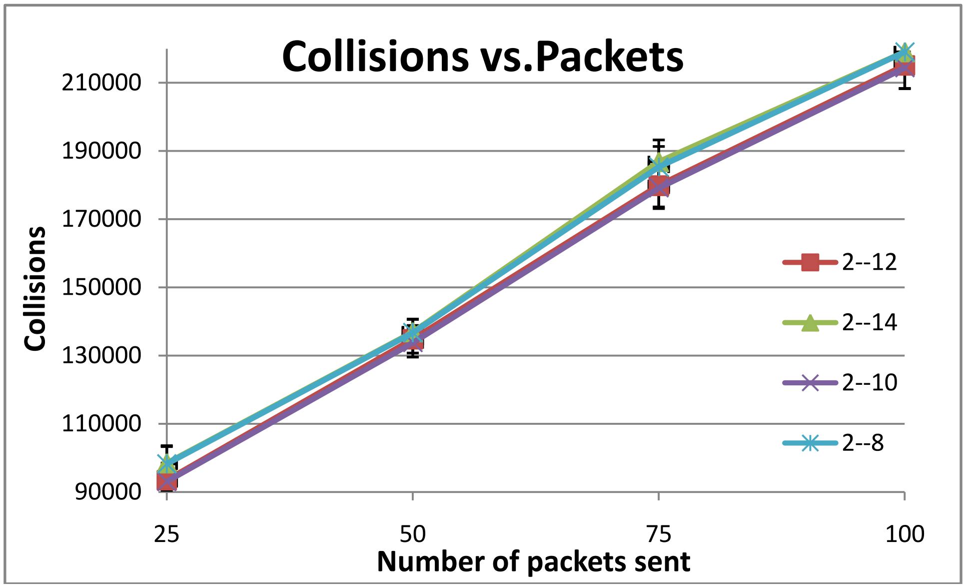
The neighbour table, nbrTable(i), for the ith node is formed by sending periodic HELLO packets and entries in the table are updated based on replies received from the neighbours which are expressed by the following inequality:

$$N\ min < nbrTable(i) < N\ max$$

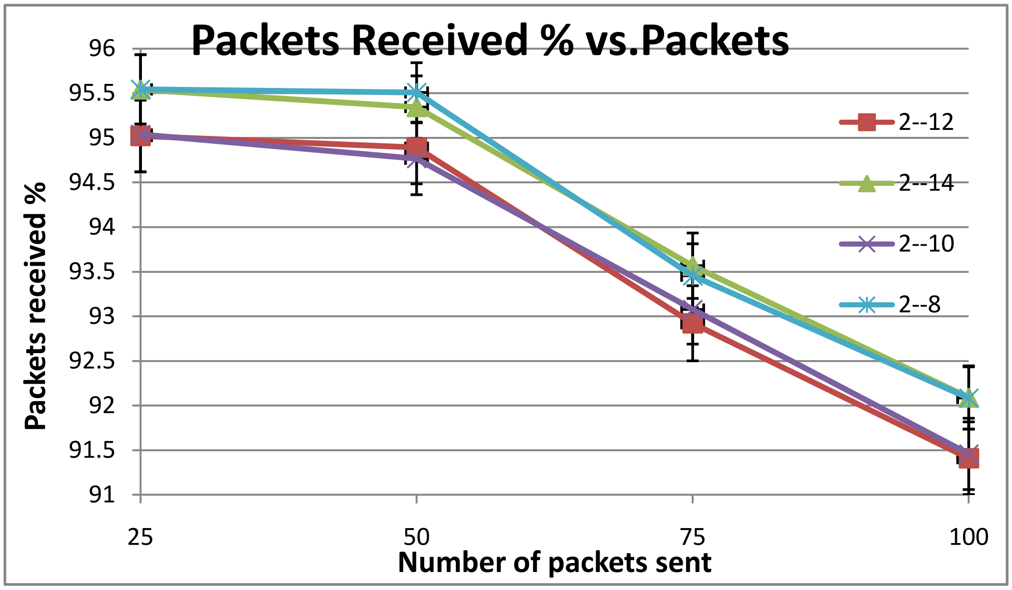
This inequality shows the upper and lower values of *nbrTable(i)* for different numbers of neighbouring nodes. By choosing different values of N min and N max for our dynamic algorithm should therefore indicate for which limits the best results can be achieved. The relevant values will be represented as [N min-- N max] for convenience. Figures 5.2, 5.3, 5.4, 5.5 and 5.6 show the results achieved.



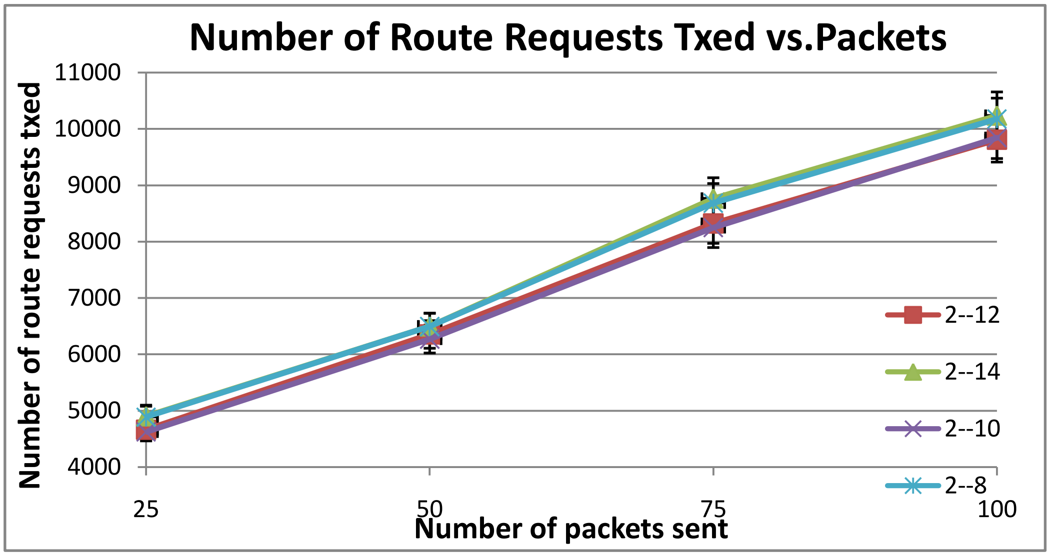
5.2 Broken links versus packets sent



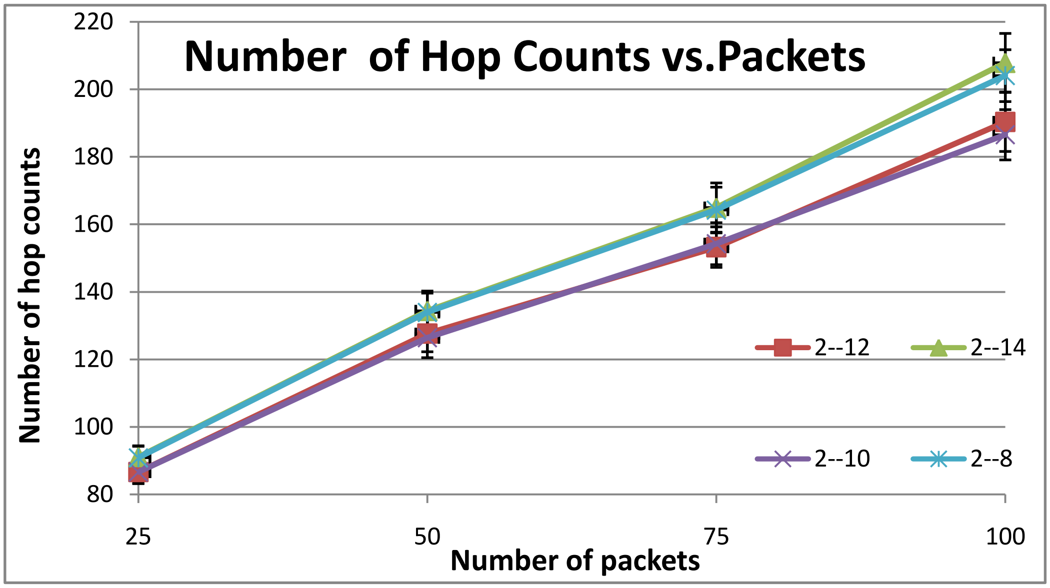
5.3 Number of collisions vesus packets



5.4 Packets received versus packets



5.5 Number of route requests txed versus packets



5.6 Number of hop counts versus packets

Algorithm

```
If a packet is received for the first time then

{         get nbrTable(i)

If size (nbrTable(i)) = = 0 then

          return (0)

     }

Else

If N min< nbrTable(i)< N max then

drop (pkt)
```

```
Else
    broadcast (pkt)
}
End if
End algorithm
```

The figures indicate that the results for the [2--12] and [2--10] are virtually the same, both of which give an improvement over the [2--8] and [2--14]. We shall subsequently use the [2--12] as the algorithm of choice.

5.3 Simulation Scenarios and Configuration

The performance of the proposed approach has been studied against available broadcasting approaches in the situation of a higher-level application, namely the AODV routing protocol [19, 20], which is included in the GloMoSim package. The original AODV protocol uses simple blind flooding to broadcast routing requests. AODV, using a method based on calculating the number of neighbours for each node,

In the simulation, a 1000 m×1000m area is used with a RWP mobility model [105, 106] with 100 mobile nodes. The network bandwidth is 2 Mbps and the MAC layer protocol is IEEE 802.11 [107, 108]. Other simulation parameters are shown in Table 5.1. These parameters have been widely used in the literature [24, 109-111] and have been chosen mainly for this reason.

Table 5.1 Simulation parameters

Simulation Parameter	**Value**
Simulator	**GloMoSim v2.03**
Network Range	**1000m×1000m**
Transmission Range	**250m**
Mobile Nodes	**100**
Bandwidth	**2 Mbps**
Packet Size	**512 Bytes**
Packet Rate	**1 Packet per Second**
Simulation Time	**900s**

The main purpose behind the proposed approach is to reduce the number of rebroadcast packets and broken links in the route-discovery phase, thus decreasing the probability of channel contention and packet collision.

Since the proposed algorithm is based on the RWP mobility model [105, 106], it does not fit every scenario, and there is a small chance that the RREQs will not be able to reach their destinations. It is necessary to re-generate the RREQ if the previous RREQ fails to reach its destination. The AODV protocol, in contrast, uses flooding in the route-discovery phase. Therefore, all RREQs reach their destinations if the network is not partitioned.

In the simulation, each node initially selects a random-movement start time, direction and distance. After travelling the specified distance along the predefined direction, the node remains there for a random pause time before starting another round of movements.

5.4 Performance Analysis and Evaluation

These simulation experiments aim to investigate the performance of the proposed broadcasting algorithm. The proposed algorithm is compared against a simple AODV flooding algorithm. The performance metrics for comparison include the average number of routing request rebroadcasts, number of broken links, average number of collisions and reachability.

5.4.1 *Saved Rebroadcasts*

In AODV, a mobile host rebroadcasts every routing-request packet if received for the first time. Consequently, there are N-1 possible rebroadcasts, where N is the total number of mobile nodes in the simulation. The number of rebroadcasts is dynamically calculated and, since this scheme uses a lower number of rebroadcasts, it is expected to improve overall performance for most measures of interest.

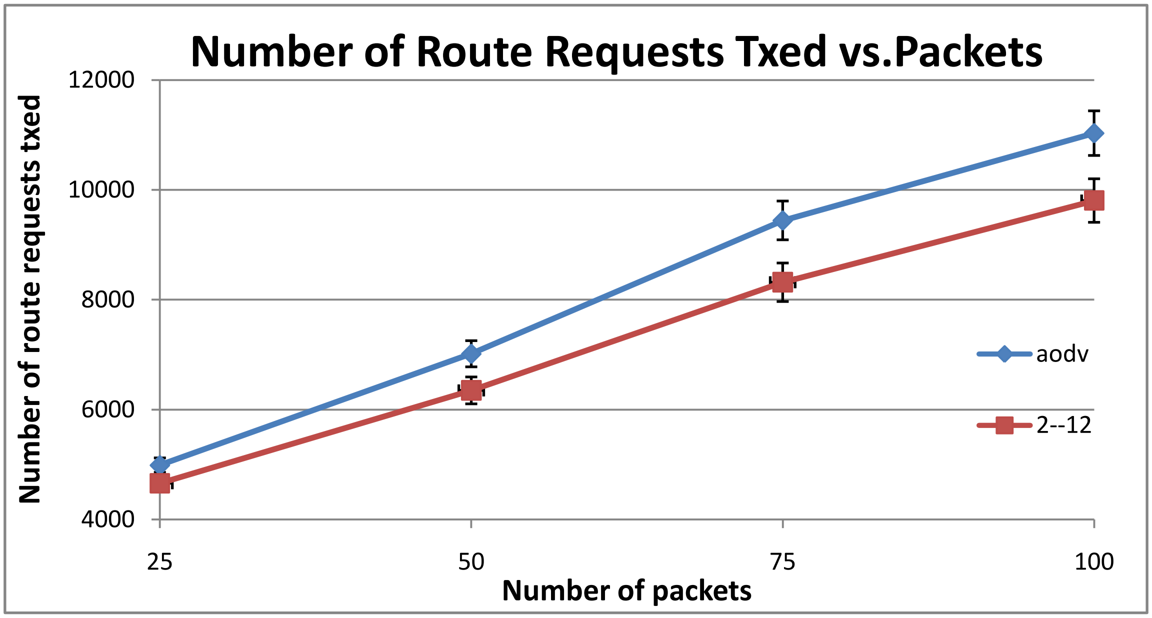


Figure 5.7 confirms the above and shows that the proposed algorithm can significantly achieve a lower number of route requests transmitted (txed) than AODV for a network of 100 nodes and 40 source-destination pairs. There is a clear difference between the two versions.

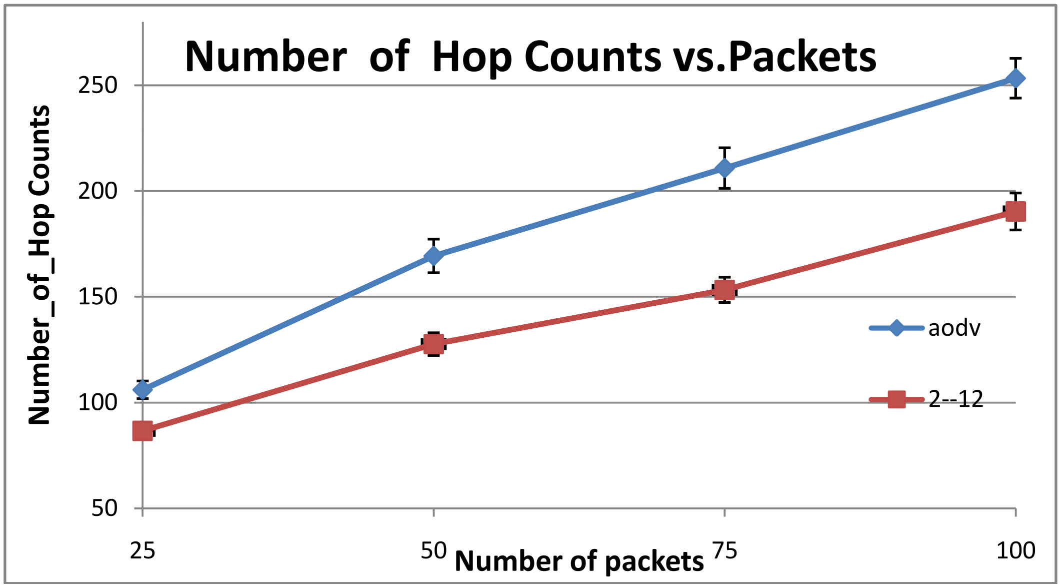


Figure 5.8 Number of hop counts versus packets

Figure 5.8 shows results for the number of hop counts in the two algorithms in a network of 100 nodes and 40 source-destination pairs. The figure reveals that the proposed algorithm still delivers a better performance than the AODV algorithm. Again, this improvement is due to the reduced number of rebroadcasts that are required in the [2--12] algorithm compared with the standard form of AODV.

5.4.2 Collisions

The number of collisions is measured for the proposed scheme and AODV at the physical layer. Since data packets and control packets share the same physical channel, the collision probability is high when there are a large number of control packets.

Figure 5.9 shows the number of collisions for networks with 100 nodes, 40 source-destination pairs and different numbers of packets [25, 50, 75 and 100] packets. As shown in Figure 5.9, the proposed algorithm incurs fewer collisions than simple AODV. It also shows the number of collisions increasing as the number of packets increases. Intuitively this makes sense because, when the numbers of packets increase, more RREQs are generated, leading to more collisions as a result of the increase in control packets. It is evident that the proposed algorithm shows the lowest number of collisions.

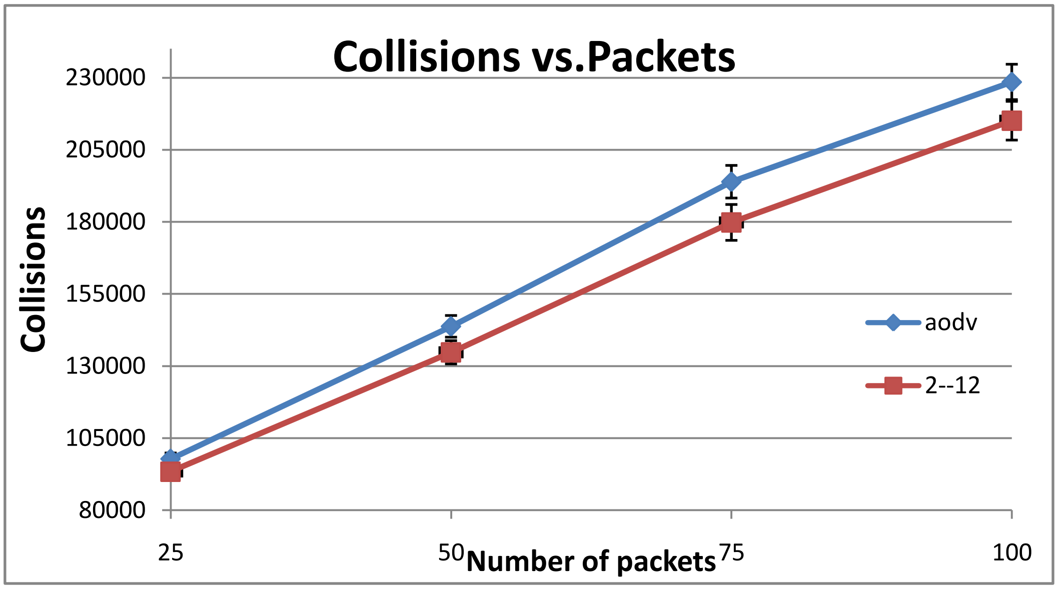


Figure 5.9 Number of collisions versus .packets

5.4.3 Broken Links

Figure 5.10 shows that our improved algorithm can significantly reduce the broken links (by about 25%) for a network of 100 nodes, 40 source-destination pairs and different numbers of packets. This is most likely due to the tendency to establish shorter routes, as previously indicated by the significant reduction in hop counts (Fig. 5.8).

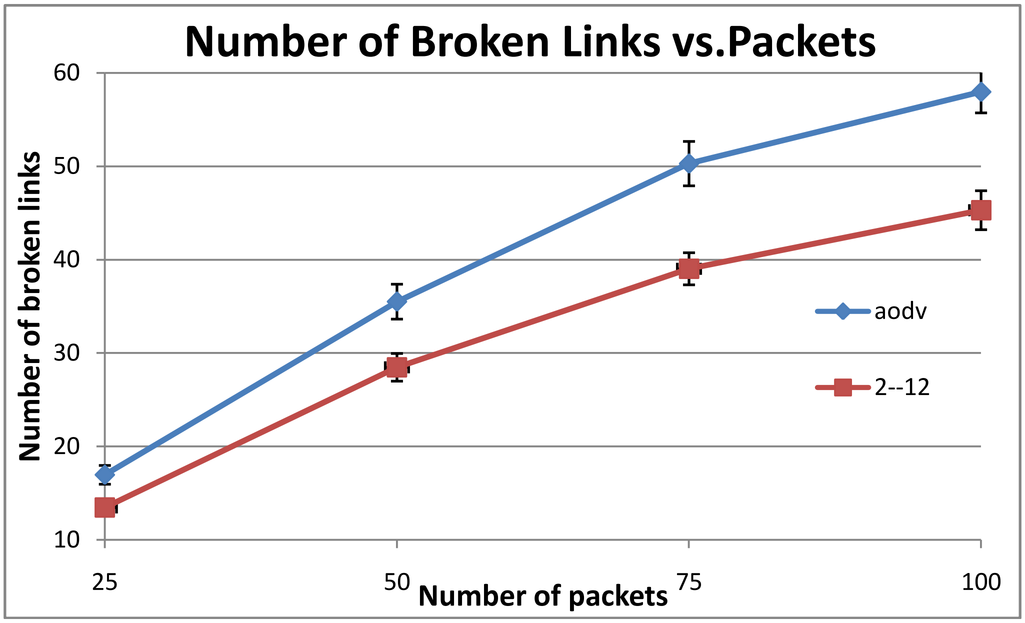


Figure 5.10 Broken links versus packets

5.4.4 Reachability (Packets Received)

The metric of reachability measures the proportion of nodes that can receive a broadcast packet. A mobile host will miss a packet if all its neighbours decide to suppress rebroadcasts.

In a network without division, the flooding approach guarantees that all nodes can receive the broadcast packets at the expense of extra traffic caused by redundant rebroadcasts. In reality however, redundant rebroadcasts also contribute to the possibility of packet collisions that may eventually cause packet drops, thus adversely affecting reachability. Source-destination node pairs are randomly selected and checked as to whether a packet could reach the destination node from the source node. If there is an existing route from the source node to the destination node, the routing request packets broadcast from the source node reach the destination nodes. The ratio of the node pairs that have a route between the source and the destination over the total number of selected pairs[111] has been calculated. This ratio is not exactly equal to the reachability, but is very close to it and is often use d to compare the reachability with simple AODV.

Figure 5.11 shows the reachability for a network with 100 nodes and 40 connections of source-destination pairs. The figure shows that the proposed algorithm has a lower reachability than AODV, which is to be expected. The AODV pays the price for this of a much higher overhead and its consequences. Figure 5.11 shows the reachability results in the proposed algorithm and flooding for a network moving according to the random waypoint mobility model.

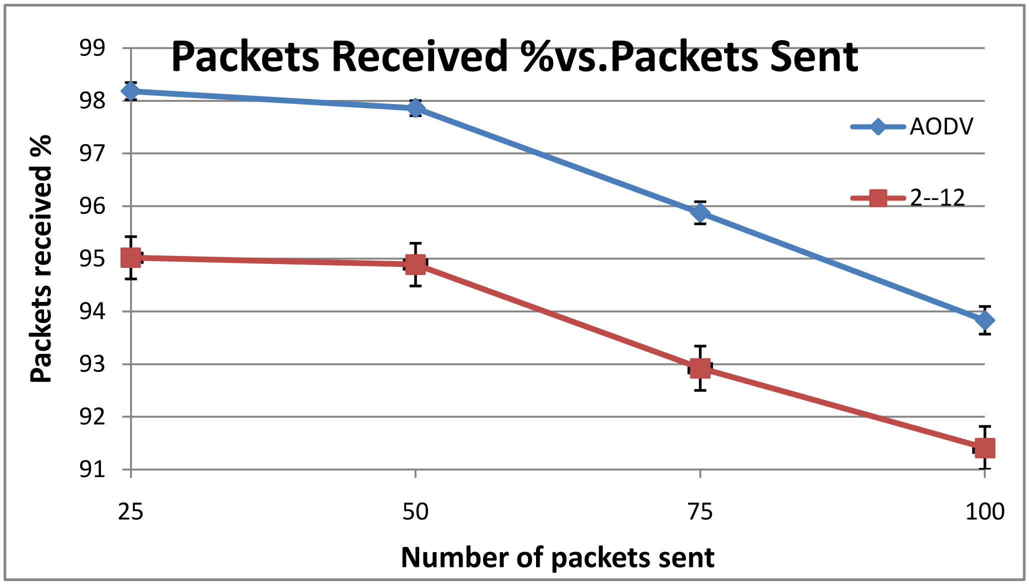


Figure 5.11 Packets received versus packets sent

5.5 Summary

In MANETs flooding is a popular message broadcasting technique for network-wide transmission. Many approaches for MANETs have been proposed to reduce the high number of unnecessary packet rebroadcasts that result from flooding. This chapter has proposed a new scheme for MANETs where the value of the rebroadcast packets for every host node is dynamically adjusted according to its neighbour's information, Performance evaluation of the proposed scheme has been conducted using the GloMoSim package with the Random Waypoint mobility model. Performance results have shown that the proposed scheme performs better than simple AODV for all performance measures examined, with the exception of reachablity.

This chapter has demonstrated that using dynamically calculated packet forwarding to network nodes according to their density regions helps to reduce the number of rebroadcasts, and as a consequence helps to reduce the number of broken links and decrease the probability of channel contention and packet collision. This should therefore be a useful way of limiting the overhead involved in the use of the heading angle which increases with node density. Another way of doing this would be the use of fixed probabilistic schemes and these are investigated in the next chapter.

Chapter 6 Fixed Probabilistic Schemes

6.1 Introduction

Most existing routing protocols that have so far been suggested for MANETs use blind flooding for the propagation of routing control packets, such as RREQ and RREP, during route discovery. This chapter presents an algorithm that aims to improve the performance of existing routing protocols that use blind flooding by reducing the communication overhead during route discovery. To this end, a new fixed probabilistic scheme is compared to the existing AODV routing protocol [19, 20]. The use of such schemes could thus be linked in with the limitation of overhead in schemes involving the heading angle.

6.2 Blind Flooding

In the blind flooding algorithm, a source node broadcasts its packet to all its neighbours. Each of these neighbours in turn rebroadcasts the packet the first time it receives the packet. Redundant packets are simply dropped. This behaviour continues until all reachable network nodes have received the packet. This approach offers simple implementation and reliability as its main advantage. However, blind flooding produces high overhead in the network, and can result in the broadcast storm problem.

```
Algorithm: blind flooding
Protocol receiving
On receiving a broadcast packet m at node X do the following.
If packet m received for the first time then
```

```
broadcast (m)
End if
End Algorithm
```

6.2.1 Broadcast Storm Problem

A side-effect of simple flooding is the broadcast storm problem, which has motivated the development of existing broadcasting protocols. The simple flooding protocol can cause radio signals to overlap with others in a geographical area. This is usually very costly and results in serious disadvantages such as an increase in redundant rebroadcasts, contention and collisions. These disadvantages, including the broadcast storm problem, are reviewed below in more detail.

6.2.2 Redundant Rebroadcast

This problem occurs when a node rebroadcasts packets that neighbouring nodes have already received For example in fig.6.1, node *A* broadcasts a packet to *B* and *C*, then node *B* rebroadcasts it to *A* and *C*, which is clearly redundant as both *A* and *C* already have a copy of the packet.

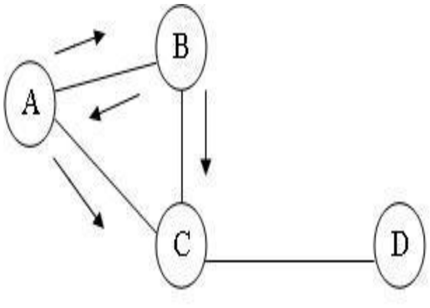


Figure 6.1 Demonstration of redundant rebroadcast and contention

6.2.3 Contentions

When neighbouring nodes receive a broadcast packet from another node, they will try to rebroadcast the packet. Since these neighbours are close to each other, there is a risk that they will contend for transmission time. This causes delays in the broadcasting of data. For example, in fig 6.1 if node *A* broadcasts to *B* and *C*, both node *B* and node *C* have to rebroadcast the packet. Node *B* may be the fastest and sends the packet even though all its neighbours have already received the data. Node *C* wants to send to *D*, but *C* is aware that this is not possible at this point in time because the channel is busy. Node *C* then has to wait.

6.2.4 Collisions

Reservation and acknowledgment mechanisms are not used in the link layer when using flooding, which gives a higher chance for simultaneous transmissions to cause collisions. However, since reservation and acknowledgment mechanisms can be too expensive in terms of transmission time, flooding-based protocols gain an advantage by not making use of them. When collisions are detected, packets are dropped by the receiver. Since an acknowledgment mechanism is not used, the sender never knows that the packet has been dropped. Figure 6.2 shows how a collision between two nodes affects a third one. Node *A* broadcasts a packet to node *B* and node *C*, then both node *B* and *C* rebroadcast the packet immediately. The transmissions from *B* and *C* collide and so the packet received by node *D* is dropped. This becomes a serious problem because the packet never gets forwarded and the data is lost[23, 112].

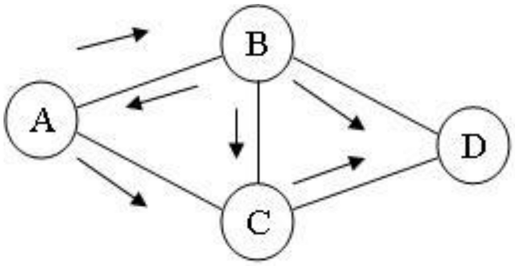


Figure 6.2 Demonstration of a collision

6.2.5 Prevention of Infinite Loops

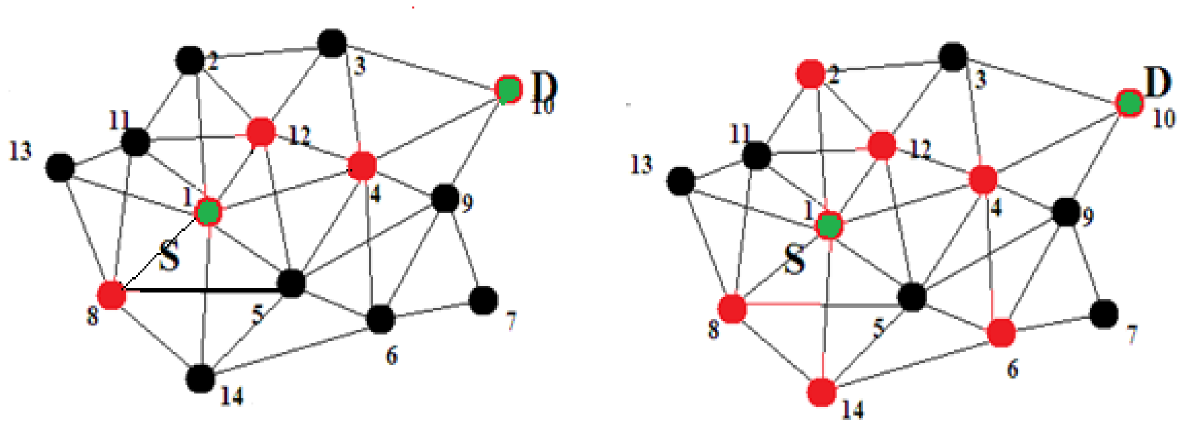
Most existing broadcast techniques[23, 112] require a node to rebroadcast a received packet a maximum of once in order to prevent infinite “transmission loops”. Thus each broadcast protocol requires that nodes cache the original source node ID of the packet and the packet ID. This allows the protocol to uniquely identify each broadcast packet.

6.3 Fixed Probabilistic Schemes

This chapter proposes a new fixed probabilistic flooding algorithm that can dynamically adjust the rebroadcasting probability at a given node according to its ID; that is, when a broadcast packet reaches a node for the first time it is rebroadcast according to a probability P which depends on the node's ID. Fixed probabilistic schemes are one of the solutions to reduce rebroadcasts and so alleviate the broadcast storm problem.

In blind flooding, a given node broadcasts a packet to every neighbour, which, in turn, rebroadcasts the received packet to its neighbours when the packet is received for the first time, and so on. There are a maximum N-1 possible rebroadcasts, where N is the total number of nodes in the network. In fixed probabilistic flooding schemes, each node decides to rebroadcast or not when receiving a broadcast packet for the first time, and rebroadcasts the packet with a probability p [25%=0.25, 50%=0.5, 75%=0.75 or 100%=1.0], with the rebroadcast probability dynamically set. The number of rebroadcasts in fixed probabilistic flooding should be lower than that in blind flooding. For example if N=100 nodes there are 99 possible rebroadcasts in the blind flooding scheme. However, this is reduced to 50 possible rebroadcasts in a fixed probabilistic scheme when the fixed rebroadcast probability p=0.5. The problem comes from the uniformity of the algorithm; every node has the probability to rebroadcast the packet. When the probability is 100% this scheme reduces to blind flooding.

A brief outline of the fixed probabilistic broadcasting algorithm.is presented in figures 6.3.and 6.4;



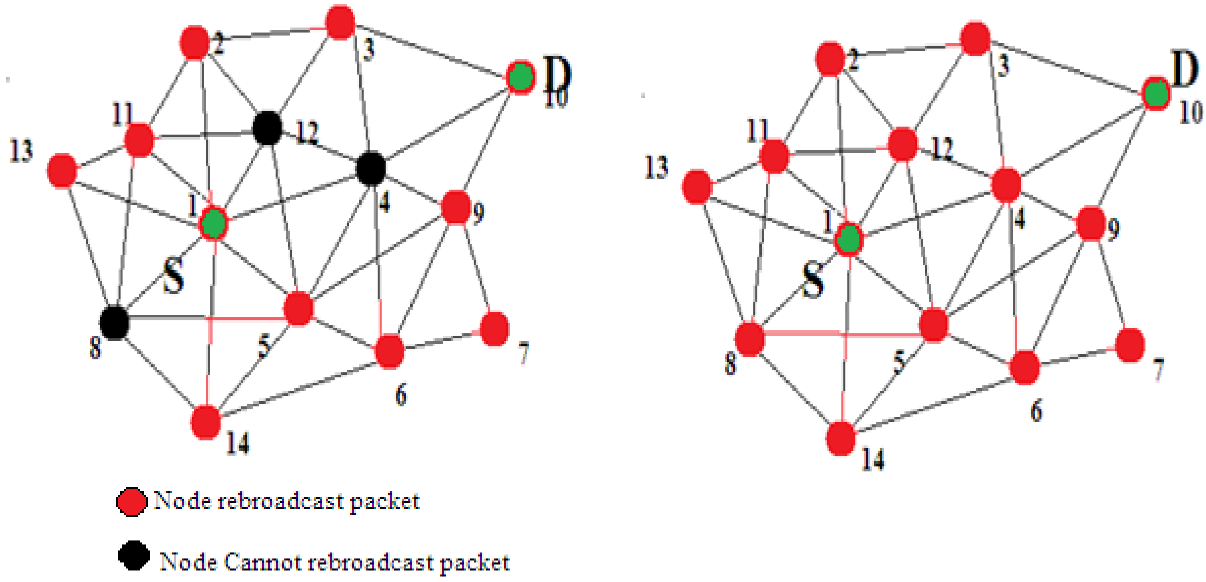
P=0.25 =25%
If (node->id%4) ==0 rebroadcast

P=0.5 =50%
If (node->id%2) ==0 rebroadcast

🔴 Node rebroadcast packet

● Node Cannot rebroadcast packet

Figure 6.3 Fixed probabilistic [25% and 50%]



P=0.75 =75%
If (node->id %) 4≠≠0 rebroadcast

P=1.0 = 100%
AODV

Figure 6.4 Fixed probabilistic [75% and 100%]

Algorithm: fixed probabilistic flooding

```
Protocol receiving 0

On receiving a broadcast packet m at node X do the following.

If packet m is received for the first time then

If (node->ID%N) ==0    then;        # {(node->id%4) ==0 for 25%, (node->id%2) ==0 for 50%,
                                    #
                                    #      (node->id %4) ≠≠0 for 75%}
Broadcast (m)

End if

End Algorithm
```

6.4 Simulation Setup

The GloMoSim network simulator (version 2.03) [85] has been adopted to conduct extensive experiments in the evaluation of the behaviour of the fixed probabilistic flooding algorithm. In the simulation, a (500, 1000, 1500m × 500, 1000, 1500m) area with 40 connections and 100 nodes has been used. The network bandwidth is 2 Mbps and the MAC layer protocol is IEEE 802.11 [107, 108]. Other simulation parameters are shown in Table 6.1.The main purpose behind the new approach is to reduce the number of rebroadcasts in the route-discovery phase, thereby decreasing the probability of channel contention and packet collision. Since the proposed algorithm is based on a fixed probabilistic approach, it does not fit every scenario, and there is a small chance that the RREQs will not be able to reach their destinations. It is necessary to re-generate the RREQ if the previous RREQ fails to reach its destination. The AODV protocol, in contrast, uses flooding in the route-discovery phase. Therefore, all RREQs will reach their destinations if the network is not partitioned.

Table 6.1 Simulation parameters

Simulation Parameter	**Value**
Simulator	**GloMoSim v2.03**
Network Range	**500, 1000, 1500 m × 500, 1000, 1500 m**
Transmission Range	**250 m**
Mobile Nodes	**100**
Bandwidth	**2 Mbps**
Packet Size	**512 Bytes**
Packet Rate	**10 Packets per Second**
Simulation Time	**900s**

In the simulation, each node initially selects a random-movement start time, direction and distance. After travelling the specified distance along the predefined direction, the node will remain there for a random pause time before starting another round of movements

6.5 Number of Route Requests Transmitted [Saved Rebroadcasts (SRB)]

We have compared the number of route requests transmitted (saved rebroadcasts (SRB)) in the three versions of fixed probabilistic flooding with the blind flooding (normal AODV). The probabilities in these versions are set in such a way to enable a particular algorithm to yield the best performance levels. The rebroadcast probability for the fixed probabilistic algorithm is set to 0.25, 0.50 and 0.75.

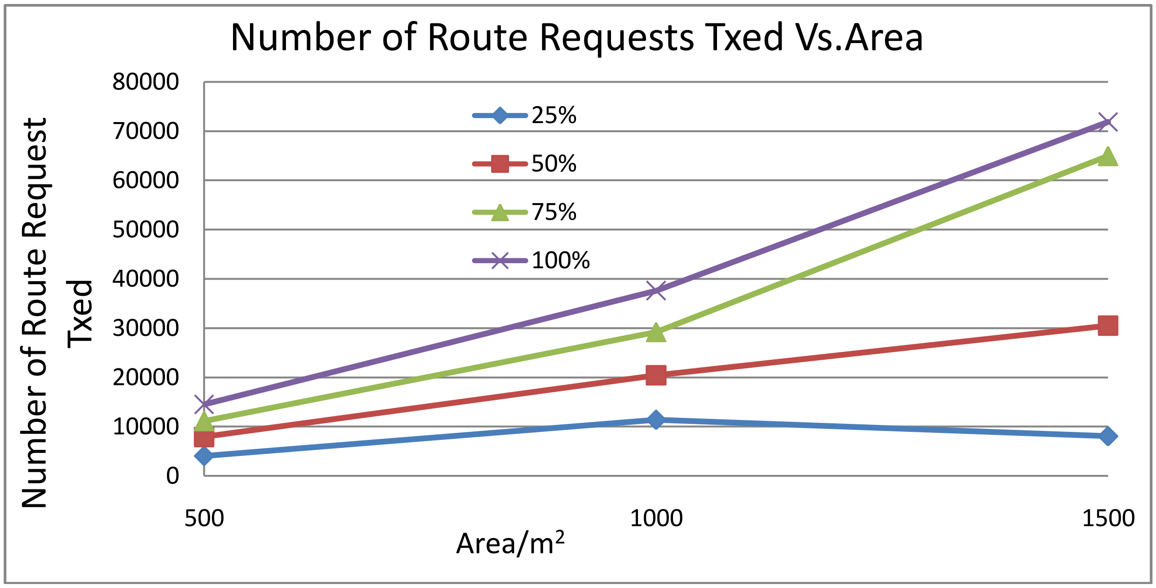


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Figure 6.5 Number of requests txed versus area

Figure 6.5 shows the SRB results in the algorithms for a network size of 100 nodes using the random waypoint mobility model. The number of RREQs in the AODV blind flooding is higher than in the fixed probabilistic versions for all of the probability values, as expected.

6.6 Reachability (RE)

From the conducted simulations it has been found that the new algorithm also manages to achieve good reachability levels of over 95%.

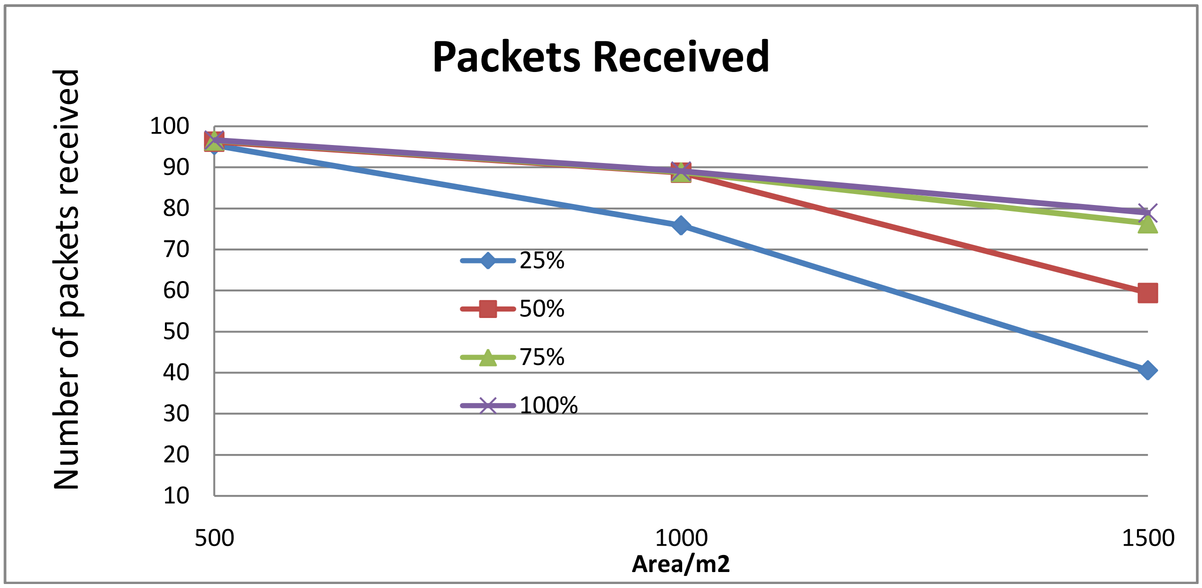


Figure 6.6 Number of packets received

Figure 6.6 shows the RE results for the fixed probability algorithms for a network with 100 nodes with the probability set to values of (0.25, 0.50, 0.75 and1.0). The figure shows that as the rebroadcast probability increases the RE increases such that the RE level can be over 95% when the rebroadcast probability is 25%, 50%, 75% and 100% and the area is 500x500m^2.

Figure 6.6 shows that RE increases when network density increases. It is well known that blind flooding has the worst SRB and the best level of reachability (close to 100%). However, this is achieved at the expense of excessive redundant re-broadcasting of packets. The objective in this research is to improve SRB while maintaining as high a reachability as possible.

6.7 Collisions:

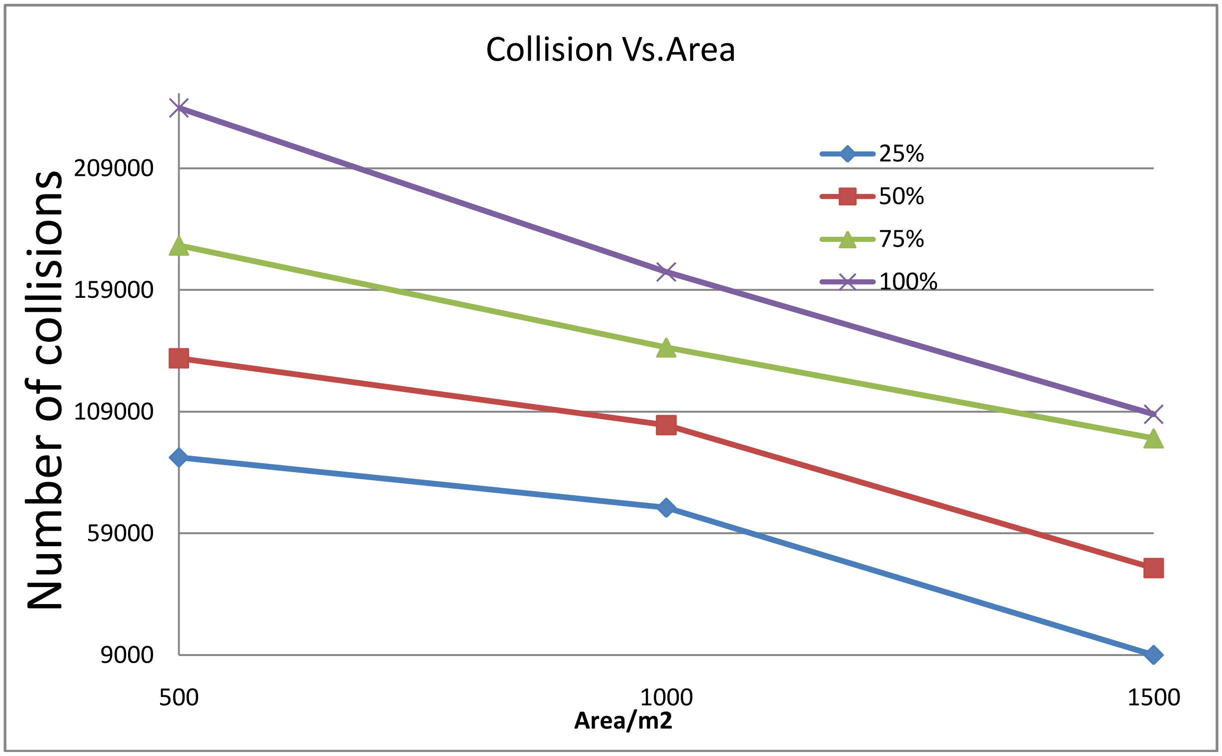


Figure 6.7 Number of collision versus area

We measure the number of collisions for these schemes at the physical layer. Since data packets and control packets share the same physical channel, the collision probability is high when there are a large number of control packets.

Figure 6.7 shows the number of collisions for a network with 100 nodes and 40 source-destination connections. As shown in Figure 6.7, the proposed algorithm incurs fewer collisions than simple AODV. It also shows the number of collisions is greater in an area of 500x500 m^2. This is because the smaller area results in higher values of node density and so more RREQs are generated thus leading to more collisions as a result of the consequent increase in control packets.

6.8 Broken Links

Figure 6.8 shows that the fixed probabilistic flooding algorithm can significantly reduce the number of broken links for a network of 100 nodes and 40 source-destination pairs and different areas (500x500, 1000x1000 and 1500x1500m^2).

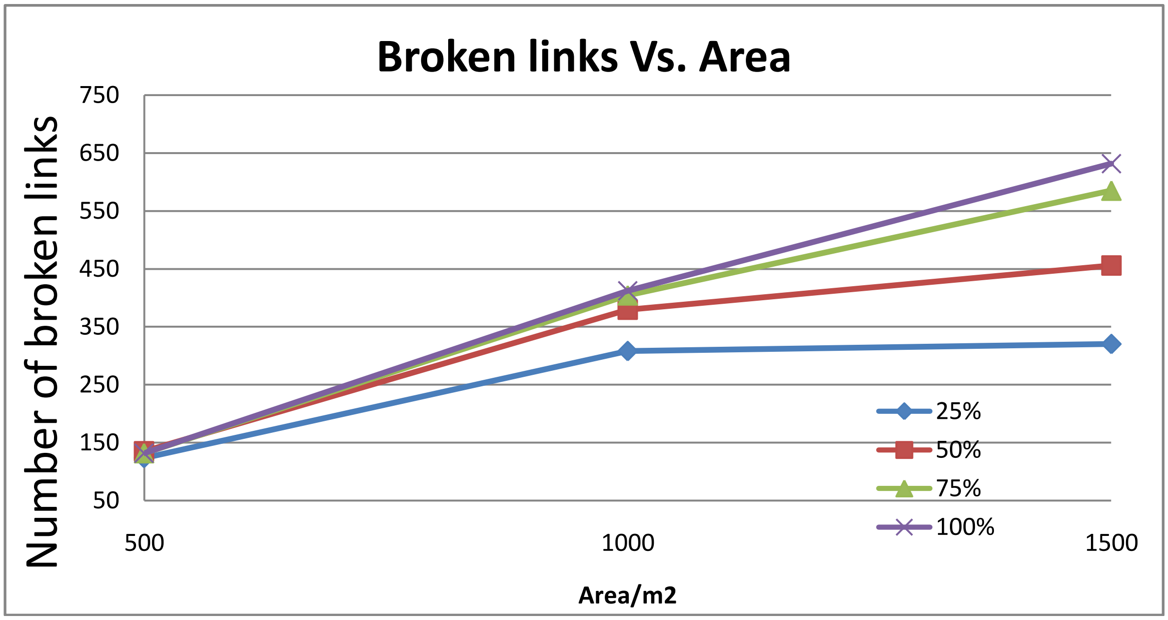


Figure 6.8 Number of broken links versus area

6.9 Number of Hop Counts

Figure 6.9 shows the number of hop counts in the fixed probabilistic flooding algorithm in a network of 100 nodes and 40 source-destination pairs. The figure reveals that the proposed fixed probabilistic flooding algorithm still delivers a better performance than the AODV algorithm.

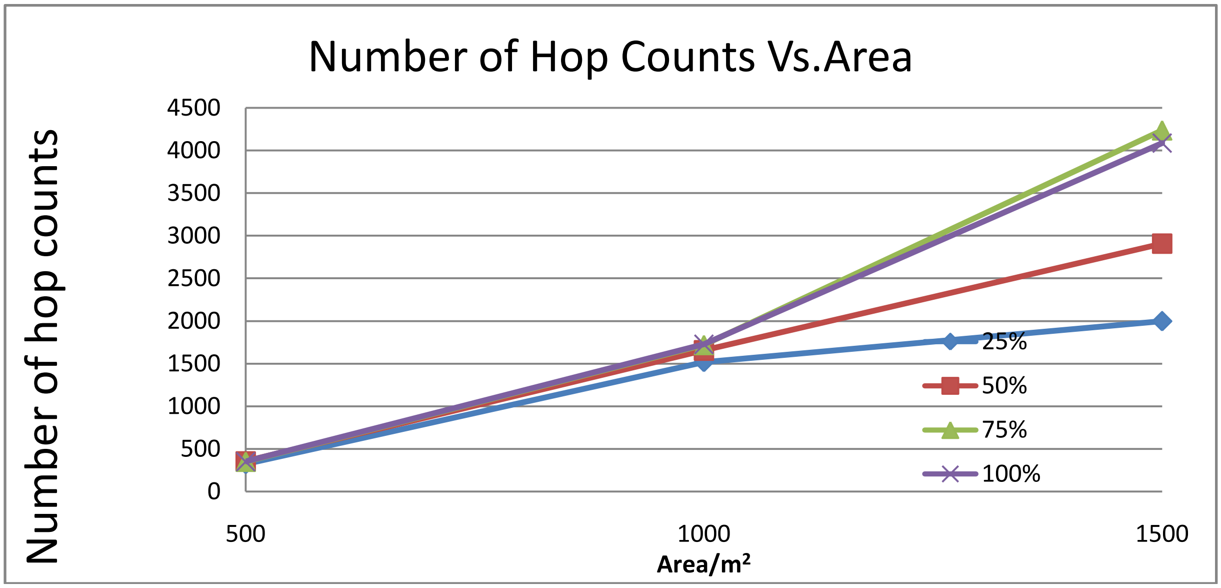


Figure 6.9 Number of hop counts versus area

The reduced hop counts are again a consequence of the reduced rebroadcasts.

6.10 Summary

This chapter has analysed the effects of fixed probabilistic flooding compared with blind flooding. Results from the simulations have revealed that the area (node density) has a substantial effect on the broken links, number of hop counts and saved rebroadcasts with the results largely as expected.

Chapter 7 Comparative Performance Analysis

7.1 Introduction

Several techniques for dissemination in MANETs have been proposed in the previous chapters to reduce the number of broken links, collisions, hop count and route requests txed and achieve a high reachability. These include the angle direction, node density and fixed probabilistic scheme. In this chapter, the comparative study is conducted between the angle direction, node density and fixed probabilistic scheme algorithms that have been presented in previous chapters and normal AODV.

7.2 Simulation Scenarios

In this section, the GloMoSim network simulator (version 2.03)[85] has been used to conduct extensive experiments for a performance comparison of the angle direction, node density and fixed probabilistic scheme and AODV algorithm. Tables 7.1 show the parameters used in the simulation.

0.1 Simulation parameters

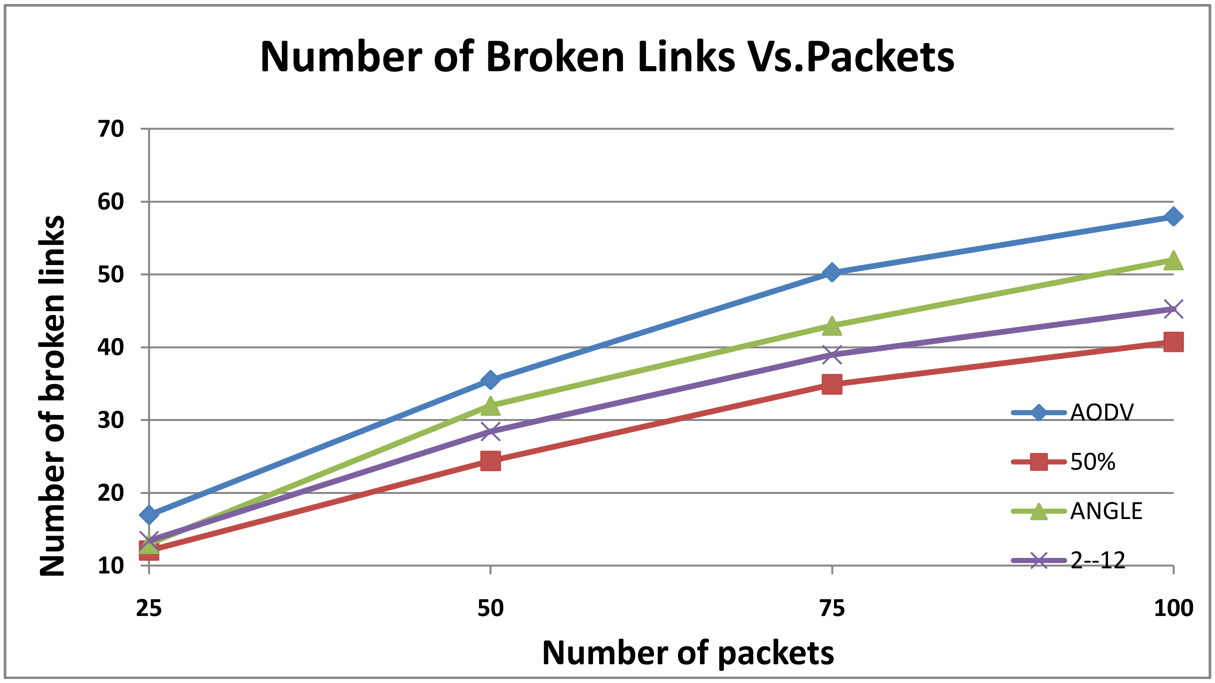
Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	1000m × 1000m
Transmission Range	250m
Mobile Nodes	100
Connections	40
Bandwidth	2 Mbps
Packet Size	512 Bytes
Packet Rate	10 Packet per Second
Simulation Time	900s

7.3 Performance Comparison

The parameters used in the following simulation experiments are listed in Table 7.1 for 40 connection nodes to achieve a performance comparison for the proposed algorithms and to show the effect of different number of packets [25, 50, 75 and 100] on the proposed techniques. The metrics for comparison include, number of broken links, number of routing request txed, number of collisions and reachability

7.4 Number of Broken Links.

In this section, we present simulation experiments to compare the performance of angle direction, node density and fixed probabilistic scheme algorithms with the AODV in terms of number of broken links using the RWP mobility model.



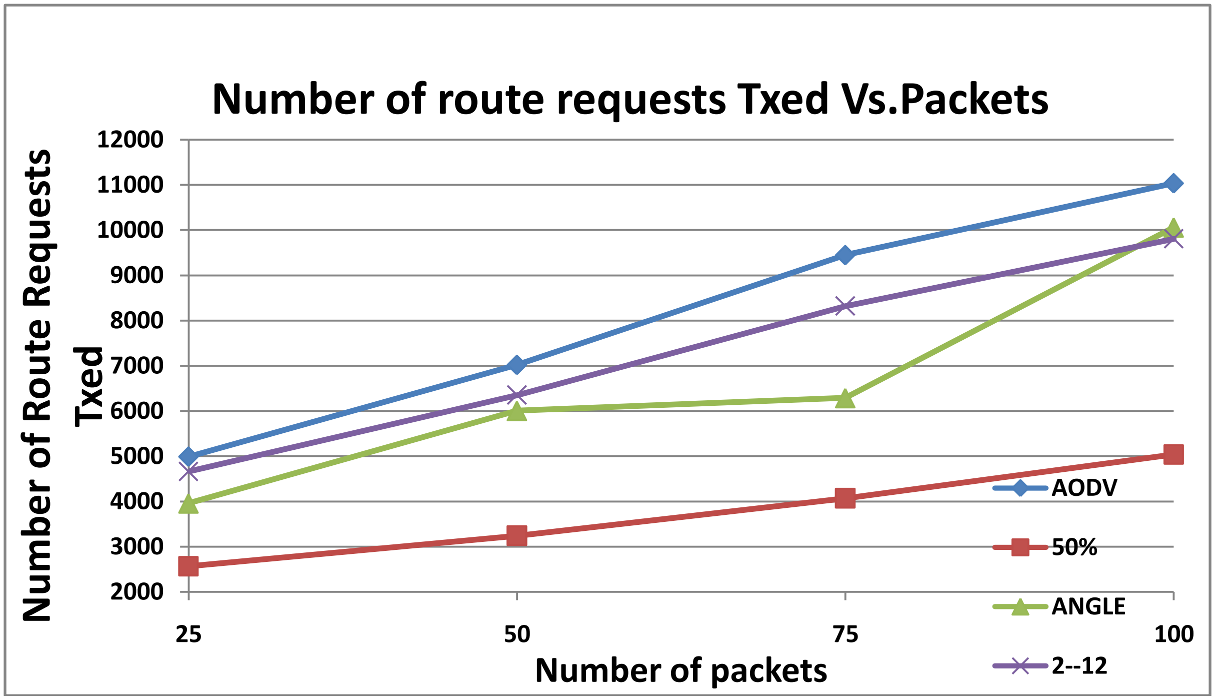
0.1 Number of broken links versus packets

Figure 7.1 shows that our improved algorithms (angle direction ,node density and fixed probabilistic scheme) can all significantly reduce the number of broken links for a network of

100 nodes and 40 source-destination pairs and varying number of packets (25, 50, 75 and 100) with the best performance by the fixed probabilistic scheme.

7.5 Number of Route Requests Transmitted

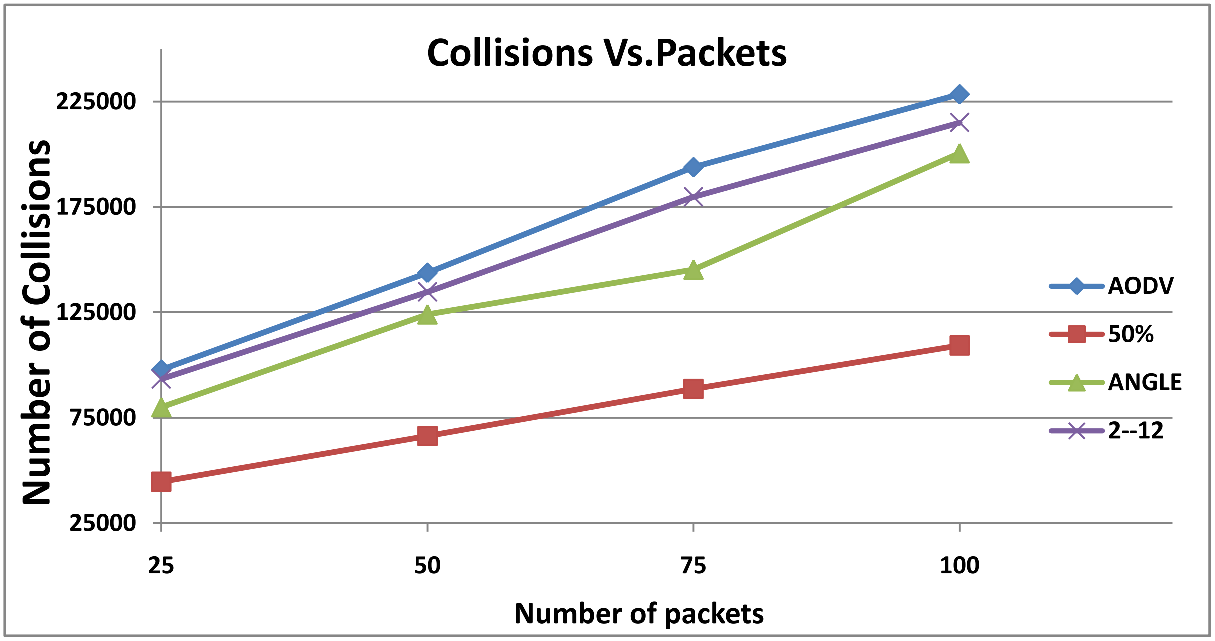
Figure 7.2 explores the saved number of route requests transmitted of angle direction, node density and fixed probabilistic scheme where system size is kept to 100 nodes under the RWP mobility model with a maximum speed of 10 m/s. Our algorithms can significantly improve the number of route requests transmitted with different numbers of packets. The figure also shows that the number of route requests transmitted increases as the number of packets increases. This is because, when the number of packet sent in the network is increased, more RREQ packets will be generated. Again, the fixed probabilistic scheme gives the better performance.



0.2 Number of route requests txed versus packets

7.6 Collisions

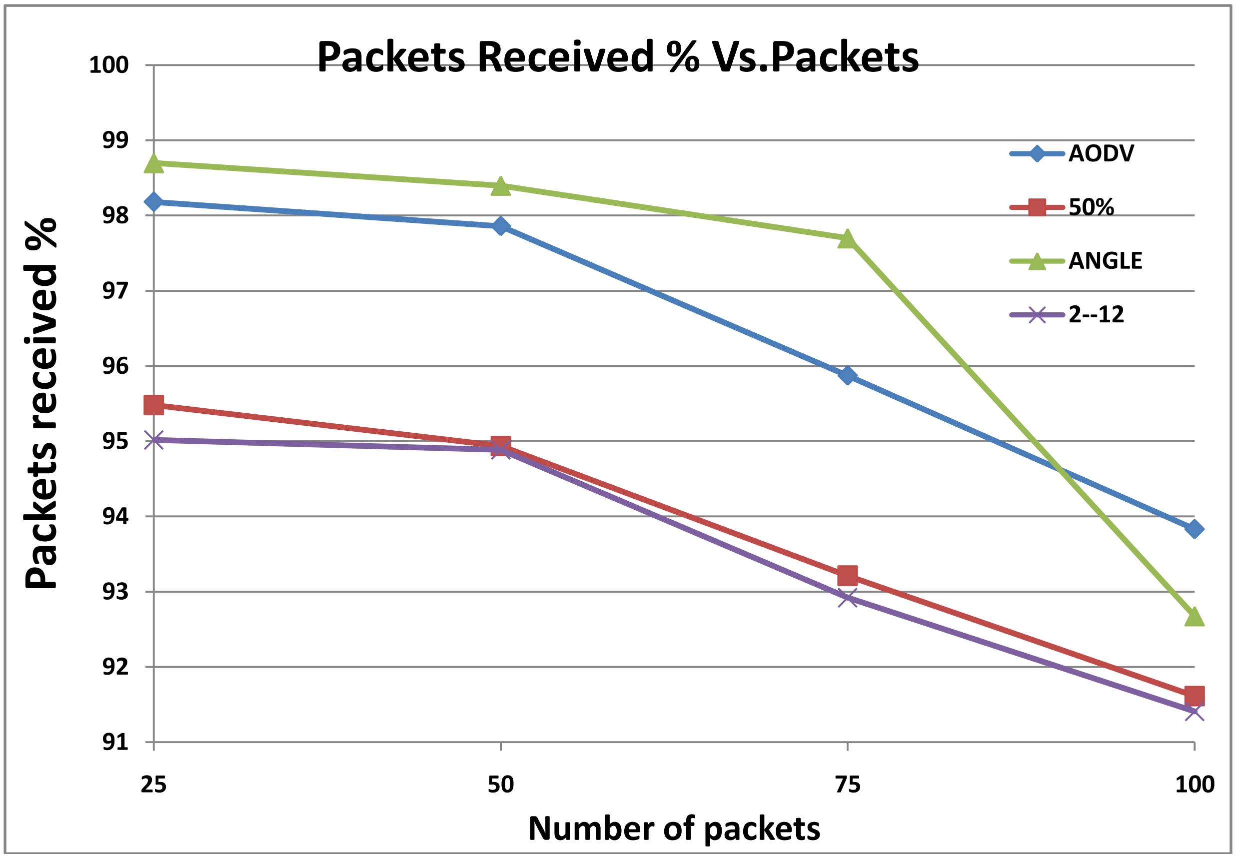
Figure 7.3 shows the collisions of the angle direction, node density and fixed probabilistic scheme under the RWP mobility model with different numbers of packets. From the figure, we can observe that under the RWP mobility model the angle direction, node density and fixed probabilistic scheme all have significantly less collisions compared with AODV. The number of collisions increases as the number of packets in the network increases.



0.3 Collisions versus packets

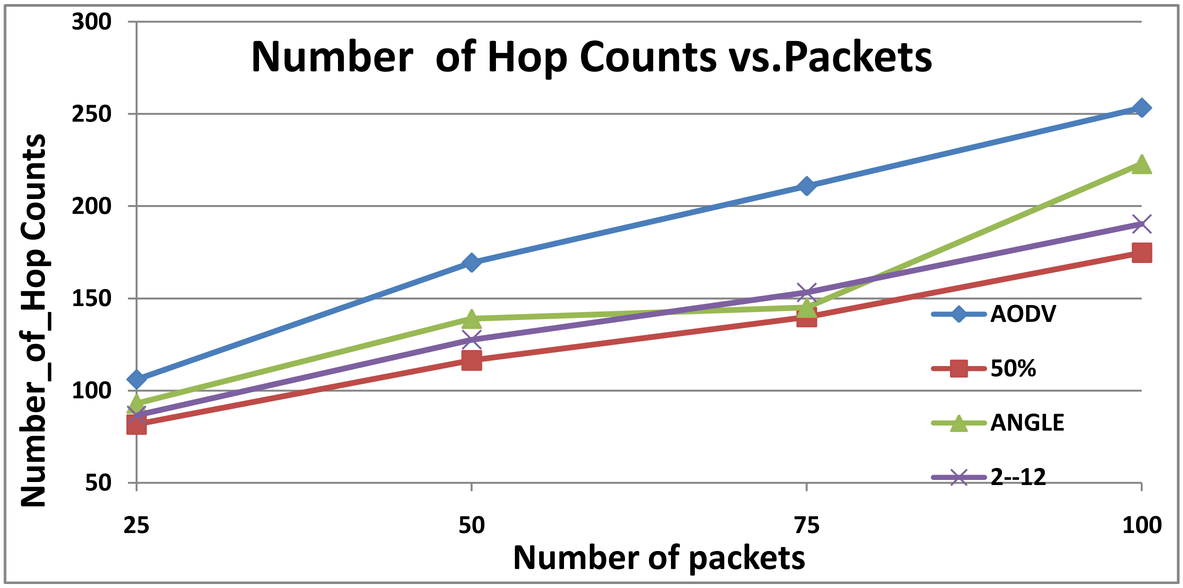
7.8 Reachability

Figure 7.4 shows the comparison between angle direction, node density and fixed probabilistic scheme algorithms and AODV in terms of reachability for the angle direction algorithm for a network with 100 nodes where nodes move at a maximum speed of 10 m/s and with 40 connections of source-destination pairs. The figure clearly shows that the reachability for the angle direction algorithm under the RWP mobility model scenario achieves better reachability than AODV.



0.4 Packets received % versus packets

7.9 Number of Hop Counts



0.5 Number of hop counts versus packets

Figures 7.5 show the number of hops counts for a network with 100 nodes and 40 source-destination pairs, (25, 50, 75 and 100) packets. The comparison between angle direction, node density and fixed probabilistic scheme algorithms and AODV in terms of hop counts. The figure reveals that the proposed algorithms still deliver the best performance over the AODV algorithm and the improvement in reducing hops is now more significant with a large number of packets.

7.10 Summary

In this chapter, the performance comparison was presented to analyse the comparative performance of our proposed algorithms (angle direction, node density and fixed probabilistic scheme), when increasing the number of packets. Our proposed algorithms result in a considerable reduction in the number of broken links, collisions, route requests transmitted and hop counts, when compared with AODV. The fixed probabilistic scheme performed well with the exception of reachability. This was most likely because of the number of reduced rebroadcasts. In terms of reachability, simulation results have shown that in the specific scenario used in this chapter the proposed angle direction algorithm achieves better reachability than the AODV and the other algorithms. This would suggest that incorporation of a fixed probabilistic scheme into the heading angle scheme might be a good avenue to explore. The mobility scenario generation and analysis tool, BonnMotion [113], was used to generate the mobility scenarios for simulation experiments in this chapter.

Chapter 8 Conclusions and Future Work

8.1 Conclusions

The major focus of the present thesis has been on the design of a heading angle algorithm for MANETs that can overcome the limitations of previous methods and deliver improved support for MANET applications. Contributions to this investigation can be summarised as follows.

In the first part of this thesis WLAN networks have been reviewed, as well as current routing principles and types in MANETs. Moreover, this thesis has provided an overview of broadcasting in MANETs and the broadcast storm problem, which causes a serious degradation in network performance due to excessive redundant retransmissions, collisions, broken links and contention.

The thesis has classified existing broadcast algorithms into two main categories: proactive and reactive schemes. In the first category, proactive schemes [102, 114-117], a node chooses some of its 1-hop neighbours as rebroadcasting nodes. When a node receives a broadcast packet, it drops the packet if it is not selected as a rebroadcasting node; otherwise, it recursively chooses some of its 1-hop neighbours as rebroadcasting nodes and forwards the packet to them. In reactive algorithms [118] each node independently determines whether or not to forward a broadcast packet. In this type, it only attempts to build routes when desired by the source node. In general, however, these techniques are not adaptive enough to cope with high node mobility, due to the fact that the network topology changes frequently. Broadcasting algorithms in the second category use probabilities to help a node decide whether or not to rebroadcast its packet.

An intensive comparative performance analysis for both the AODV and EAODV algorithms has been presented using the RWP mobility model. This comparative analysis has demonstrated the performance of the algorithms under the RWP mobility model and showed which performed better in terms of SRB, collisions, hop count and the number of broken links; this was despite the RWP mobility model is effectively a worst-case mobility model for heading angle algorithms.

Extensive simulation experiments have been conducted to investigate and analyse the performances of the algorithms [hop count and angle direction, angle direction and hop count and the mean of all angle directions in the route] and compare them to simple AODV under the RWP mobility model scenario. Performance results have revealed that the proposed scheme outperforms the AODV in terms of SRB, broken links, hop counts and collisions.

A number of simulation experiments have been performed in order to determine the minimum, average and maximum number of neighbours for a given node in a network. One of the main aims of this thesis has been to improve the performance of existing broadcast flooding techniques in order to reduce the broadcast storm problem. To achieve this aim we have proposed a new dynamic flooding scheme, which has been incorporated in the AODV protocol. Each node dynamically sets the rebroadcast probability according to the number of its neighbouring nodes. This is conducted on the basis of locally available neighbourhood information without requiring any assistance from distance measurements or exact location-determination devices. The performance of the new algorithm has been evaluated by comparing it against simple AODV under the RWP mobility model scenario. The performance results have shown that the proposed algorithm outperforms the AODV in terms of broken links, hop counts and RREQs while keeping the reachability high. It has also demonstrated fewer collisions than simple AODV in all scenarios.

In the last part of this thesis, in order to achieve high SRB while keeping reachability acceptable, we have presented an algorithm, referred to as the fixed probabilistic scheme, in which the node broadcasting is calculated dynamically according to the ID number of the nodes. Extensive simulation experiments have been used to investigate the performance of the fixed probabilistic scheme and compare it to the simple AODV/RWP model. The performance results have demonstrated that the fixed scheme outperforms the simple AODV in terms of SRB, collisions and broken links, whereas in terms of reachability the AODV outperforms the fixed probabilistic scheme as expected. A comparison of the proposed algorithms indicated that the fixed probabilistic scheme gave the best results for all but reachability. Best reachability was achieved by the mean heading angle scheme. This suggested a marrying of these two schemes in some way might be a promising way forward in the future.

8.2 Future Work

Other directions for future work might include the following:

- There could be an investigation into the effects of other important system parameters that have not been used in this research; for example, the transmission range of nodes could be investigated along with the heading angle and the dynamic flooding scheme. Extending or compressing the transmission range could have a significant effect on the number of neighbour nodes involved in a broadcast although the power level would then become another variable parameter to consider with corresponding increase in overhead, particularly if this was to be changed dynamically to suit a specific situation.

- One of the possible directions for future research would be to implement the new heading angle protocol on a real practical MANETs in order to evaluate the performance and, more importantly, validate the results obtained via the simulation approach. Clearly such an approach would be costly since a hardware based experiment would need to be set up and tested under laboratory conditions. It may however pay a commercial enterprise to do this if market conditions dictated, since gaining such a novel foothold may reap considerable rewards.
- Studies [111, 119] have proposed a counter threshold in several existing broadcasting algorithms to enable a node to keep track of the number of copies of broadcast packets received in a particular time interval. The node can then decide to rebroadcast the packet if the counter has not reached the pre-determined threshold. It would be interesting to combine the proposed dynamic algorithms with the counter-based approach and note if the resulting algorithms yield further performance enhancement. This approach would again come at the cost of an increase in overhead, although this would be mainly local computational overhead confined to the nodes rather than communication overhead impacting on the network as a whole. In view of this the approach looks a useful one to pursue, possibly giving the benefits of performance gain at relatively little cost.
- Further research could be dedicated to the investigation of the performance merits of the dynamic flooding scheme for other routing protocols, such as DSR, under different mobility model scenarios. This would require a similar technique and incur similar overhead to that described for AODV in chapter 5. Although DSR is an on-demand protocol like AODV, it is likely that different node densities to those indentified for AODV will result in optimum performance so a comparison would prove interesting.

- Finally, as stated above the performance evaluations of MANETs have been conducted mostly through simulation experiments, and to date there has been relatively little activity in the use of analytical modelling to analyse MANET performance. It would be interesting if a mathematical model were developed to investigate the interaction between important parameters affecting the performance of algorithms and summarise more accurately the performance behaviour analysis of these algorithms, since simulations can be highly dependent on the scenarios used. Although analytical modelling techniques have moved on since the introduction of the first MANETs, the main drawback would still appear to be the rapidly changing topology. The precise effects of this would be difficult to capture without considerable simplifications or approximations. For example, one might model a changing topology using a Markov chain by associating a random variable with each node to represent the node density. These random variables would need to change subject to their sum always being equal to the network population. However, such an approach would soon become intractable for a large number of nodes (and hence a large number of variables) due to the state space explosion and so we would have to restrict this to small networks unless approximation techniques were used. Alternatively, one could forget the variables and assume the same node density for each node. This would be solvable but not realistic. It would therefore seem that analytical modelling still has some way to go in the context of MANETs before it is likely to be adopted on a more widespread basis.

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