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Enhanced Probabilistic Broadcasting Scheme for Routing in MANETs

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Enhanced Probabilistic Broadcasting Scheme for Routing in MANETs

An investigation in the design analysis and performance evaluation of an enhanced probabilistic broadcasting scheme for on-demand routing protocols in mobile ad-hoc networks

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Abstract

Broadcasting is an essential and effective data propagation mechanism with several important applications, such as route discovery, address resolution and many other network services. Though data broadcasting has many advantages, it can also cause a high degree of contention, collision and congestion, leading to what is known as "broadcast storm problems". Broadcasting has traditionally been based on the flooding protocol, which simply overflows the network with a high number of rebroadcast messages until these reach all the network nodes. A good probabilistic broadcast protocol can achieve high saved rebroadcast (SRB), low collision and a lower number of relays.

When a node is in a sparse region of the network, rebroadcasting is relatively more important while the potential redundancy of rebroadcast is low because there are few neighbours which might rebroadcast the packet unnecessarily. Further, in such a situation, contention over the wireless medium resulting from Redundant broadcasts is not as serious as in scenarios with medium or high density node populations. This research proposes a dynamic probabilistic approach that dynamically fine-tunes the rebroadcast probability according to the number of neighbouring nodes distributed in the ad-hoc network for routing request packets (RREQs) without requiring the assistance of distance measurements or location-determination devices. The main goal of this approach is to reduce the number of rebroadcast packets and collisions in the

network. The performance of the proposed approach is investigated and compared with simple AODV, fixed-probabilistic and adjusted-probabilistic flooding [1] schemes using the GloMoSim network simulator and a number of important MANET parameters, including node speed, traffic load and node density under a Random Waypoint (RWP) mobility model. Performance results reveal that the proposed approach is able to achieve higher SRB and less collision as well as a lower number of relays than fixed probabilistic, simple AODV and adjusted-probabilistic flooding.

In this research, extensive simulation experiments have been conducted in order to study and analyse the proposed dynamic probabilistic approach under different mobility models. The mobility model is designed to describe the movement pattern of mobile customers, and how their position, velocity and acceleration change over time.

In this study, a new enhanced dynamic probabilistic flooding scheme is presented. The rebroadcast probability p will be calculated dynamically and the rebroadcasting decision will be based on the average number of nodes in the ad-hoc networks. The performance of the new enhanced algorithm is evaluated and compared to the simple AODV, fixed-probabilistic, adjusted-probabilistic and dynamic-probabilistic flooding schemes. It is demonstrated that the new algorithm has superior performance characteristics in terms of collision, relays and SRB.

Finally, the proposed schemes are tested and evaluated through a set of experiments under different mobility models to demonstrate the relative merits and capabilities of these schemes.

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List of Abbreviations

AODV   Ad-hoc On-demand Distance Vector

CBR   Constant Bit Rate

CSMA/CA   Carrier Sense Multiple Accesses with Collision Avoidance

DSDV   Destination-Sequenced Distance-Vector Routing

DSR   Dynamic Source Routing

GloMoSim   Global Mobile Information System Simulator

GPS   Global Position System

IEEE   Institute of Electrical and Electronics Engineers

IETF   Internet Engineering Task Force

MAC   Medium Access Control

MANETs   Mobile Ad-hoc Networks

MG   Manhattan Grid Mobility

OLSR   Optimised Link State Routing

PDA   Personal Digital Assistants

RAD   Random Accesses Delay

RFC   Distributed Fair Scheduling

RPGM   Reference Point Group Mobility

RREP   Route Reply

RREQ   Route Request

RWP   Random Waypoint

SBA   Scalable Broadcast Algorithm

SRB   Saved Rebroadcast

TORA   Temporally Ordered Routing Algorithm

TTL   Time To Live

WLANs   Wireless Local Area Networks

Chapter 1

Introduction

1.1 Background

Flooding is 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" [2-4], which is characterised by a large number of redundant rebroadcast packets, collision and network bandwidth contention. Ni *et al.* [2] have studied the flooding protocol experimentally and analytically. Their results have indicated that rebroadcast could provide at most 61% additional coverage and only 41% additional coverage in average over that already covered by the previous broadcast attempt. Consequently, they have concluded that retransmits are very costly and should be used advisedly. The authors in [2] have classified existing broadcasting techniques into five classes in terms of their ability to reduce contention, collision and redundancy. These classes are: 1) probabilistic, 2) distance-based, 3) counter-based, 4) cluster-based, and 5) location-based. 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 the same messages it has received during a random period of time. The counter-based scheme assumes that the expected additional coverage is so small that rebroadcast 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, whose rebroadcast can cover all hosts in that 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 the new emission, is larger than a certain pre-determined threshold value.

Another classification for broadcasting techniques in MANETs can also be found in [4]. This study has classified broadcasting techniques into the following four flooding

categories: 1) simple, 2) probability-based, 3) area-based, and 4) neighbour-knowledge. In the simple flooding scheme, each node rebroadcasts to its neighbours as a response to every recently received message. The probability-based scheme is a very simple method of controlling message floods. Every node rebroadcasts with a fixed probability p [5, 6]. Clearly, when $p=1$, this scheme is similar to simple flooding. In the area-based scheme, a node determines whether or not to rebroadcast a packet by calculating and using its additional coverage area [2]. The neighbour-knowledge scheme [4] maintains neighbouring node information to decide who should rebroadcast. This method requires mobile hosts to explicitly exchange neighbourhood information amongst themselves using periodic Hello packets. The neighbour list at the present host is added to every broadcast packet. When the packets arrive at the neighbours of the present host, every neighbour compares its neighbour list with the list recorded in the packets. It rebroadcasts the packets if not all of its own neighbours are included in the list recorded in the packets. The length of the period affects the performance of this approach. Very short periods could cause contention or collision while too long periods may debase the protocol's ability to deal with mobility.

Cartigny and Simplot [7] have described a probabilistic scheme where the probability p of a node for retransmitting a message is computed from the local density n (i.e., the number of neighbours) and a fixed value k for the efficiency parameter to achieve the reachability of the broadcast. This technique has the drawback of being locally uniform. In fact, each node in a given area receives a broadcast and determines the probability according to a constant efficiency parameter (to achieve some reachability) and from the local density [7].

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Zhang and Dharma [8, 9] have also described a dynamic probabilistic scheme that uses a combination of probabilistic and counter-based schemes. This scheme dynamically adjusts the rebroadcast probability p at every mobile host according to the value of the packet counters. The value of the packet counter does not necessarily correspond to the exact number of neighbours from the current host, since some of its neighbours may have suppressed their rebroadcasts according to their local rebroadcast probability. On the other hand, the decision to rebroadcast is made after a random delay, which increases latency (the start time of a broadcast was recorded as well as the time when the broadcast packet reached the last node. The difference between these two values is used as the broadcast latency).

Bani Yassein *et al.* [1, 10] have proposed a fixed pair of adjusted probabilistic broadcasting scheme where the forwarding probability p is adjusted by the local topology information. Topology information is obtained by proactive exchange of Hello packets between neighbours to construct a 1-hop neighbour list at every host.

1.2 Motivation

Broadcasting is an active research topic and has wide applications in MANETs. For example, it is used in the route-discovery technique of several well-known routing protocols [11-15], such as Route Request (RREQ) and Route Reply (RREP), [12, 13,

16]. 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 efficient probabilistic broadcast algorithms that aim to reduce the number of rebroadcast packets 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 attempt to analyse their performance behaviour in a MANET environment. Moreover, no study has analysed the performance of probabilistic flooding taking into account the effects of a number of important system parameters in MANETs, such as traffic load, node speed and network density under different mobility models.

In most existing probabilistic techniques that have been put forward in the literature [2, 3, 5-7, 17, 18], the rebroadcast probability at a received node is fixed, resulting in low reachability (as discussed in [2, 3]). One of the reasons for this is that each node in the network has the same probability of retransmitting a packet despite the number of neighbouring nodes. In dense networks, multiple nodes share similar transmission ranges. Therefore, these probabilities control the number of rebroadcasts and might thus save network resources without affecting reachability. Note that in sparse networks there is considerably less shared coverage, which means that some nodes will not receive all the broadcast packets unless the probability parameter is high. Therefore, the rebroadcast probability should be set in a different value from one node to another in order to calculate a given node's coverage.

The rebroadcast probability p should vary in different areas. In a sparser area, the rebroadcast probability is larger whilst in a denser area, the probability is lower. A

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higher value of p means a higher number of redundant rebroadcasts while a smaller value of p means lower reachability. In order to achieve both high saved broadcast and high reachability when network topology changes frequently, the rebroadcast probability should be set high for nodes located in sparse areas and low for nodes located in dense areas. These issues motivate the investigation of techniques for enhancing the performance of the routing protocol.

This research investigates the performance of new probabilistic flooding algorithms where the value of rebroadcast probability p is dynamically calculated at each mobile host according to the number of its neighbouring nodes to increase reachability and SRB as well as reducing the collision ratio.

1.3 Research Aims

The main aim of this research is to design and implement a dynamic probabilistic broadcasting algorithm incorporated in the Ad-hoc On-demand Distance Vector (AODV) Routing protocol, one of the better-known and better-studied algorithms over recent years that employ simple flooding, in order to reduce the number of rebroadcast packets.

To achieve this aim, the objectives are:

- To analyse in depth the performance behaviour of probabilistic flooding techniques in a MANETs environment.

- To investigate and improve the Ad-hoc On-demand Distance Vector (AODV) routing protocol in MANETs.

- To investigate the performance impact of a number of important parameters in MANETs, including node speed, traffic load 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 probabilistic broadcasting scheme for MANETs in order to reduce the number of redundant rebroadcasts and collisions.

- To evaluate the performance of a dynamic probabilistic broadcasting scheme in MANETs using different mobility models.

- To develop an enhanced dynamic probabilistic scheme to increase the SRB.

- To compare the proposed dynamic probabilistic schemes with existing approaches to demonstrate their merits and capabilities.

1.4 Original Contributions

Original contributions are:

- The proposal of new probabilistic flooding algorithms where each node dynamically sets the rebroadcast probability according to information about the number of its neighbouring nodes in order to reduce redundancy, contention and collision. 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 would be low when the number of neighbouring nodes is high, i.e. the host is in dense area, and the probability would be high when the number of neighbouring nodes is low, i.e. the host is in sparse area. The proposed algorithm is referred to as Dynamic Probabilistic Flooding.

- The broadcast storm problem in MANETs is studied. In particular, we use the GloMoSim network simulator (version 2.03) and CBR traffic generator to conduct extensive experiments to evaluate the behaviour of the proposed dynamic probabilistic flooding algorithm under different mobility models.

- In order to achieve high SRB while keeping reachability acceptable, a new algorithm is proposed, referred to as Enhanced Dynamic Probabilistic Flooding, which is a further refinement of the algorithm first proposed. While with the first algorithm the broadcasting probability is calculated dynamically according to the information about the number of neighbouring nodes, in the second proposed algorithm the rebroadcast probability will also be calculated dynamically but will be based on the average number of nodes in the ad-hoc network.

As stated above, there have been a number of research studies on probabilistic flooding, including the one laid out above. However, so far there has been comparatively little activity in the investigation of the performance merits of probabilistic flooding algorithms in real applications. In an effort to fill this gap, this research assesses the impact of probabilistic flooding on the performance of AODV, one of the better-known and widely studied routing protocols over the past few years. AODV sets up routes on demand in order to minimise the traffic generated due to broadcasting RREQ packets. AODV is considered to be a pure on-demand routing protocol since nodes that are not in the selected path to a destination do not participate in routing decisions or maintain any routes. Routes in AODV are discovered and established and maintained only when and as long as needed. To ensure loop freedom during message routing, sequence numbers are created and updated by each node as used. The sequence numbers also allow the nodes to select the most recent route to a given destination node. Our newly proposed algorithms, adjusted probabilistic flooding [1, 10] and fixed probabilistic flooding are incorporated into AODV and compared against the traditional AODV version that employs simple flooding [1] using the GloMoSim (2.03) network simulator under different mobility models.

1.5 Outline of the Thesis

The rest of the thesis is organized as follows.

Chapter 2 describes Wireless Local Area Networks (WLANs), including their types, advantages/disadvantages, current routing principle and types in MANETs. Moreover,

this chapter gives an overview of broadcasting in MANETs and the broadcast storm problem that results in the serious degradation of network performance due to extreme redundant retransmission, collision and contention. Chapter 2 also reviews existing broadcast algorithms in MANETs .

Chapter 3 presents the new idea and the algorithm of the dynamic probabilistic broadcasting scheme. It then goes on to describe the experimental scenarios and the setting of simulation parameters. Additionally, this chapter presents and analyses the performance results of the dynamic algorithm for static and mobility nodes when nodes move according to the Random Waypoint (RWP) mobility model.

Chapter 4 describes the important mobility models of MANETs before presenting simulation scenarios and analysing the performance results of the dynamic probabilistic scheme under different mobility models.

Chapter 5 introduces the Enhanced Dynamic Probabilistic Flooding algorithm and presents the simulation scenarios and parameters. Comprehensive performance evaluation of the Enhanced Dynamic Probabilistic Flooding algorithm follows.

In Chapter 6, a comparative performance of the proposed algorithms under different mobility model scenarios is presented.

Chapter 7 concludes the thesis and points to potential areas for future research.

Chapter 2

An Overview of MANETs

2.1 Introduction

Early uses of wireless networks began in the 1970s and their development has continued ever since. Over the last decade, research interest in the area has grown substantially due to the wide availability and fast deployment of wireless transceivers in a variety of computing devices such as PDAs and desktop and laptop computers [19-21]. Initially, the deployment of these wireless technological advances came in the form of an extension to the fixed LAN infrastructure model, as detailed in the 802.11 standard [22-24].

The Wireless Local Area Network (WLAN) is a flexible data communication system that can either replace or extend a wired LAN to provide location-independent network access between computation and communication devices using waves rather than a cable infrastructure [25, 26].

Wireless communication has become one of the most developed areas of technology renew. Cellular wireless networks have experienced dramatic global growth for the past decade. WLANs are currently being rapidly deployed in industrial, commercial and home networks. Several organisations are actively developing standards for future

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wireless networks. One important reason for their growing popularity is that wireless networks, to some extent, enable people to exchange information on the move anytime and anywhere in the world. As wireless devices become more inexpensive and widely available, communication networks will become more stable and far reaching in daily life [27].

There are currently two variations of mobile wireless networks. The first is known as the infrastructure network. The bridges for these networks are known as base stations. A mobile unit within these networks connects to, and communicates with, the nearest base station that is within its communication range. As the mobile travels out of range of one base station and into the range of another, a "handoff" occurs from the old base station to the new, and the mobile is able to continue communication seamlessly throughout the network. 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 cellular phone system. Typical applications of this type of network include office WLANs.

The second type of mobile wireless network is the infrastructure-less mobile network, commonly known as an ad-hoc network. Infrastructure-less networks have no fixed routers: all nodes are capable of movement and can be connected dynamically and randomly. The nodes of these networks function as routers, discovering and maintaining routes to other nodes in the network [20, 27].

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The wireless and self-configuring character of MANETs make them appropriate for multiple applications [19, 20, 22, 28], from military operations and rescues to virtual classrooms. This type of communication paradigm stimulates the desire for sharing information among mobile devices. Furthermore, MANETs could be useful in areas such as disaster sites, battlefields and temporary local-area networks. In such environments, where there is often little or no communication infrastructure or the existing infrastructure is not suitable for use, wireless mobile customers could communicate through the quick formation of a MANET [19-21].

The communication abilities of the mobile nodes in MANETs are delimited by their wireless transmission ranges; that is to say, two nodes can communicate directly with each other only if they are within their transmission ranges. When two nodes are outside one another's transmission range, their communications require the support of intermediate nodes, which configure a communication between both nodes to relay packets between the source and destination. For example, as shown in Figure 2.1, node *B* is within the transmission ranges of nodes *A* and *C*, but *A* and *C* are not in each other's transmission ranges. If *A* and *C* wish to exchange a packet, node *B* has to forward the packet for them, since *B* is inside both *A* and *C'*s transmission ranges.

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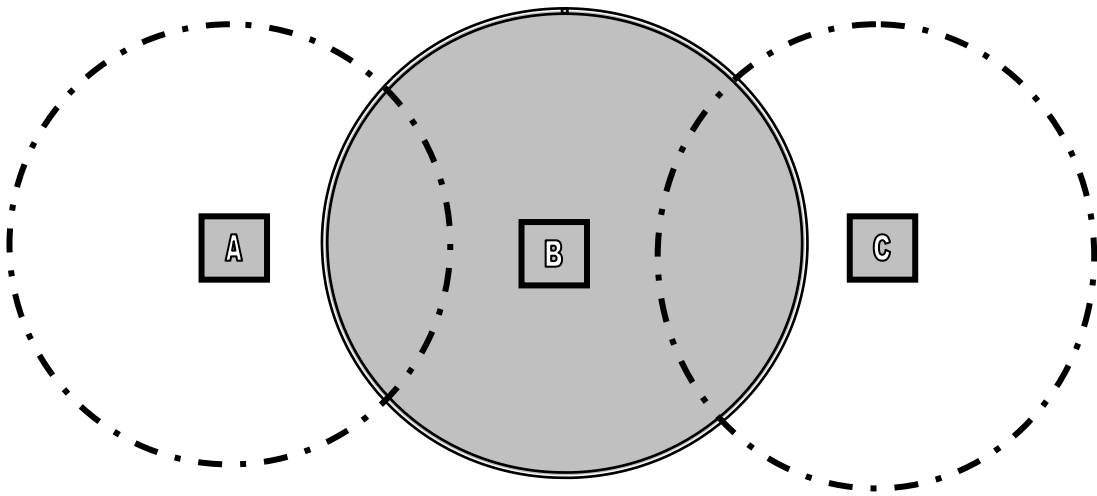
Figure 2-1:A simple mobile ad-hoc network

2.2 Features of MANETs

Whilst MANETs share many of the properties of wired-infrastructure LANs, they also possess certain distinctive features which obtain from the nature of the wireless medium and the disseminated function of the medium-access mechanism they employ [19, 20, 29-31]. These features, described below, are considerations stemming from the mobile node, the dynamic network topology and the routing protocol used to establish and maintain communication paths. These characteristics affect the functionality of mechanisms throughout the communication protocol [19, 20, 29, 30, 32].

1) Independent Nodes. In a mobile ad-hoc network, every mobile node is independent of the others, and may work as a host that generates and consumes packets, as well as a router that relays packets along network paths.

2) Dynamic Network Topology. Nodes in the network dynamically establish routing among themselves as they move around, forming their own network connectivity within the area. Furthermore, since the nodes are mobile, the network topology may change quickly and unpredictably and the connectivity among the nodes may differ with time.

3) Distributed Operation. Nodes involved in mobile ad-hoc networks cooperate with each other and every node operates as a relay as and when needed to implement important functions such as routing and security. Since there is no background network for the central control of network operations, control and management of the network must be disseminated among the nodes.

4) Limited Resource. The nodes in a MANET suffer from constrained resources compared to their wired counterparts [19, 20, 33]. 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 [34-37].

2.3 Applications of MANETs

Because MANETs are flexible networks that can be set up anywhere and any time without an infrastructure and possess a rapid, economically less demanding deployment, they find application in several areas, from military applications and emergency operations to collaborative/group communication [19, 20].

Military Applications. Mobile ad-hoc networks can be very useful in setting up a fixed infrastructure for communication amongst a group of soldiers in enemy territory or

inhospitable terrains. They are also useful in establishing communication amongst a group of soldiers for strategic operations. In such environments, MANETs can provide the required communication mechanism very fast.

Emergency Operations. In emergency operations (environments, for example, where conventional infrastructure-based communication facilities have been destroyed due to natural calamities such as earthquakes), mobile ad-hoc networks are very helpful. Immediate deployment of ad-hoc wireless networks would be a good solution for activity coordination. Moreover, the major factors that favour MANETs for such tasks are the self-configuration of the system with minimal overhead, independent of fixed or centralised infrastructure, the freedom and flexibility of mobility, and the unavailability of conventional communication infrastructure.

Collaborative/Group Communication. MANETs can be very useful in setting up the requirements of a short-term communication infrastructure for quick communication with minimum configuration for a group of people in a conference or gathering. An example would be a group of researchers who want to share their research results or presentation materials during a conference or a lecture, distributing notes to the class on the air. In such a scenario, the formation of a MANET would serve this purpose [24, 38].

2.4 Advantages and Disadvantages of WLANs

WLANs have many advantages compared to fixed (wired) networks, such as:

Flexibility. This constitutes one of the major advantages of WLANs. The use of radio waves to communicate between wireless devices increases their ability to roam throughout business organisations. Additionally, there is no need to install new network cables to expand existing WLANs [39-44].

Accessibility. Mobile users are provided with access to real-time information even when they are away from their home or office.

Cost. Building a WLAN is one of the cheapest ways to achieve a connection with the surroundings. The price of a single wireless adapter is no longer high and wireless LAN is a reasonable choice for large networks. There is no need to set all the wires around [39-44].

On the other hand, WLANs do have their disadvantages, such as:

Security. This is one of the major concerns in the use of WLANs. Since radio waves are used in communicating between wireless devices, any other foreign wireless device (as long as it has a certain software, which is available from various sources on the Internet) could be capable of listening in on the encrypted data traversing the network [39-44].

Interference. This can be caused by the weather, other radio-frequency devices, or obstructions such as walls.

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2.5 Routing Principles in MANETs

The basic routing problem is that of finding an ordered series of intermediate nodes to transport a packet across a network from its source to its destination. In traditional hop-by-hop solutions to the routing problem, every 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. These routing protocols may generally be categorised as either proactive or reactive [20, 45].

2.5.1 Table-driven Routing Protocols (Proactive)

These protocols are also known as proactive protocols, because they maintain routing information even before it is needed. Each node attempts to maintain a correct view of the network topology at all times and build routes from each node to every other node before these are needed. These protocols require each node to maintain one or more tables to store routing information. Any changes in topology are propagated through the network, so that all nodes know of the changes in topology. Destination-Sequenced Distance-Vector Routing (DSDV) and Optimised Link State Routing (OLSR) [20, 46] are examples of proactive protocols.

2.5.2 On-demand Routing Protocols (Reactive)

These protocols are also known as reactive protocols because they do not maintain routing information at the network nodes if there is no communication. This type of

routing only attempts to build routes when desired by the source node. Network topology is detected as needed (on demand). When a node wants to send packets to some destination but has no routes to the destination, it initiates a route-discovery process within the network. Once a route is established, it is maintained by a route-maintenance procedure until the destination becomes inaccessible or until the route is no longer desired. Examples include Ad-hoc On-demand Distance Vector Routing (AODV) [13, 47], Dynamic Source Routing (DSR) [15, 16], and the Temporally Ordered Routing Algorithm (TORA) [12].

2.6 Broadcasting in MANETs

Flooding is one of the earliest broadcast mechanisms in wired and wireless networks. Upon receiving the message for the first time, each node in the network rebroadcasts a message to all its neighbours. In the one-to-all model, a transmission by every node can reach all nodes that are within its transmission range, while in the one-to-one model, every transmission is directed to only one neighbour (using narrow-beam directional antennas or separate frequencies for each node) [2, 48]. While flooding is simple and easy to implement, it can affect the performance of a network and may lead to a serious problem, often referred to as the "broadcast storm problem" [2, 3], which consists of a large number of redundant rebroadcast packets, collision and network bandwidth contention. Proper use of a broadcasting method can reduce the number of rebroadcasts, and as a result reduce the chance of contention and collision among neighbouring nodes.

2.6.1 Applications of Broadcasting

Broadcasting has many significant uses and some MANET protocols assume the availability of an underlying broadcast service [9, 27]. Applications which make use of broadcasting include paging a particular node or distributing information to the entire network. Broadcasting can also be used for route discovery in on-demand routing protocols. For example, in Ad-hoc On-demand Distance Vector Routing (AODV) [13, 42, 47] and Dynamic Source Routing (DSR) [15, 16], a route request is transmitted in the network to discover a path to a particular destination. Each node keeps the broadcasting ID and the name of the node from which the packet has been received. When the destination is reached, it replies with a unicast (point-to-point) packet and each intermediate node is able to establish return routes [13, 15, 16, 47].

Any communication protocol for MANETs should contend with the issue of interference in the wireless medium. When two or more nodes broadcast a packet to a neighbour at the same time, the common node will not receive any of these packets. In such a case, we say that a collision has occurred at the common node. In multi-hop MANETs where all the nodes may not be within the communication range of the source, intermediate nodes may need to help the broadcast operation by retransmitting the packet to other nodes in the network. Rebroadcast uses up valuable resources in the network, such as power and bandwidth, so it is important to choose the intermediate nodes carefully to avoid redundancy in retransmissions.

2.6.2 Characteristics of Broadcasting

The simplest approach for broadcasting is blind flooding, where every node in the network forwards the packet only once. Blind flooding ensures maximum coverage of the whole network. That is, the broadcast packet is most likely to reach every network node.

Taking the example of a MANET consisting of a set of cooperating mobile nodes, every mobile node is equipped with a CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) transceiver which can access the air medium following the IEEE 802.11 protocol [22, 23, 38].

The broadcasting is unprompted; any mobile node can issue a broadcast operation at any time. The broadcasting is unreliable in that a broadcast is transmitted in a CSMA/CA manner, and no acknowledgment mechanism is used. Note that in IEEE 802.11 [22, 23, 49, 50], the MAC specification does not allow acknowledgment on reception of a broadcast transmission. This is reasonable because if all receiving nodes send acknowledgments to the sending node, these acknowledgments are likely to collide with each other at the sender's side, resulting in a "many-to-one" broadcast storm [2, 3, 17, 18]. After receiving a broadcast packet, a node may rebroadcast the packet at least once. Additionally, it is assumed here that a node can detect duplicate broadcast packets. This is necessary to prevent endless flooding of the packet. One way to achieve this by associating each broadcast packet tuple with source ID and sequence number.

A broadcast request can be issued by any source node which has a packet for transmission to the entire network. This broadcast packet is disseminated in the network

to reach all of the nodes with a minimum number of rebroadcasts. All other nodes have a responsibility to help in disseminating the packet by rebroadcasting it. An attempt should be made to successfully distribute the packet to a potentially large number of nodes without incurring substantial computational and communication overhead.

Constant Bit Rate (CBR) traffic is usually used for connections that transfer traffic at a fixed-bit rate, where there is natural dependence on time synchronisation between the traffic source and destination. CBR is often assumed for any kind of data for which end-systems require a predictable response time and amount of bandwidth. In this research, we have used CBR traffic for evaluating the broadcast algorithms discussed above, so that a regular amount of data is inserted into the network to ensure that any type of change in the saved broadcast and reachability metrics is a result of the broadcast algorithm in use and is not affected by the status of the traffic sources. CBR is used over UDP. As UDP, unlike TCP, has no congestion mechanisms and no self-checking mechanism to ensure that data is received, or received in order. On the other hand, TCP provides more reliable connection-oriented delivery and is suitable for hard real time applications.

Additionally, UDP is more appropriate for sending limited amounts of data per packet and it is usually better for gaming, voice conferencing, and other low-latency applications. as rebroadcast is concerned, TCP is a more time consuming protocol than UDP, due to the complexity of TCP's structure, i.e. acknowledgment packets must be send, as well as packet retransmissions are forced.

2.7 The Broadcast Storm Problem

A side-effect of simple flooding is the broadcast storm problem, which has motivated the development of existing broadcasting protocols (described in the following sections). The simple flooding protocol makes radio signals likely to overlap with others in a geographical area. This is usually very costly and will result in serious disadvantages: redundant rebroadcast, contention and collision [2, 3, 6, 17]. These disadvantages include the broadcast storm problem, and are reviewed below in more detail.

2.7.1 Redundant Rebroadcast

This problem occurs when a node rebroadcasts packets that neighbouring nodes have already received [2, 3, 5, 6, 17]. For example, 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 2.2, below, illustrates the problem.
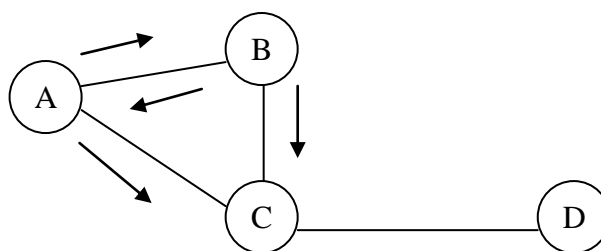
Figure 2-2: Demonstration of redundant rebroadcast and contention

2.7.2 Contention

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 dissemination of data. For example, if node *A* broadcasts to *B* and *C*, both node *B* and node *C* have to rebroadcast the packet. Node *B* is 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 that point in time because the channel is busy. Node *C* then has to wait . Figure 2.2, above, also illustrates this problem.

2.7.3 Collision

Both reservation and acknowledgment mechanisms are not used in the link layer when using flooding. This 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 2.3 shows how 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 the packet received by node *D* is dropped. This results in collision, a serious problem because the packet never gets forwarded and the data is lost [2, 3, 6, 17].
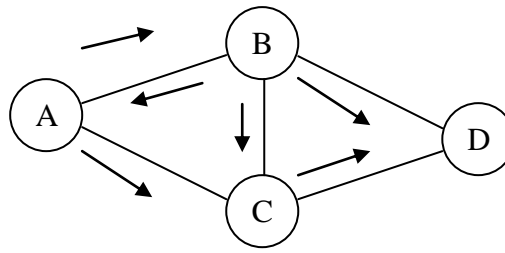
Figure 2-3: Demonstration of collision

2.7.4 Prevention of Infinite Loops

Most existing broadcast techniques [2, 3, 6, 17] 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.

2.8 Existing Broadcast Algorithms in MANETs

In both wired and wireless networks, flooding was one of the earliest broadcasting mechanisms [2, 3], with each node in the network rebroadcasting a message to its neighbours upon receiving it for the first time. The only optimisation that can be applied to this approach is for nodes to remember received packets during the flooding process without rebroadcasting if they receive duplicated copies of the same packet [51, 52]. While flooding is simple and easy to implement, it can affect the performance of a network and may lead to a serious problem commonly referred to as the "broadcast storm problem" [2, 3], consisting of a large number of redundant rebroadcast packets, collision and network bandwidth contention [2, 3, 17, 18]. A number of researchers [2-

4, 17, 18] have identified this problem and demonstrated how serious it can be through simulations and analyses, proposing several broadcasting schemes to reduce redundant rebroadcasts and differentiate timing of rebroadcasts to alleviate this problem.

Some sources [2, 3] have classified existing broadcasting techniques according to whether they are: 1) neighbour-knowledge-based, 2) location-based, 3) distance-based, 4) simple (blind), 5) counter-based, or 6) probabilistic. Further, neighbour-knowledge schemes are subdivided into those that select forwarding neighbours and those that are cluster-based. In the location-based scheme, it is assumed that a node determines whether or not to rebroadcast a packet by calculating and using its additional coverage area such as GPS [3, 17, 53]. Such schemes will therefore not form part of this treatment. as they limit the scope of any proposed algorithm to GPS-enabled agents, which are a small subset of existing MANET-enabled wireless agents. The aim of this section is to review existing broadcasting schemes in MANETs.

2.8.1 Neighbour-knowledge-based Schemes

A neighbour-knowledge scheme [48, 53-56] maintains neighbouring node information to decide who should rebroadcast. This method requires mobile hosts to explicitly exchange neighbourhood information among mobile hosts using periodic Hello packets. These schemes are classified into those selecting forwarding neighbours [48, 55] and those that are cluster-based [54].

2.8.1.1   Selecting Forwarding-neighbour Algorithms

The selection of forwarding-neighbour algorithms includes flooding with self-pruning [52], scalable broadcast [48] and dominant pruning [55, 57]. These are discussed below.

- Flooding with a Self-pruning Algorithm

Flooding with self-pruning is the simplest protocol of the neighbour-knowledge-based schemes [52]. Every node has knowledge of its 1-hop neighbours, obtained via periodic Hello packets. A node includes its list of known neighbours in the header of each broadcast packet. A node receiving a broadcast packet compares its neighbour list to the sender's neighbour list. If the receiving node would not reach any additional nodes, it abstains from rebroadcast; otherwise the node rebroadcasts the packet.

- Scalable Broadcast Algorithm (SBA)

In this algorithm, all nodes have knowledge of their neighbours within a 2-hop radius [48]. This neighbour knowledge, attached to the identity of the node from which a packet is received, allows a receiving node to determine if it would reach additional nodes by performing a rebroadcast. The 2-hop neighbour-knowledge is achievable by periodic Hello packets, each Hello packet containing the node's identifier and the list of known neighbours. After a node receives a Hello packet from all its neighbours, it has 2-hop topology information centred at itself.

- Dominant Pruning Algorithm

While self-pruning [48, 56] uses the knowledge of its 1-hop neighbours only, dominant pruning [57] extends the range of neighbourhood information into 2-hop-apart nodes.

This 2-hop-neighbourhood knowledge can be obtained by the exchange of Hello packets with neighbours. Dominant pruning should perform better than self-pruning because it is based on extended knowledge.

Another important point is that dominant pruning differs from self-pruning in terms of routing-decision point. In self-pruning, a node receiving a packet independently decides whether or not to send the packet forwards. In dominant pruning, the sender node selects neighbouring nodes that should rebroadcast the packet to complete flooding. The IDs of selected neighbouring nodes are recorded in the packet as a forward list. A neighbouring node that is requested to rebroadcast a packet again determines the forward list. This process is repeated until flooding is complete.

2.8.1.2 Clustering-based Schemes

The cluster-based scheme [53, 54] 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 whose rebroadcast can cover all hosts in that cluster. Only gateways can communicate with other clusters, and have the responsibility of disseminating the broadcast message to other clusters. Although clustering can be desirable in MANETs, the overhead of cluster configuration and maintenance is non-trivial in most cases [58]. Consequently, the total number of transmissions (forward nodes) is generally used as the cost measure for broadcasting. Cluster-head and gateway nodes together create a connected dominating set [53, 54, 58].

The maintenance of cluster configuration requires extreme communication overhead due to the "chain effect" caused by node mobility [53, 54]. Even though a lowest-ID or

highest-node-degree cluster algorithm is localised (with delayed decisions), it has no localised maintenance property. To achieve localised maintenance property, the cluster maintenance can use a different algorithm to make the update localised [53, 54, 58]. Once the cluster is constructed, a non-cluster head will never challenge the current cluster head. If a cluster head moves into an existing cluster, one of the cluster heads will give up its role as a cluster head based on some predefined priority. The localised maintenance is preserved, but at the price of increasing the number of clusters with increased node mobility [54, 59].

2.8.2 Distance-based Schemes

In the distance-based scheme [3, 5], upon receiving the packet, a node initiates a waiting timer. Before the waiting timer expires, the node checks the distance of the senders of each received packet. If the distance between the sender and receiver is larger than a threshold distance value [3, 5], the node rebroadcasts the packet. Otherwise, the node will not rebroadcast the packet.

Nodes using this scheme compare the distance between themselves and every neighbouring node that has previously rebroadcast a received packet. Upon receiving of a previously unseen packet, a Random Delay (RAD) is initiated and redundant packets are cached. When the RAD expires, all source-node positions are checked to see if any node is less than a threshold distance value. If so, the node does not rebroadcast.

This protocol requires information of neighbour positions. Signal strength could be used to measure the distance to the source of a received packet. On the other hand, if a Global Positioning System (GPS) is available, nodes could include their position

information in every packet transmitted. The distance-based scheme succeeds in reaching a large part of the network but does not economise the number of broadcast packets because a node may have received a broadcast packet many times and still rebroadcast the packet, as none of the transmission distances are less than a given distance threshold.

2.8.3 Location-based Schemes

In the location-based scheme [2, 3], upon receiving the message for the fist time the node initialises a waiting timer and accrues the coverage area that was covered by the arrived packet. When the waiting timer expires, if the accrued coverage area is lower than a threshold value, the node will rebroadcast the packet. Otherwise, the node will not rebroadcast it.

The location-based scheme [2, 3] uses a more specific estimation of expected additional coverage to make the decision to rebroadcast. In this technique, every node must have the means to determine its own position (e.g. using GPS); rebroadcasting nodes attach their positions to the header of the packet. When a node first receives a packet, it notes the position of the sender and computes the additional coverage area obtainable were to rebroadcast. If the additional area is greater than a threshold value, the node assigns a RAD before delivery. Otherwise, the node will not rebroadcast, and all future receivers of the same packet will be ignored. If the node receives a redundant packet during the RAD, it re-computes the additional coverage area and compares that value with the threshold. The area computation and threshold comparison occur with all redundant broadcasts received.

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2.8.4 Blind Flooding

Flooding is the simplest broadcasting technique [2, 3, 60-62]. In this technique, each mobile host rebroadcasts the route-request packets when received for the first time. Packets that have already been received are just discarded. In this scheme the total number of rebroadcasts is equal to $N-1$, where N is the total number of mobile nodes in the network. Though flooding is simple, it consumes considerable network resources as it introduces a large number of duplicate messages. It leads to serious redundancy, contention and collision in mobile wireless networks − i.e. a broadcast storm problem [2, 4].

2.8.5 Counter-based Schemes

The counter-based scheme inhibits the rebroadcast if the message has already been received for more than a fixed number C times [3, 8]. The counter-based scheme assumes that the expected additional coverage is so small that rebroadcast would be ineffective when the number of received broadcasting messages exceeds a certain threshold value. The authors of the scheme have used a fixed threshold C (where C is a pre-determined number of times) to reduce redundant rebroadcasts. If a node has already received the same broadcast packet more than C times, it will not rebroadcast the packet because it is unlikely that the rebroadcast will provide new information to the node's neighbourhood. When a small threshold value C (such as 2) is used [3, 4], the counter-based scheme does provide significant savings. Unfortunately, in a sparse network, reachability decreases sharply when this parameter is used, as revealed in [2, 3]. By increasing the value of C, the reachability will improve, but, once again, a metric

of SRB will suffer. To resolve the quandary between reachability and saved rebroadcasts, the authors in [17, 18] have proposed an adaptive counter-based approach in which every individual node can dynamically fine-tune its threshold C based on its neighbourhood status.

2.8.6 Probabilistic Schemes

One of the proposed solutions to reduce redundant rebroadcasts and improve the broadcast storm problem is the probabilistic scheme [2, 3, 6]. In the probabilistic scheme, when a node receives a broadcast packet for the first time, it rebroadcasts the packet with a pre-determined probability p. These types of schemes are simpler and easier to implement than their deterministic counterparts. However, the authors in [2, 3, 5, 7, 9, 17, 34] have illustrated that probabilistic flooding does not achieve a high degree of reachability in most cases, because every node has the same probability p of rebroadcasting packets regardless of its neighbours. The problem arises from the regularity of the algorithm: every node has the same probability p to rebroadcast a received packet. In dense networks, several nodes share similar transmission coverages. Thus, randomly selecting nodes not to rebroadcast saves nodes and network resources without damaging delivery effectiveness (for example, reachability). In sparse areas, there is considerably less shared coverage, so nodes may not receive all the broadcast packets with the probabilistic scheme unless the probability parameters are high.

Tseng *et al* [2] have described simple probabilistic flooding schemes. They have shown that these schemes have poor reachability and cannot achieve high levels of saved

rebroadcast packets, especially in a low-density network, because every node has the same probability of rebroadcasting the packet regardless of its number of neighbours.

Cartigny and Simplot [7] have described a probabilistic scheme where the probability p is calculated from the local density n, which is the number of neighbours, and a fixed value k as an efficiency parameter, to achieve reachability of the broadcast. However, the authors have not discussed how the parameter k is fixed for a particular network setup.

Zhang and Agrawal [8, 9] have also described a dynamic probabilistic scheme which uses a combination of probabilistic and counter-based schemes. This scheme dynamically adjusts the rebroadcast probability p at every mobile host according to the value of the packet counter. The value of the packet counter does not necessarily correspond to the exact number of neighbours from the current host, since some of its neighbours may have suppressed their rebroadcasts according to their local rebroadcast probability. The authors in [2, 3, 17] have used a fixed threshold C to reduce redundant rebroadcasts. If a node has already received the same broadcast packet more than C times, it will not rebroadcast the packet because it is unlikely that the rebroadcast will provide new information to the node's neighbourhood. As shown in [2, 3, 17], a threshold C of 3 and 4 can significantly reduce the redundant rebroadcast in a dense network while achieving better reachability, comparable with that achieved by flooding. A larger threshold value of C (i.e. 6) will provide lower savings of redundant rebroadcasts and may perform similar to flooding. Increasing the value of C improves reachability, but the efficiency of the broadcast algorithm in terms of redundant rebroadcasts will suffer. To determine the trade-off between reachability and redundant

rebroadcast control, what is required is a dynamic counter-based scheme in which each individual node can dynamically adjust the counter value using neighbourhood information. It should be noted, however, that the decision to rebroadcast is made after a random delay, which does increase latency.

Bani Yassein *et al*. [1, 10] have proposed a fixed pair of adjusted probabilistic broadcasting scheme *p1* and *p2* where the forwarding probability *p* is adjusted by the local topology information. Topology information is obtained by proactive exchange of Hello packets between neighbours to construct a 1-hop neighbour list at every host. The adjusted probabilistic flooding scheme is a combination of the probabilistic and knowledge-based approaches. The adjusted probabilistic flooding algorithm also uses the average number of nodes to decide whether or not to rebroadcast. On receiving a broadcast message at a node, the node rebroadcasts it with high probability if the message is received for the first time and the number of its neighbours is less than the average number of neighbours typical of its neighbouring environment. Hence, if a node has a low degree, i.e. a low number of neighbours, rebroadcast should be likely. If it has a high degree, its rebroadcast probability is set low.

The limitations of the adjusted probabilistic route discovery algorithm motivates a 2-*p* scheme which defines the forwarding probability at a node as a function of its neighbourhood information. In such a case, the nodes are logically classified into two groups based on their number of neighbours. A node is classified as a member of group 1 if its number of neighbours (n) is less than or equal to $\bar{n}$, otherwise it is classified as a member of group 2. Nodes in group 1 are in sparse areas of the network and as such are

assigned high forwarding probability, $p1$. Nodes in group 2 are located in dense areas and are assigned low forwarding probability, $p2$.

2.9 Ad-hoc On-demand Distance Vector (AODV) Routing

AODV is a reactive routing protocol [13, 47] that is responsible for routing data between a specified pair of nodes in a MANET. It sets up a route to a destination only when desired by the source node. AODV, like many other existing routing protocols, uses simple blind flooding to establish routes between a known pair of nodes. AODV uses similar route discovery and maintenance mechanisms as DSR [15, 16] and the sequence number technique of DSDV [21]. It creates routes on demand in order to minimise the traffic generated due to broadcasting RREQ packets. Unlike DSDV, AODV does away with the maintenance of the routing table of the entire network.

AODV is considered to be a pure on-demand routing protocol because nodes that are not in the selected path to a destination do not participate in routing decisions or maintain any routes. Routes in AODV are discovered, created and maintained only as and when needed. To ensure loop freedom during message routing, sequence numbers are created and updated by every node as and when used. The sequence numbers also allow the nodes to select the most recent (fresh) route to a selected destination node.

Moreover, in AODV a node stores other routing information, such as next destination and hop addresses as well as the sequence number of a destination. Beside that, a node also keeps a list of the precursor nodes that route through it in order to make route maintenance easier after link breakage. To avoid storing information and maintaining

routes that are no longer used, each route has a lifetime. If during this time the route has not been used, it is discarded.

Basic Operation:

Whenever a source wants to talk with a destination, it checks if there is any an existing route to that destination. If there is no present route, it initiates a route discovery by broadcasting a RREQ packet to its neighbours. The source address and the broadcast ID (incremented for every RREQ) generated uniquely identifies an RREQ packet. The RREQ packet is disseminated [12, 13, 16, 46, 52, 63] onto the MANET until it reaches the destination or reaches a node which has the better route to the destination. The route with the highest sequence number is indicated as the latest (or better) route. The destination or intermediate node sends back an RREP packet, which includes the number of hops in between and a sequence number. The RREP is forwarded along the reverse path over which the RREQ was received. Every node receiving the RREP packet creates a forward route to the destination. Thus, every node remembers only the next hop required to reach a given destination, as there is no need to know the whole route. Every route has a timer associated with it, which indicates the time period for which the route is valid.

If no RREQ packet has been sent within, by default, one second, each node broadcasts a Hello packet to its neighbours in order to keep connectivity up to date. These packets contain the node's IP address and its current sequence number. The Hello packets have a Time to Live (TTL) value so that they are not forwarded from the node's neighbours to third parties.

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2.10 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, and 3) simulation [64, 65]. In this section, these three techniques are introduced.

2.10.1 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 characteristics of performance evaluation using this approach is the employment of real or synthetic workloads to measures their performance on actual hardware [64, 65]. Monitoring tools which 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 [64, 65]. Hardware monitoring tools are electronic devices that are connected to specific communication system points in order to detect signals characterising phenomena to be observed. As for hybrid monitoring tools, these are a combination of software and hardware monitoring tools. Measurements may not give accurate results simply because many of the environmental parameters, such as system

configuration, type of workload, and time of the measurement, may be unique to the experiment. Also, the parameters may not represent the range of variables found in the real world. Thus, the accuracy of results can vary from very high to none when using the measurements technique. Measurement requires real equipment, instruments, and time. It is the most costly of the three techniques. Cost, along with the ease of being able to change configurations, is often the reason for developing simulations for expensive systems.

2.10.2 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 [64, 65]. 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 that are tractable.

2.10.3 Simulation Technique

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 [64, 65]. 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.

2.11 Justification of the Method of Research

In this work, extensive simulations were conducted to explore performance-related issues of probabilistic flooding in MANETs. This section briefly discusses the choice of simulation as the proper method of study for the purpose of this thesis, justifying the adoption of the GloMoSim as the preferred simulator, and further provides information on the techniques used to reduce the incidence of simulation errors.

After some consideration, simulation was chosen as the method of study for this thesis because when this research was begun, 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 probabilistic flooding with any reasonable degree of accuracy. It should be noted, however, that understanding of multi-hop wireless communications has improved in current years [66]. Furthermore, since the scope of this study of broadcasting in MANETs involves several mobiles nodes, even a moderate deployment of nodes as an experimental test-bed could involve substantial and too-expensive costs. As such, simulation was 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, there are many network simulators available for example OMNET++ [67], Opnet [68],Ns2 [69] and GloMoSim [70], the popular Global Mobile Information System Simulator (GloMoSim) (v2.23) [70] has been used extensively in this work. The GloMoSim is a scalable simulation environment for large wireless and wired communication networks [70]. The GloMoSim was chosen primarily because it is a proven simulation tool and has recently gained popularity within the wireless ad-hoc networking community due to the fact that it was designed specifically for scalable network simulation [71, 72]. The GloMoSim implements a technique called "node aggregation" where in multiple simulations, nodes are multiplexed within a single Parsec entity [73], effectively reducing memory consumption. The GloMoSim simulates networks with up to one 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.

Further, real-life implementations of routing agents such as AODV [13] were used in some of the simulations conducted in this thesis in order to achieve a close approximation of real system behaviour.

2.12 Summary

In order to provide a background of the performance evaluation of MANETs, this chapter describes the MANETs including their types, features, applications and advantages/disadvantages. This chapter has described the routing principles in MANETs and the characteristics of broadcast operations in MANETs including redundancy, collision and contention. The chapter has also provided a general overview of existing broadcasting techniques proposed in MANETs including neighbour-knowledge-based, distance-based, location-based, counter-based, blind and probabilistic flooding schemes. It then went on to provide a description of Ad-hoc On-demand Distance Vector (AODV) Routing protocols. This chapter also described performance evaluation techniques. Finally, the chapter has provided justification for using GloMoSim simulations as the method of study for this research.

Chapter 3

Dynamic Probabilistic Broadcasting Flooding Scheme for Routing Protocols in MANETs

3.1 Introduction

Mobile Ad-hoc Networks (MANETs) are self-organising mobile wireless networks that do not rely on pre-existing infrastructures to communicate. Network-wide dissemination is used widely in MANETs [7, 48] for the process of route invention, address resolution and other network-layer tasks. For example, on-demand routing protocols such as Ad-hoc On-demand Distance Vector (AODV) [13, 20] and Dynamic Source Routing (DSR) [15, 16] 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 various 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 [63].

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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 received for the first time. Packets that have already been received are just discarded. Though flooding is simple, it consumes much 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 a broadcast storm problem [2, 3].

In order to enhance the performance of dynamic routing protocols, we propose a dynamic probabilistic broadcast approach that can efficiently reduce broadcast redundancy in mobile wireless networks. The proposed algorithm dynamically calculates the host rebroadcast probability according to the information about the number of neighbouring nodes. The rebroadcast probability would be low when the number of neighbouring nodes is high, i.e. the host is in dense area, and the probability would be high when the number of neighbouring nodes is low, i.e. the host is in a sparse area. Performance results based on simulation experiments demonstrate that the proposed algorithm scheme outperforms simple flooding (AODV) and fixed probabilistic algorithms in terms of SRB, collision, relays, throughput and end-to-end delay.

The remainder of this chapter is organised as follows: Section 3.2 presents the ideas and algorithm of the dynamic probabilistic flooding scheme. Section 3.3 describes the experimental scenarios and the setting of simulation parameters. Section 3.4 presents and analyses the performance results obtained from simulation experiments. Finally, Section 3.5 summarises this chapter.

3.2 Proposed Dynamic Probabilistic Broadcasting Scheme

As explained above, traditional flooding [5] 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 fixed probabilistic flooding the rebroadcast probability p is fixed for every node. This scheme is one of the alternative approaches to flooding that aims to limit the number of redundant transmissions. In this scheme, when receiving a broadcast message for the first time, a node rebroadcasts the message with a pre-determined probability p. Thus, every node has the same probability of rebroadcasting the message, regardless of its number of neighbours.

In dense networks, multiple nodes share similar transmission ranges. Therefore, these probabilities control 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 unless the probability parameter is high. Therefore, setting the rebroadcast probability p to a very low value will result in a poor reachability. On the other hand, if p is set to a very high value, many redundant rebroadcasts will be generated.

The proposed algorithm dynamically calculates the value of rebroadcast probability p at each mobile host according to the number of its neighbouring nodes. The value of p will differ from area to area. In a sparser area the rebroadcast probability is higher, while in a denser area the probability is lower (as shown in Figures 3.1 a. and b.). A higher value

of p means a higher number of redundant rebroadcasts, while a lower value of p means lower reachability.

a. Sparse Region   b. Dense Region
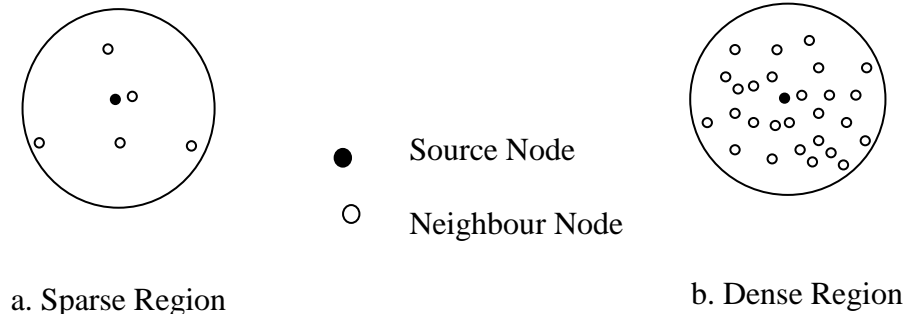
Figure 3-1: a. Sparse region and b. dense region

Figure 3.2 describes the dynamic probabilistic broadcasting algorithm.

Procedure

Input Parameters:
$pkt(i)$: Packet to relay by i^{th} node.
p(i): Rebroadcast probability of packet (*pkt*) of ith node.
$RN(i)$: Random Number for i^{th} node to compare with rebroadcast probability p.
$n_{nbr}(i)$: Number of neighbouring nodes of ith node.
$nbrTable(i)$: Neighbour table for i^{th} node.

Output Parameters:
$Discpkt(i)$: Packet (*pkt*) will be discarded by the ith node, if it is already in its list.
$Rbdpkt(i)$: Packet (*pkt*) will be rebroadcast by i^{th} node, if probability p is high.
$Drpkt(i)$: Packet (*pkt*) will be dropped by i^{th} node, if probability p is low.

Calculation of broadcasting probability upon receiving a broadcast packet (*pkt*)
if a packet (*pkt*) is received for the 1st time at the ith node then
   {
      get *nbrTable(i)*

```
        if size (nbrTable(i)) = = 0 then
           return (0)
        else
         {
           p_max =0.9 ;
           p_min =0.4
```

$$S_n = p_{\max} \sum_{n=0}^{nbr} p_{\max}^n$$

$$S_n = p_{\max} \frac{\left(1 - p_{\max}^{nbr}\right)}{1 - p_{\max}}$$

```
          where n= 1, 2, 3, ...

          To get value of p for any term at i^th node

          p(i) = S_n - S_{n-1}
```

Since we have p^n_{max} and as: $0 < p^n_{max} < 1$, this term will tend to zero for large values of n_{nbr}, so the above expressions can be simplified as:

$$S_\infty = \frac{1}{1 - p_{\max}}$$

```
        if p(i) < p_min then
     {
             p(i) = p_min

             Relay the packet (pkt) only if (p(i) > RN(i) )
          }
           else
       Drop (pkt)
          }
}
  else
Drop (pkt)
```

Figure 3-2: Dynamic probabilistic flooding algorithm

The neighbour table *nbrTable(i)* for i^{th} node is formed by sending periodic Hello packets and entries in the table are updated based on replies received from the neighbours.

$$P_{min} \leq p(i) \leq P_{max} \qquad\qquad (3.1)$$

Equation (3.1) shows the upper and lower values of $p(i)$ for different numbers of neighbouring nodes.

The proposed algorithm dynamically calculates the value of rebroadcast probability $p(i)$. A higher value of $p(i)$ means a higher number of redundant rebroadcasts, as demonstrated by Figure 3.3, where a smaller value of $p(i)$ indicates lower reachability, as demonstrated in Figure 3.4. Hence, the rebroadcast probability $p(i)$ is calculated according to the information from neighbouring nodes. Figure 3.3 shows the collision result for different value of p_{min}(0.3,0.4 and 0.5) under different number of connections as well as figure 3.4 shows the reachability result for the same values of p_{min}. By choosing different values of P_{min} for our dynamic probabilistic flooding algorithm and getting simulation results, we conclude that the best results can be achieved for $P_{min}=0.4$ because we are looking to get less number of collision and at the same time to keep reachability acceptable
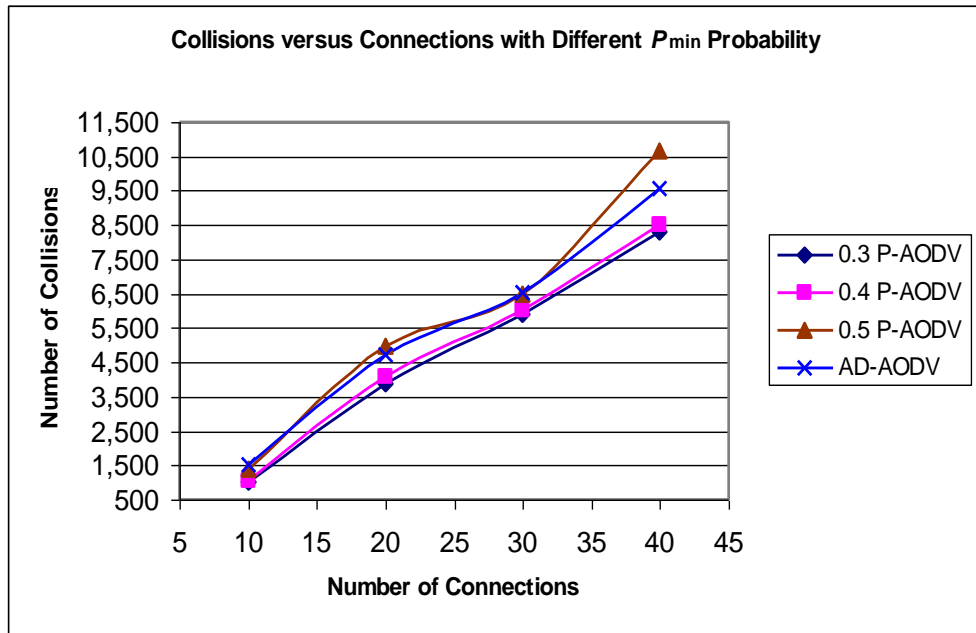
Figure 3-3: Collisions versus traffic load
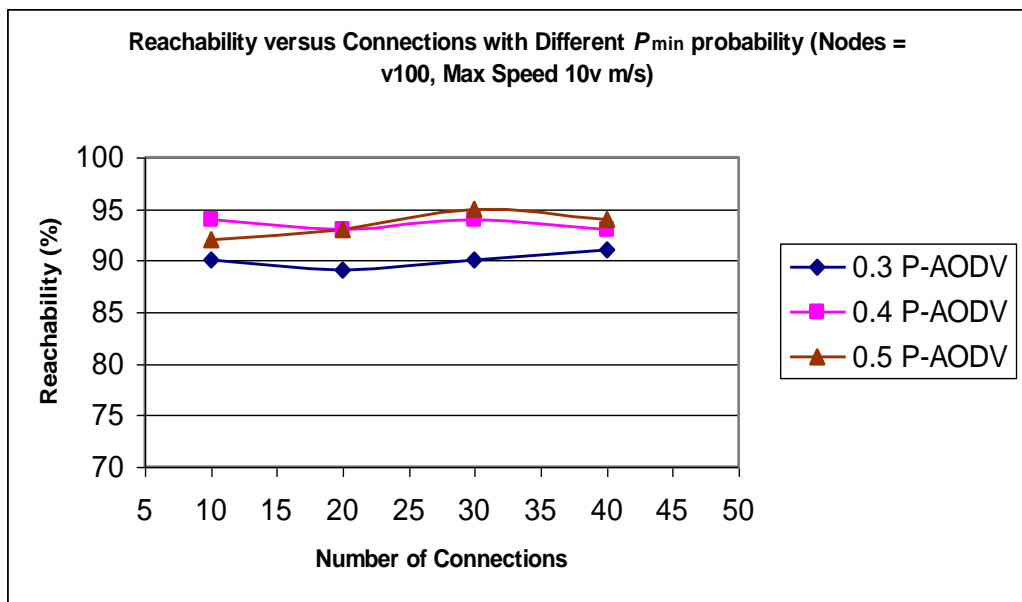
Figure 3-4: Reachability versus traffic load

3.3 Simulation Scenarios and Configuration

The well-known Global Mobile Simulator Network (GloMoSim) version 2.03 [70] has been used to conduct extensive experiments for the evaluation of the behaviour of the proposed dynamic probabilistic flooding algorithm. 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 [5, 6, 13], which is included in the GloMoSim package. The original AODV protocol uses simple blind flooding to broadcast routing requests. Three AODV variations were implemented: first using a probabilistic method with fixed probability [3, 4], called FP-AODV (AODV + Fixed Probability), second using Adjusted Probabilistic Flooding (AD-AODV) [1, 10], and third using a method based on dynamically calculating the rebroadcast probability for each node, called P-AODV (AODV + Dynamic Probability).

In our simulation, we use a 600m $\times$ 600m and a 1000m $\times$ 1000m area with a Random Waypoint (RWP) mobility model [74, 75] of 80 and 100 mobile hosts in random distribution. The network bandwidth is 2 Mbps and the medium access control (MAC) layer protocol is IEEE 802.11[25, 50]. The packet size is 10 p/s witch will generate enough traffic when we increase the number of connections for example at 40 connection of source-destination pairs, it will generate 400 packets per second for hole scenario. Other simulation parameters are shown in Table 3.1. These parameters have been widely used in the literature [1, 4, 8-10].

The main purpose behind the proposed approach is to reduce the number of rebroadcast packets in the route-discovery phase, thus reducing network traffic and decreasing the

probability of channel contention and packet collision. As a result, end-to-end delay can also be reduced and the throughput can be improved.

Since the proposed algorithm is based on a probabilistic approach, it does not fit every scenario, and there is a small chance that the route requests will not be able to reach their destinations. It is necessary to re-generate the route request if the previous route request failed to reach its destination. The AODV protocol, in contrast, uses flooding in the route-discovery phase. Therefore, all route requests will reach their destinations if the network is not partitioned. Based on this analysis, our algorithm performs better than AODV in dense networks.

Table 3.1: Simulation Parameters

Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	600m × 600m and 1000m × 1000m
Transmission Range	250m
Mobile Nodes	80 and 100
Traffic Generator	Constant Bit Rate
Band Width	2 Mbps
Packet Size	512 Bytes
Packet Rate	10 Packet 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.

3.4 Performance Analysis and Evaluation

These simulation experiments aim to investigate the performance of the proposed dynamic probabilistic broadcasting algorithm. We compare the proposed algorithm against a simple flooding algorithm, a probabilistic algorithm, fixed rebroadcast probability and adjusted flooding. The performance metrics for comparison include the average number of routing request rebroadcasts, SRB, average number of collisions, reachability and end-to-end delay. Figure 3.5 shows the network topology.
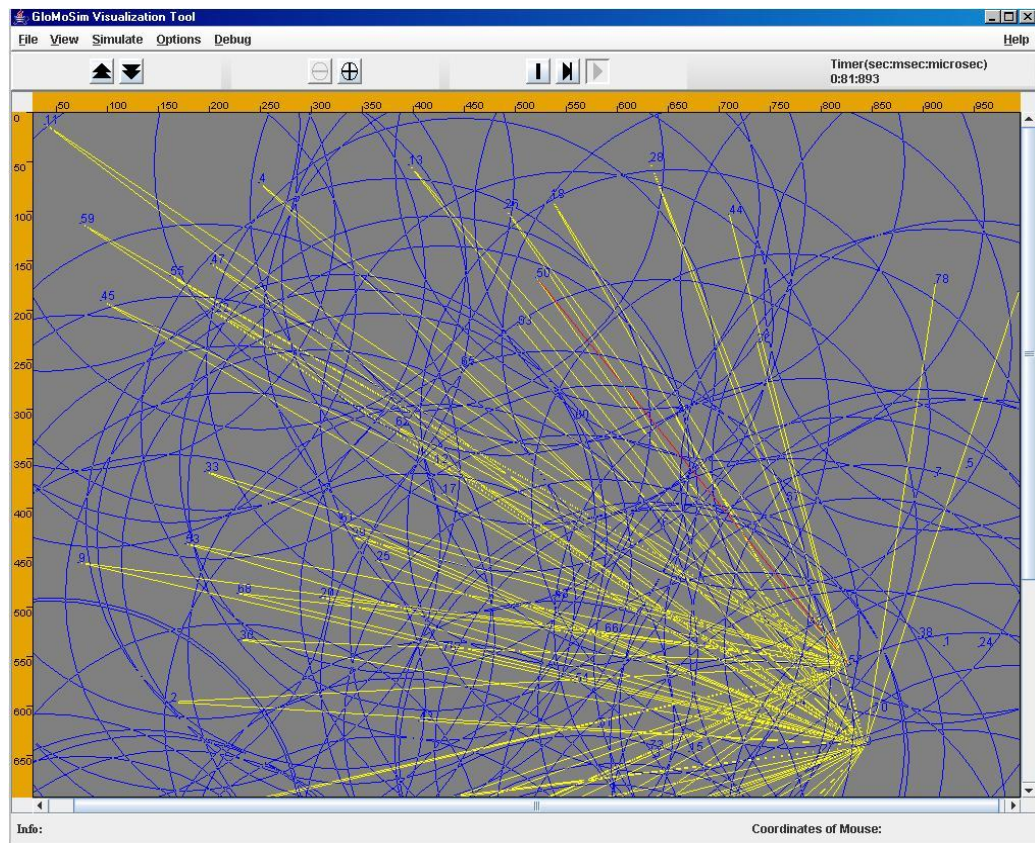
Figure 3-5: Network Topology

3.4.1 Saved Rebroadcast (SRB)

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 FP-AODV, every node decides to rebroadcast according to a fixed probability *p*. As their decisions are independent, the total number of rebroadcasts is, on average, *p*(N-1)*. In our proposed algorithm, the rebroadcast probability is dynamically calculated. In sparser areas, the probability is high and in denser areas it is low. This scheme ensures a high reachability and a less number of rebroadcasts, thus significantly improving overall performance. SRB, expressed in equation 3.2 (below), is the ratio of the number of route-request packets rebroadcast (*RREQs-B*) over the total number of route-request packets received (*RREQs-R*), excluding those expired by Time To Live (*TTL*). As a result, the ratio of SRB in P-AODV is significantly higher than that of FP-AODV and AD-AODV. Next, we evaluate the number of rebroadcasts in AODV, FP-AODV, AD-AODV and P-AODV through simulation.

$$SRB = (RREQs \ B \ / \ (RREQs \ R - TTL)) * 100$$

(3.2)

Figure 3.6 shows that the proposed algorithm can significantly achieve a higher number of SRB than fixed probability for a network of 80 nodes, no mobility and a varying number of connections. For instance, the SRB of P-AODV is 55% at 20 source-destination connections and 38% at 40 source-destination connections compared with fixed probability. There is a noticeable difference between the two variants in that the

performance of the proposed algorithm over fixed probability is higher by around 25% in lowest source-destination connections and 9% in highest source-destination connections.

Figure 3.7 also explores SRB in the two algorithms for various network mobility conditions where the maximum node speed has been varied from 10 to 25 m/s in a network of 100 nodes and 10 source-destination pairs. The figure reveals that the proposed improved algorithm still delivers the best performance over the other algorithm.

In Figure 3.8, we have varied the number of connections by considering four traffic loads, notably 10, 20, 30 and 40 source-destination pairs. The number of nodes has been kept at 100 nodes with a maximum speed of 10 m/s and a 95% confidence under 50 times runs. Again, the figure shows that our algorithm can significantly improves SRB at different traffic loads compared to the adjusted flooding scheme. For instance, our algorithm achieves 36% in terms of SRB in low connections and 54% in high connections, while the adjusted flooding scheme achieves 29% in low connections and 48% in high connections. As Figures 3.6, 3.7 and 3.8 demonstrate, there are real savings in the number of rebroadcasts. This is due to the fact that in probabilistic flooding, some nodes might be prohibited from rebroadcasting a packet if its probability value is higher than the set threshold, thereby increasing the number of savings made by nodes in terms of rebroadcasting.

Figure 3.9 shows the relationship between the number of relays and different traffic loads with 80 nodes and a maximum speed 10 m/s. It demonstrates that the number of route-request rebroadcasts increases when the traffic load increases. The P-AODV has the least number of rebroadcasts for almost all traffic loads. The traffic load was varied by using different numbers of Constant Bite Rate (CBR) source-destination connections. As shown in the figure, savings are higher when the traffic load is heavier.

Figure 3.10 shows the relationship between the number of relays and different mobility speeds from 15 to 25 m/s for a network with 100 nodes and 10 source-destination pairs. After the introduction of mobility, more route requests are generated and some of them may fail to reach their destinations. Such failures cause another round of route-request packet transmission. As shown in Figure 3.10, the proposed approach has lower relay numbers than FP-AODV.

Figure 3.11 shows the relationship between the numbers of relays and different numbers of connections for a network with 100 nodes and 10 m/s maximum speed. As shown in the figure, the proposed algorithm has achieved fewer numbers of relays than AD-AODV. It also shows the number of route-request rebroadcasts increasing when the traffic load increases, due to the generation of higher numbers of route requests when increasing the number of connections in the network.
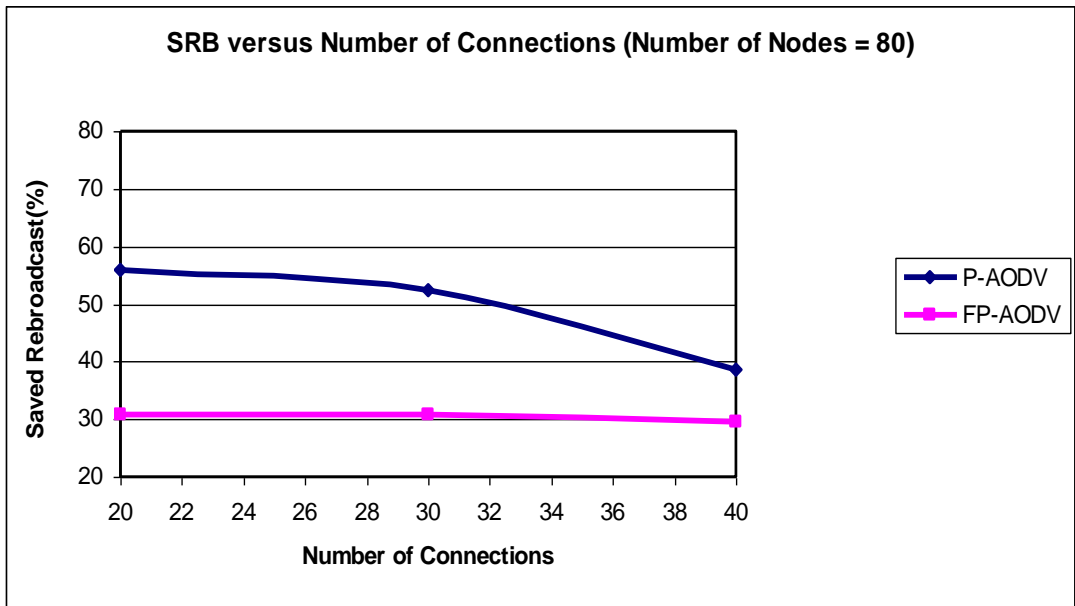
54

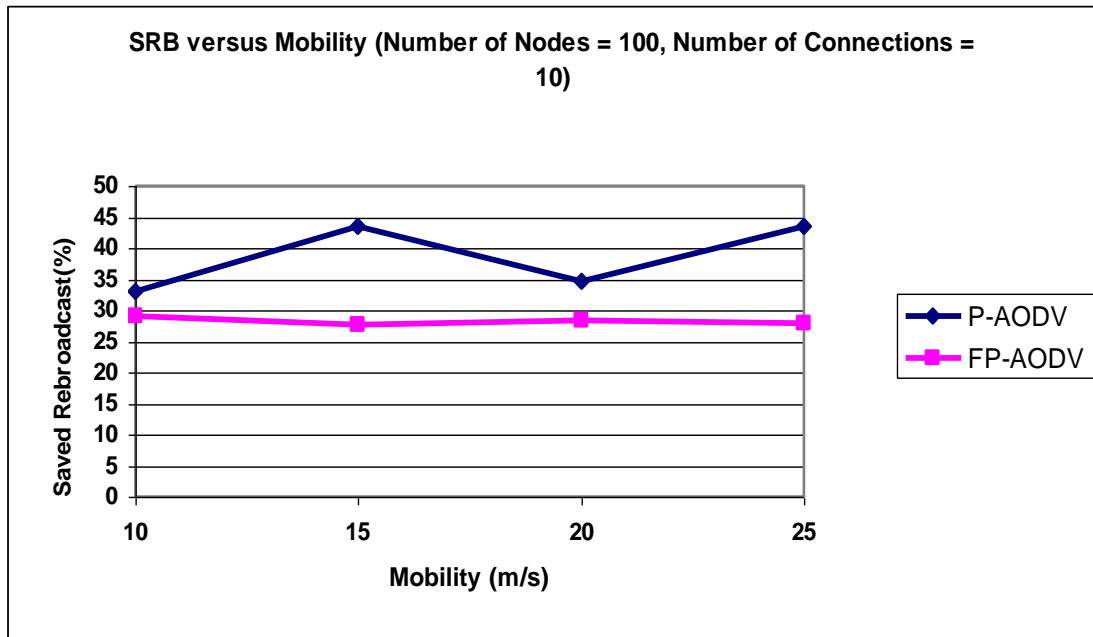Figure 3-6: SRB versus traffic load

Figure 3-7: SRB versus mobility
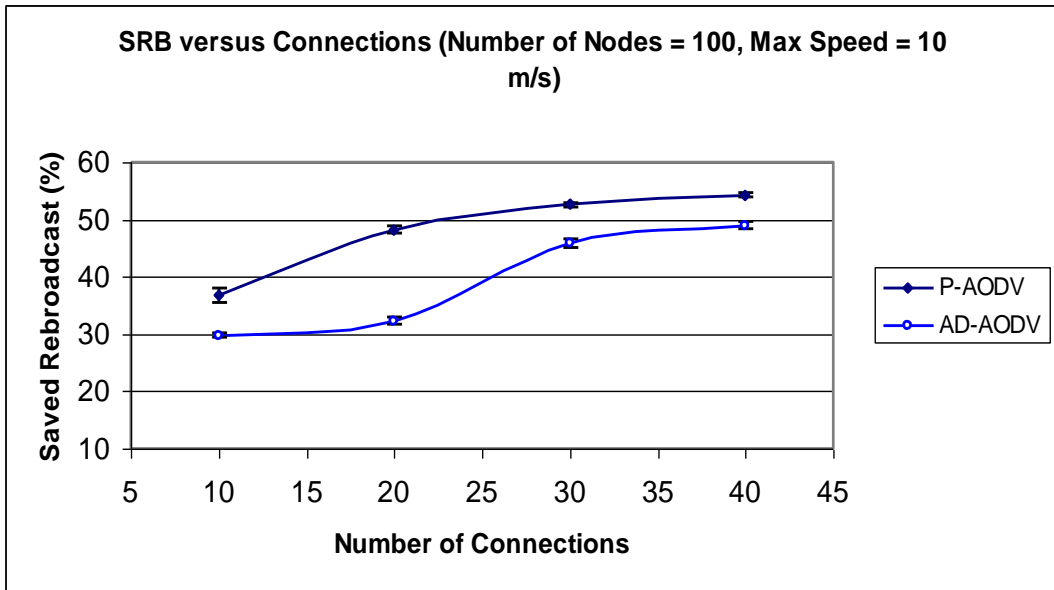
Figure 3-8: SRB versus traffic load
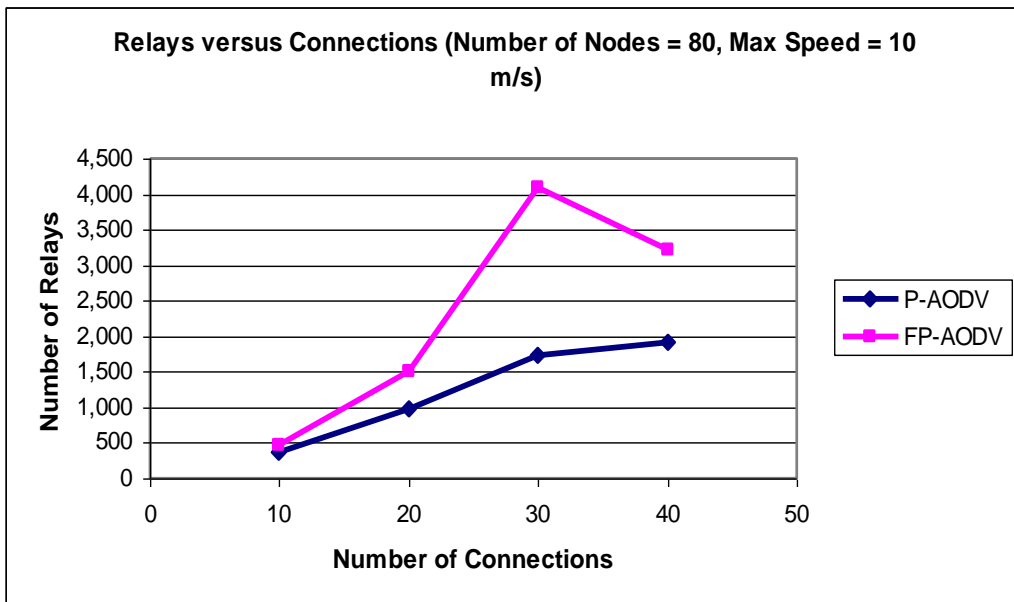
Figure 3-9: Relays versus traffic load
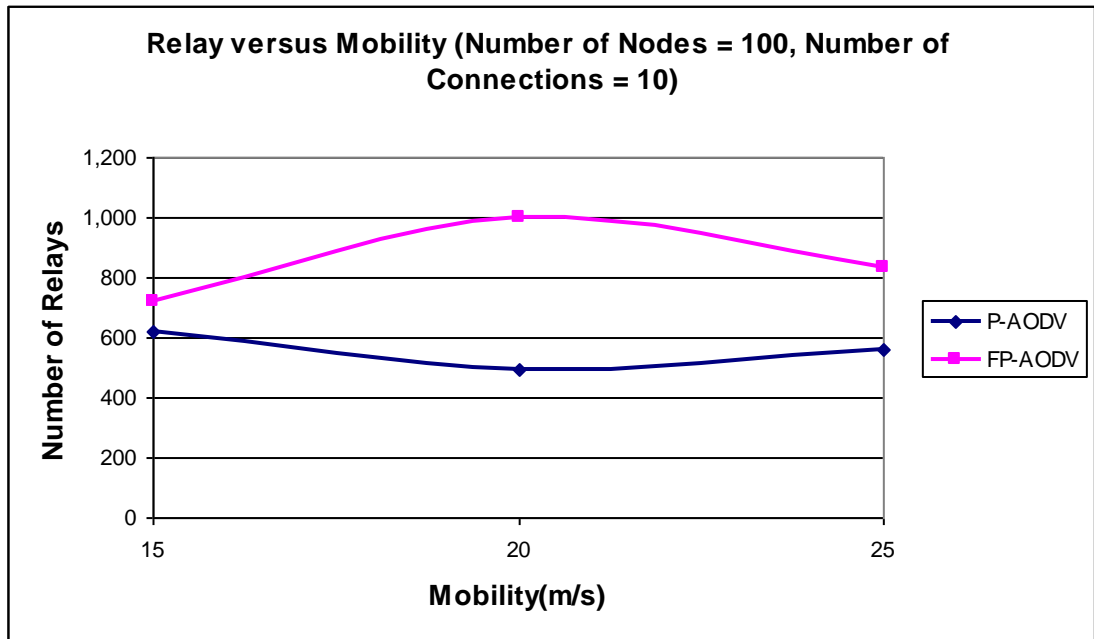
Figure 3-10: Relays versus mobility
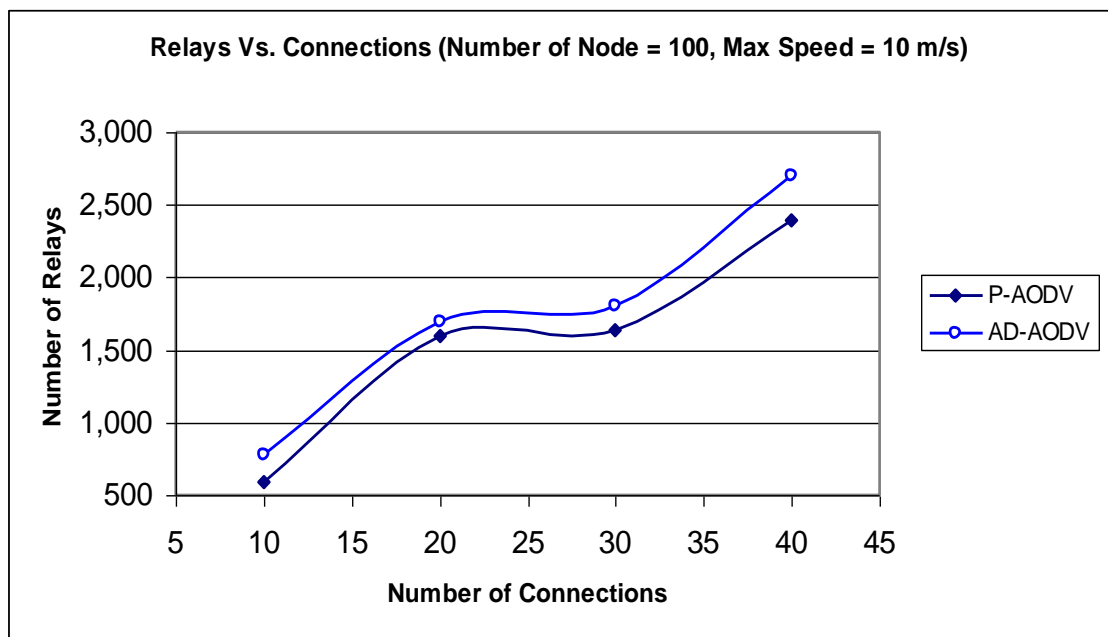
Figure 3-11: Relays versus traffic load

3.4.2 Collisions

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 3.12 shows the number of collisions for networks with 80 nodes, 10 m/s maximum speed and different numbers of connections from 10, 20 and 30 to 40 source destinations. As shown in Figure 3.12, the proposed algorithm incurs fewer collisions than simple AODV and FP-AODV. It also shows the number of collisions increasing as traffic load increases. This is because when the number of connections increases, more route requests are generated, leading to more collisions as a result of the increase in control packets.

Figure 3.13 shows the number of collisions for a network with 100 nodes, 10 connections of source-destination pairs under the RWP mobility model with a variety of maximum speeds from 10, 15 and 20 to 25 m/s. In Figure 3.13 we show performance with different mobility settings. When node mobility increases, more route requests fail to reach their destinations. In such cases, more route requests are generated, leading to more collisions as a result of the increasing number of control packets. It is clearly showed that the proposed algorithm shows the lowest number of collisions amongst all.

Figure 3.14 depicts collision results where the different source-destination pairs have been applied to the network and where the number of nodes is kept at 100 nodes under

the RWP mobility model with a maximum speed of 10 m/s. Again, in this scenario the proposed algorithm incurs fewer collisions compared to adjusted flooding. It also shows that collisions increase when the traffic load is increasing.
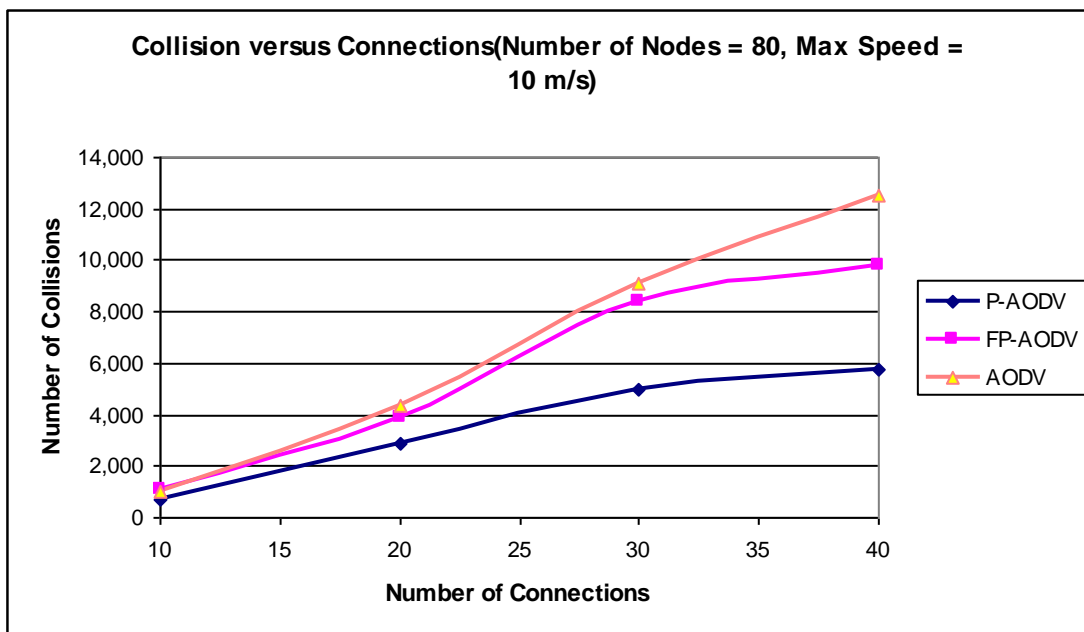
Figure 3-12: Number of collisions versus traffic load
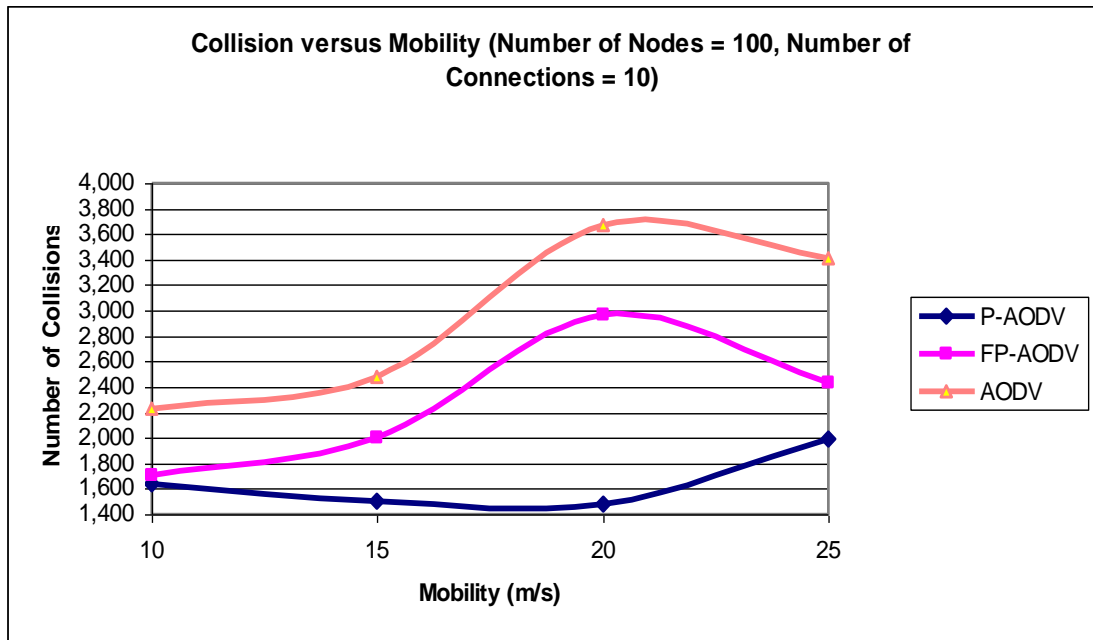
Figure 3-13: Number of collisions versus mobility
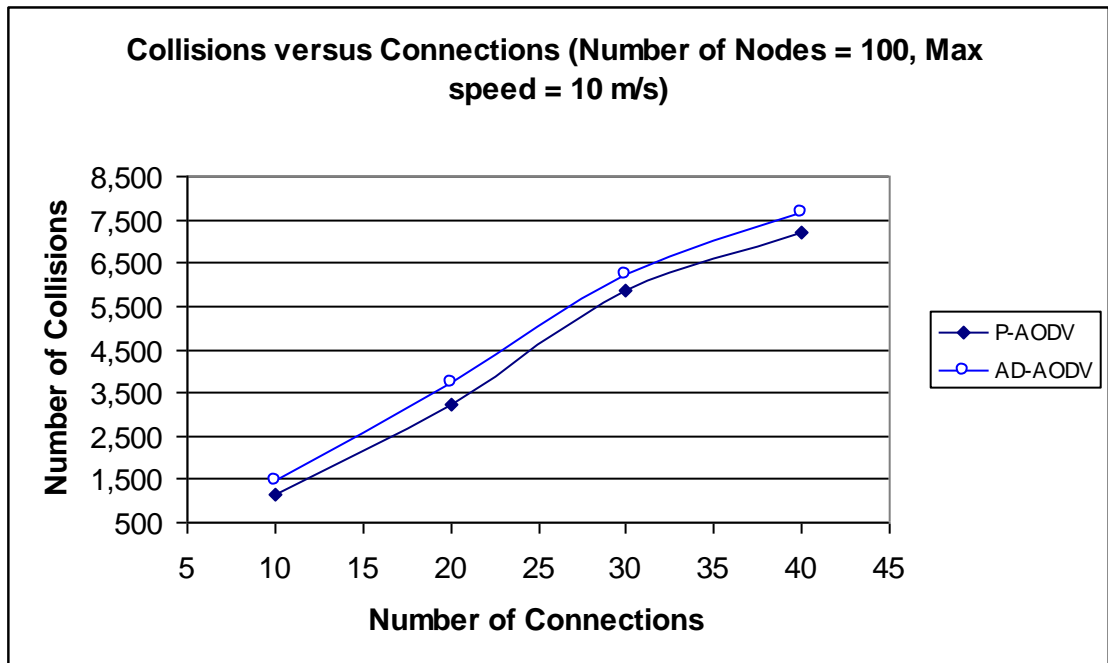
Figure 3-14: Number of collisions versus traffic load

3.4.3 Reachability

The metric of reachability measures the proportion of nodes which 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. Reachability in the context of the AODV routing protocol was examined.

We randomly selected source-destination node pairs and checked if 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. We calculated the ratio of the node pairs that have a route between the source and the destination over the total number of selected pairs [8, 9]. This ratio is not exactly equal to the reachability, but it is proportional to it. We used this ratio to compare the reachability of different approaches.

Figure 3.15 shows the reachability for a network with 80 nodes, no mobility, and 20, 30 and 40 connections of source-destination pairs for 10 times run of simulation with 95% of confidence. The figure shows that an improved probabilistic algorithm has a higher

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reachability than fixed-probabilistic and simple flooding at 20 and 40 connections. For instance, reachability is 95% for our algorithm at 20 connections compared to 85% for fixed-probabilistic and simple flooding. Reachability for all approaches with 30 connections is the same. This can be attributed to the increasing number of collisions of rebroadcast packets.

Figure 3.16 explores reachability results in the proposed algorithm and adjusted flooding for a network with 100 nodes moving according to an RWP mobility model at a maximum mobility speed of 10 m/s. The performance of our algorithm shows that reachability is above 93% for any traffic load. For all traffic loads, reachability in the proposed algorithm is the same or better than in the adjusted flooding scheme.
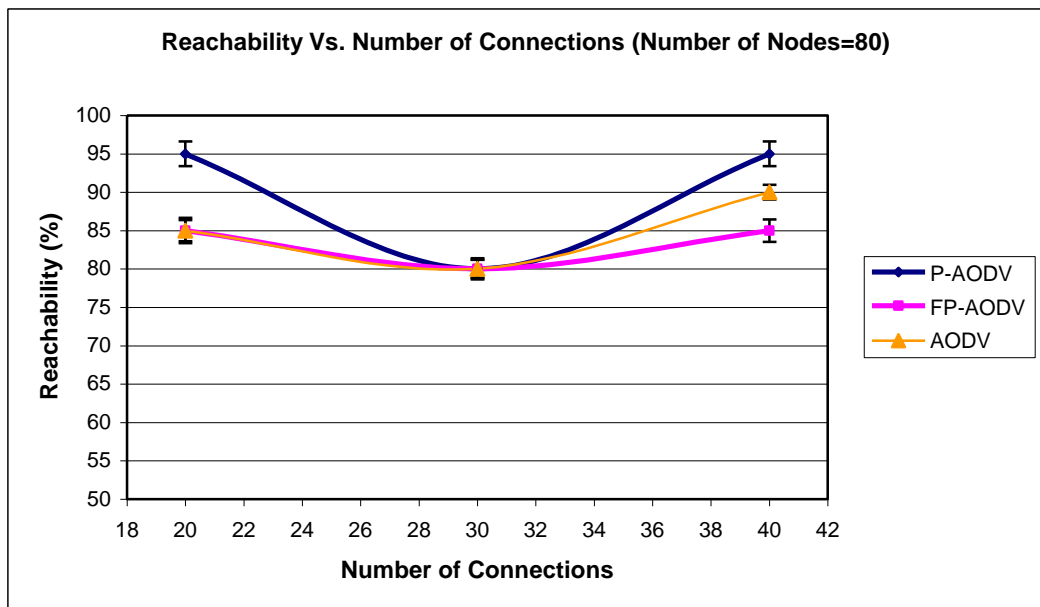
Figure 3-15: Reachability versus traffic load
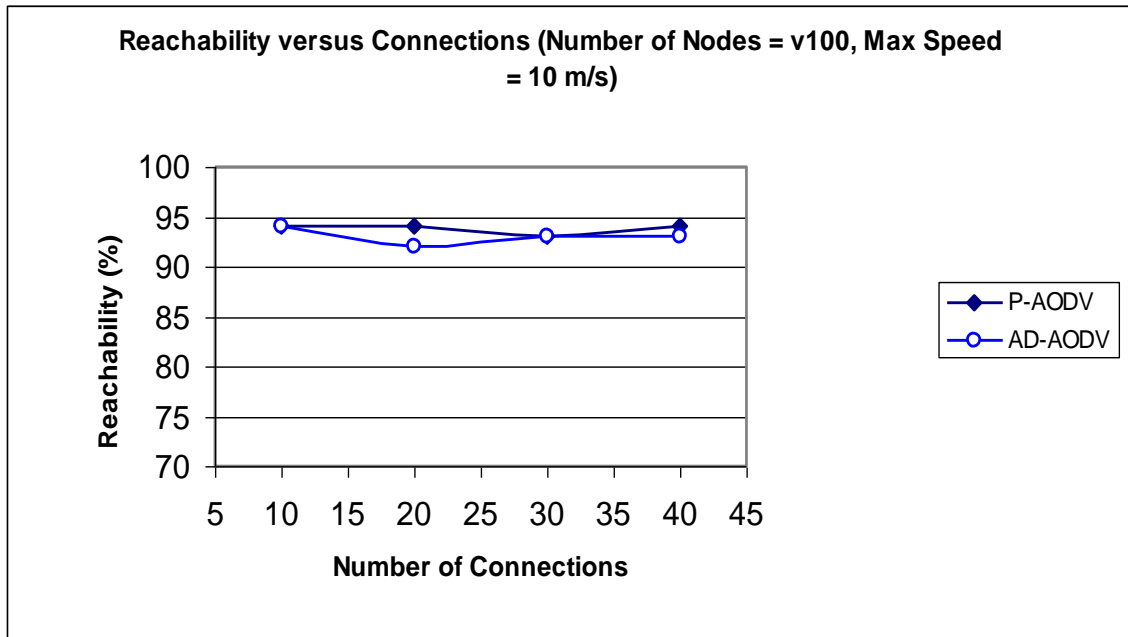
Figure 3-16: Reachability Vs. Traffic Load.

3.4.4 Latency

Broadcast latency was measured for the four approaches. The start time of a broadcast was recorded as well as the time when the broadcast packet reached the last node.

The difference between these two values is used as the broadcast latency. Since rebroadcasts can cause collision and possible contention for shared channels, the improved probabilistic approach incurs the lowest number of rebroadcasts and consequently generates the lowest latency.

Figure 3.17 shows the latency of data packets in three routing protocols for different levels of traffic loads and no node mobility. The number of total packets transmitted on a wireless channel has a significant impact on latency. If the number of packets is high, then the number of collisions will increase, leading in turn to more retransmissions. As a result, packets experience high latencies. As expected, the improved probabilistic algorithm displays lower latency than blind flooding and fixed probabilistic approaches. This is due to the fact that there are higher numbers of redundant rebroadcasts of RREQ packets in blind flooding and fixed probabilistic approaches. This causes contention and collision, and as a result many RREQ packets fail to reach their destinations. As a consequence, another RREQ packet is initiated and the overall latency to establish route increases. For instance, latency increlases from 0.04 to 0.14 sec in P-AODV when the traffic load increases from 20 to 40 connections of source destination pairs. Latency in FP-AODV increases from 0.06 to 0.15 sec whereas it increases from 0.06 to 0.12 sec in AODV. As expected, data packets in AODV experience a lower latency than in P-AODV and FP-AODV when the number of connection increases more than 30 connections. This is due to the fact that there are number of rebroadcasts of RREQ packets in P-AODV and FP-AODV prevent from rebroadcast becuase of the probability. This causes contention and collision, and as a result many RREQ packets fail to reach the destinations which will affect the latency. As a consequence, another RREQ packet is initiated and the overall latency to establish route increases

Figure 3.18 compares the latency of a different number of traffic loads for a network with 100 nodes when the nodes move at a maximum mobility speed of 10 m/s for the proposed algorithm (P-AODV) and adjusted flooding (AD-AODV). The figure shows

again that in P-AODV, data packets experience a lower latency than in AD-AODV. For example, latency increases from 0.4 to 3.6 sec in P-AODV whereas it increases from 0.5 to 4.4 sec in AD-AODV when the traffic load increases from 10 to 40 connections of source-destination pairs.
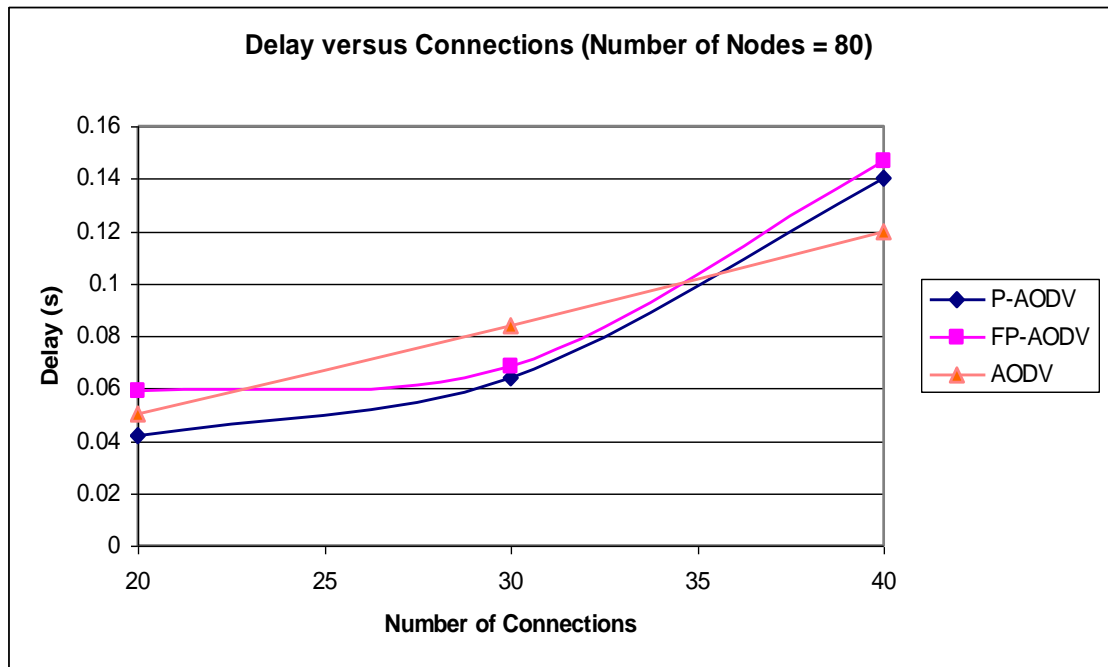
Figure 3-17: Latency versus traffic load
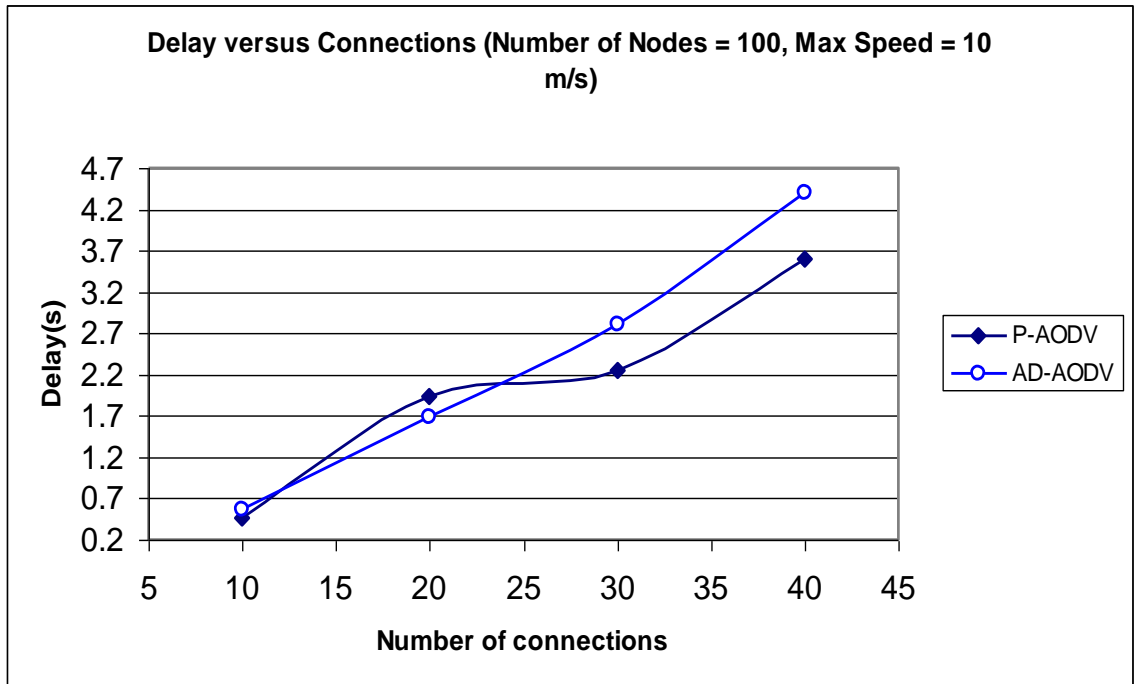
Figure 3-18: Latency versus traffic load

3.5 Summary

In Mobile Ad-hoc Networks (MANETs), flooding is an obligatory message broadcasting technique for network-wide transmission. Many approaches for dissemination in MANETs have been proposed to reduce a high number of unnecessary packet rebroadcasts. This chapter has proposed a new dynamic probabilistic broadcasting scheme for mobile ad-hoc networks where the value of the rebroadcast probability for every host node dynamically sets according to its neighbour's information, in order to improve performance in terms of SRB while maintaining an acceptable reachability level. Performance evaluation of the proposed scheme has been

conducted using the global mobile simulator network (GloMoSim) under static and Random Waypoint (RWP) mobility models. Performance results have shown that the proposed scheme performs with better results than other schemes used. More specifically, the proposed approach can improve saved broadcasts by up to 25% compared to fixed probabilistic flooding and by up to 10% compared to adjusted probabilistic flooding [1, 10], even under conditions of high mobility and high traffic load. A similar improvement can also be obtained when various traffic loads are applied to the network. It also demonstrates lower collision and less relays than the fixed-value probabilistic approach [3], the adjusted probabilistic flooding [1, 10] and the simple AODV, in all scenarios.

In terms of reachability also our improved probabilistic algorithm has a higher reachability than fixed-probabilistic and simple flooding at 20 and 40 connections. For instance, reachability is 95% for our algorithm at 20 connections compared to 85% for fixed-probabilistic and simple flooding. Reachability for all approaches with 30 connections is the same. It also demonstrates lower broadcast latency than F-AODV and AD-AODV.

This chapter has demonstrated that using dynamically calculating forwarding probabilities to network nodes according to their density regions helps to reduce the number of rebroadcasts, and as a consequence helps to reduce network traffic and decrease the probability of channel contention and packet collision.

Chapter 4

Performance Evaluation of a Dynamic Probabilistic Broadcasting Flooding Scheme under Different Mobility Models in MANETs

4.1 Introduction

A Mobile Ad-hoc Network (MANET) is a group of wireless nodes communicating with each other without any infrastructure. Due to the availability of small and economical wireless communication devices, the MANET research field has attracted much attention from academics and the industry in recent years. MANETs could potentially be used in several applications, such as battlefield communications, mobile classrooms and disaster relief [7, 76, 77].

In such networks, the members can move arbitrarily and network topology can change frequently. For this reason, the development of routing protocols in MANETs is extremely challenging [78]. The aim of this chapter is to study and analyse Mobile Ad-hoc Network protocols and simulate the protocol and evaluate its performance under different mobility models to see witch mobility model performer better with the protocol. The mobility model is designed to describe the movement pattern of mobile customers, and how their position, velocity and acceleration change over time [76].

The performance results based on simulation experiments demonstrate that the proposed algorithm scheme outperforms the simple flooding (AODV) and fixed probabilistic algorithm in terms of SRB, collisions and number of relays.

The rest of the chapter is organised as follows: Section 4.2 describes the simulation scenarios and configurations and introduces the mobility models. Section 4.3 presents the performance results obtained from simulation experiments. Finally, Section 4.4 summarises this chapter.

4.2 Simulation Scenarios and Configuration

The well-known network simulator GloMoSim version 2.03 [70] has been adopted to conduct the simulation experiments. This section will lay out the experimental scenarios and how simulation parameters were configured. The simulation scenarios studied in this research were designed to investigate the performance of the dynamic probabilistic broadcasting flooding scheme in MANETs under different mobility models.

The scenarios are composed of 70, 80, 90 and 100 mobile stations with an area of 1000m x 1000m. Each mobile station operates under the IEEE 802.11 [25,50] standard at a 2 Mbps network bandwidth [79]; other parameters are shown in Table 4.1.

Table 4.1: Simulation Parameters.

Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	1000m $\times$ 1000m
Transmission Range	250m
Mobile Nodes	70,80,90 and 100
Traffic Generator	Constant Bit Rate
Band Width	2 Mbps
Packet Size	512 Bytes
Packet Rate	10 Packet Per Second
Simulation Time	900s

4.2.1 Mobility Models

Appropriate mobility models that can accurately capture the properties of real-world mobility patterns are required for effective and reliable performance evaluations of MANETs. Due to the different types of movement patterns of mobile users, and how their location, velocity and acceleration change over time, different mobility models should be used to emulate the movement pattern of targeted real-life applications. In our study, three different mobility models were considered, including Random Waypoint (RWP), Manhattan Grid (MG) and Reference Point Group Mobility (RPGM) models [80-82]. The mobility scenario generation and analysis tool, BonnMotion [83], was used to generate the mobility scenarios for simulation experiments in this study.

4.2.1.1   Random Waypoint (RWP) Mobility Model

The Random Waypoint (RWP) mobility model proposed by Johnson and Maltz [78] is

the most popular mobility model used for performance analysis of MANETs. Two key

parameters of the RWP model are V_{max} and T_{pause} where V_{max} is the maximum

velocity for every mobile station and T_{pause} is the pause time. A mobile station in the

RWP model selects a random destination and a random speed between [0, V_{max}], and

then moves to the selected destination at the selected speed. Upon reaching the

destination, the mobile station stops for some pause time T_{pause} , and then repeats the

process by selecting a new destination and speed and resuming the movement. Figure

4.1 shows the movement trace of a mobile station using an RWP mobility model.
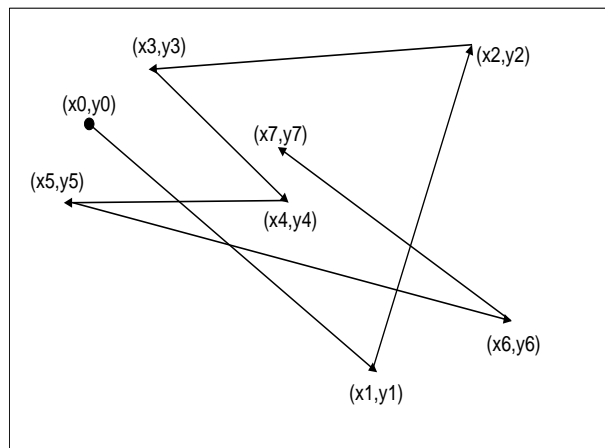
Figure 4-1: Example of mobile station movement in the RWP model

4.2.1.2   Manhattan Grid (MG) Mobility Model

Unlike RWP mobility, the Manhattan mobility model uses a grid-road topology, as shown in Figure 4.2. Initially, the wireless stations are randomly placed at the edge of the graph. The wireless stations then move towards randomly chosen destinations employing a probabilistic approach in the selection of station movements with a ½ probability of keeping moving in the same direction and a ¼ probability of turning left or right [81].
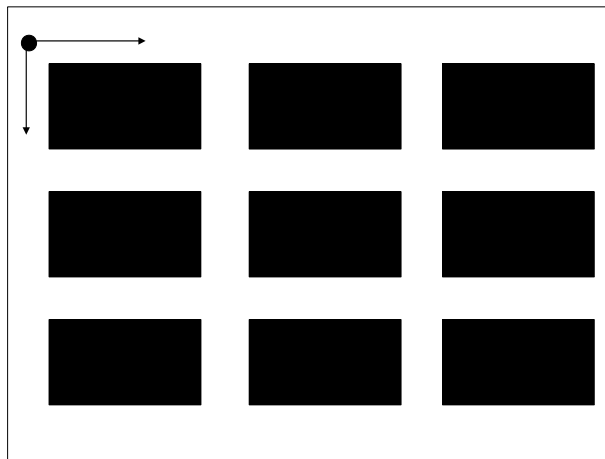
Figure 4-2: Example of mobile station movement in the Manhattan mobility model

4.2.1.3   Reference Point Group Mobility (RPGM) Model

In addition to RWP and Manhattan mobility models, the Reference Point Group Mobility (RPGM) model is proposed in [82]. Figure 4.3 shows an example of node movement in Reference Point Group Mobility Model. In this model, each group has a number of wireless station members and a center, which is either a logical center or a group leader. This model represents the random motion of a group of mobile nodes (MNs) as well as the random motion of every individual MN within the group. The

group leader movement determines the mobility behaviours of all other members in the group. The group leader is used to calculate group motion via a group movement vector, $\overline{GM}$. The movement of the group centre completely characterizes the movement of its corresponding group of MNs, including their direction and speed. Individual MNs randomly move about their own predefined reference points, whose movements rely on the group movement. As the individual reference points move from time t to t+1, their locations are updated according to the group's logical centre. Once the updated reference points, RP(t+1), are calculated, they are combined with a random motion vector, $\overline{RM}$, to represent the random motion of each MN about its individual reference point. One of the real applications which RPGM model can represent it accurately is the mobility behaviours of soldiers moving together in a group.
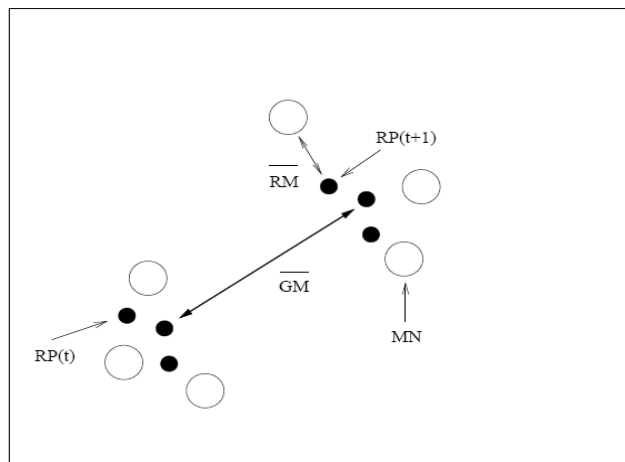
Figure 4-3: Example of mobile station movement in the RPGM model

4.3 Performance Analysis and Evaluation

In this section, we evaluate the performance of the proposed dynamic probabilistic broadcasting flooding algorithm. We compare the proposed algorithm with a simple flooding algorithm and a fixed probabilistic algorithm. The metrics for comparison include saved rebroadcast (SRB), average number of routing request rebroadcasts and average number of collisions (as defined in Section 3.4, above).

4.3.1 Saved Rebroadcast (SRB)

In the effort to investigate the performance of the proposed dynamic probabilistic broadcasting flooding scheme, Figures 4.4, 4.5 and 4.6 compare the SRB of the fixed probabilistic scheme and the proposed dynamic probabilistic broadcasting flooding scheme under three different mobility models scenarios versus the number of mobile nodes. For the RWP scenario (Figure 4.4), the proposed dynamic probabilistic broadcasting flooding scheme can significantly reduce rebroadcasts for networks with different numbers of nodes and 10 source-destination pair connections, and achieves higher SRB than the fixed probabilistic (FP-AODV) scheme. For instance, the SRB for the proposed algorithm is 31.3% in low-density networks (e.g. 70 nodes) and 43% in high-density networks (e.g. 100 nodes), whereas it is 28% and 30%, respectively, with fixed probability.
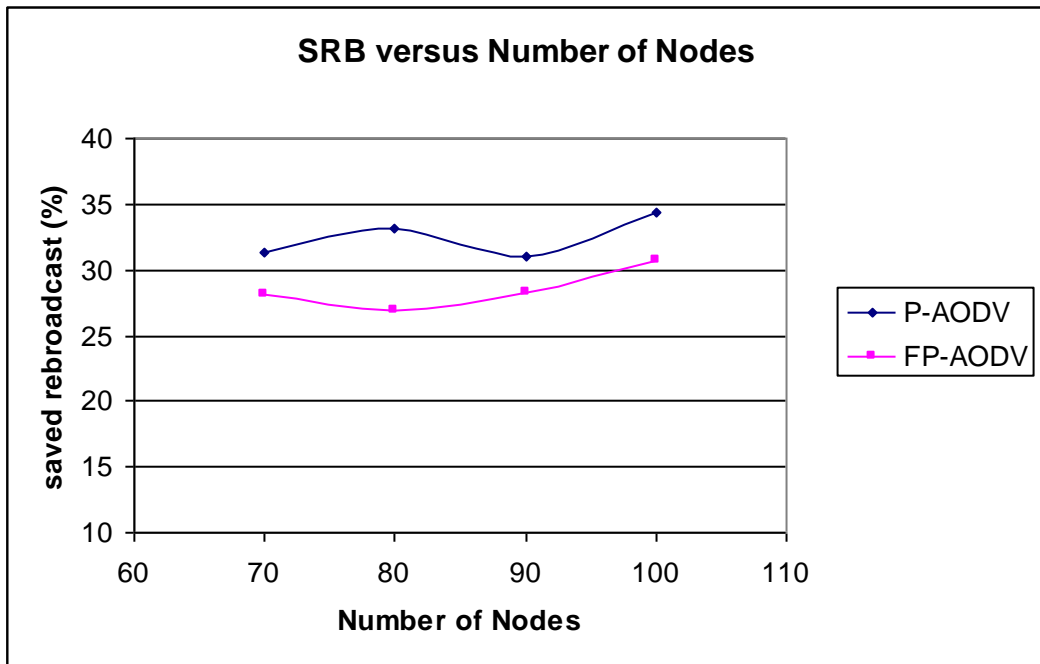
Figure 4-4: Saved rebroadcast comparison between the proposed dynamic probabilistic and fixed

probabilistic flooding schemes for the RWP mobility model scenario
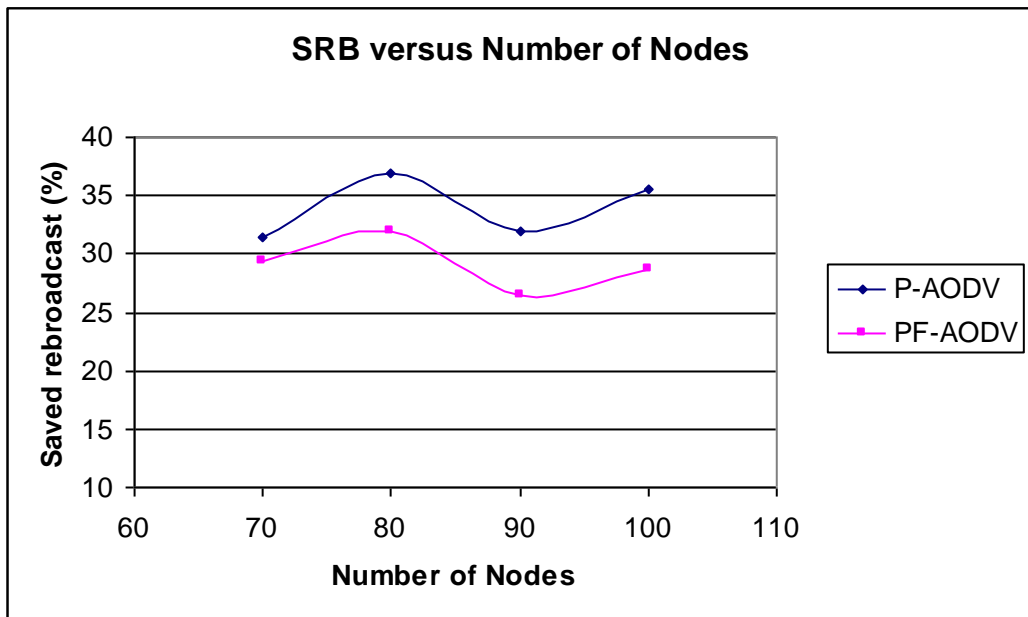
Figure 4-5: Saved rebroadcast comparison between the proposed dynamic probabilistic and fixed

probabilistic flooding schemes for the Manhattan mobility model scenario
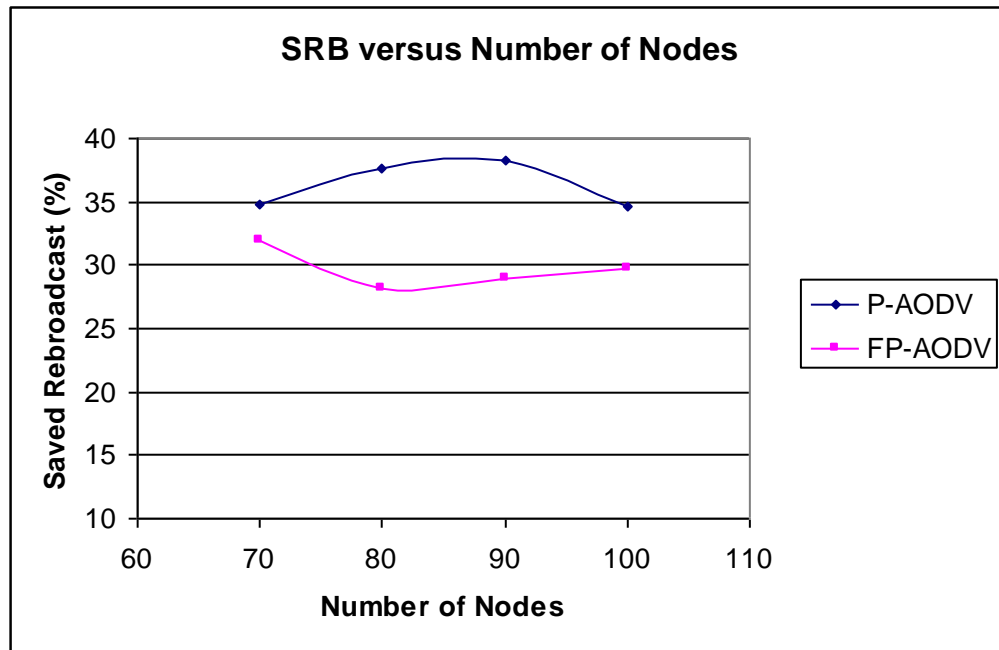
Figure 4-6: Saved rebroadcast comparison between the proposed dynamic probabilistic and fixed

probabilistic flooding schemes for the RPGM mobility model scenario

Figure 4-4-7: Comparison of relays between the proposed dynamic probabilistic, fixed probabilistic

and blind flooding schemes for the RWP mobility model scenario

Figure 4-8: Comparison of relays between the proposed dynamic probabilistic, fixed probabilistic and

blind flooding schemes for the Manhattan mobility model scenario

Figure 4-9: Comparison of relays between the proposed dynamic probabilistic, fixed probabilistic and

blind flooding schemes for the RPGM mobility model scenario

Figure 4.5 illustrates the SRB of the fixed probabilistic and the proposed dynamic probabilistic schemes under the Manhattan mobility scenario and different network densities. As a result of applying Manhattan mobility model scenario, along with compare to the fixed probabilistic scheme, the proposed dynamic probabilistic broadcasting flooding scheme can achieve 31% and 35% of SRB in low and high network densities, respectively.

Figure 4.6 shows the SRB of the proposed algorithm and the fixed probabilistic algorithm under the RPGM mobility model and different network densities. From the figure, we can see that the proposed dynamic probabilistic broadcasting flooding scheme achieves better results than the fixed probabilistic scheme. For instance, SRB for P-AODV is 34% in low density and 38% in high density (e.g. 90 nodes), compared to FP-AODV.

After mobility is introduced, more route requests are generated and some of them may fail to reach their destinations. Such failures cause another round of transmissions of route-request packets. Figure 4.7 shows the number of relays of the proposed dynamic probabilistic broadcasting flooding scheme, FP-AODV and blind AODV under the RWP model, different number of nodes and 10 source-destination connection pairs. As shown in Figure 4.7, the proposed algorithm has a lower number of relays than FP-AODV and blind AODV. It also shows that the number of route-request rebroadcasts increases when the number of nodes increases; this is due to the generation of a higher number of route requests with an increasing number of nodes in the network.

Figure 4.8 compares relays for the Manhattan mobility model scenario. Once again, the figure shows that the proposed algorithm incurs lower relays compared to other algorithms. As a result, as far as route requests are concerned the proposed scheme can definitely outperform FP-AODV and blind AODV in these scenarios.

Figure 4.9 shows performance with the RPGM mobility model. Due to increasing the number of mobile nodes in the network with mobility, more route requests fail to reach their destinations. In these instances, more route requests are generated. The figure implies that the proposed probabilistic approach can achieve less route requests than FP-AODV and blind AODV in this mobility model too.

4.3.2 Collisions

Figures 4.10, 4.11 and 4.12 represent a comparison of collision between the proposed dynamic probabilistic broadcasting flooding, FP-AODV and blind flooding (AODV) schemes under different mobility models. As shown in the figures, the proposed dynamic probabilistic broadcasting flooding incurs fewer numbers of collisions than that of FP-AODV and blind AODV in most cases under RWP, Manhattan Grid (MG) and RPGM mobility models.
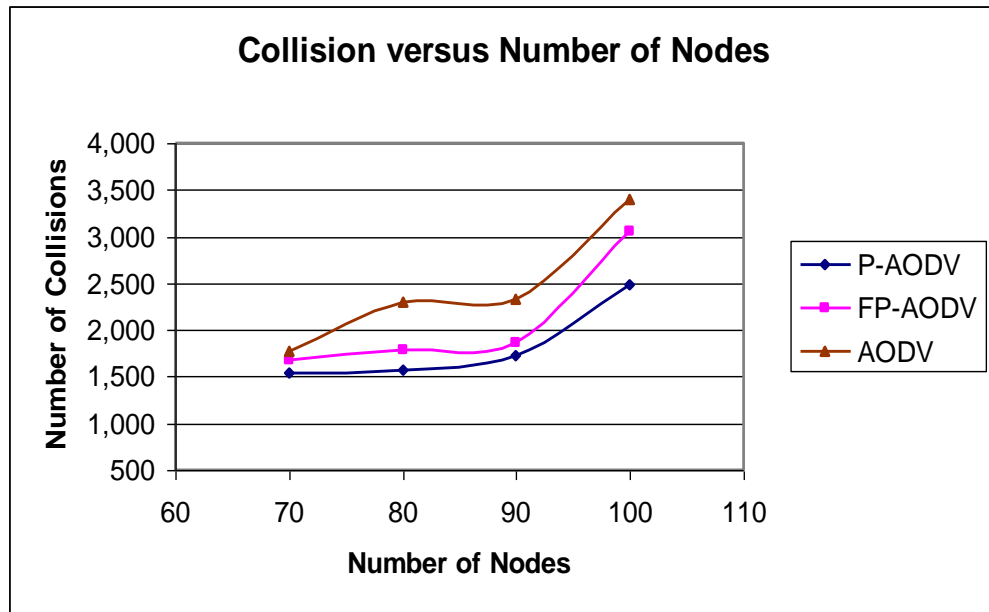
Figure 4-10: Comparison of collisions between the proposed dynamic probabilistic, fixed probabilistic

and blind flooding schemes for the RWP mobility model scenario
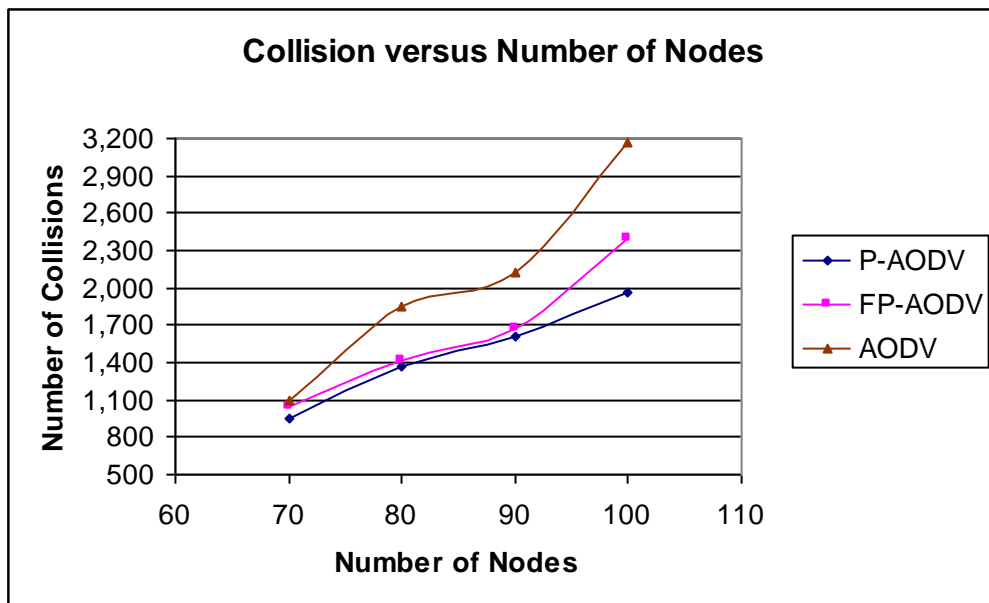
Figure 4-11: Comparison of collisions between the proposed dynamic probabilistic, fixed probabilistic

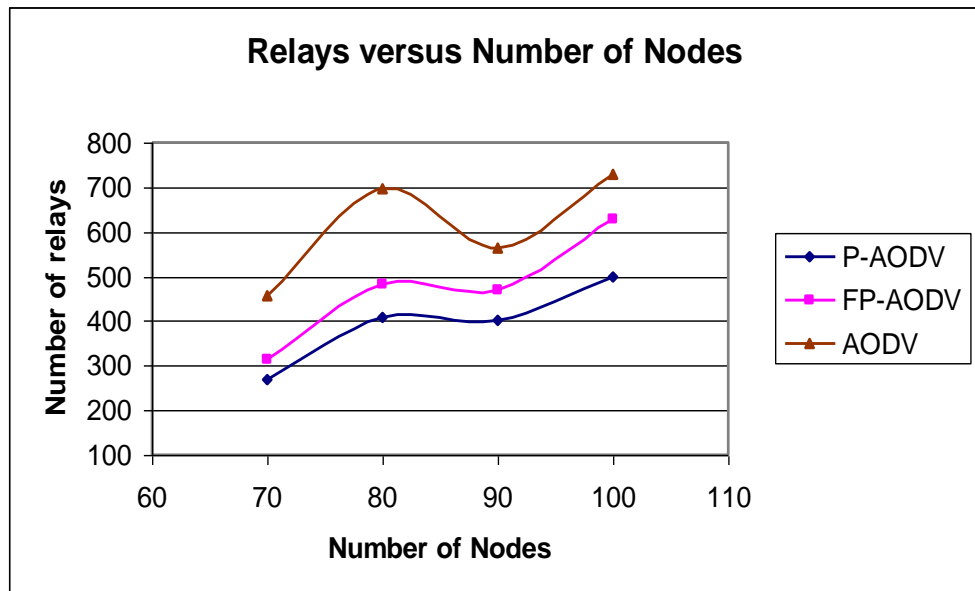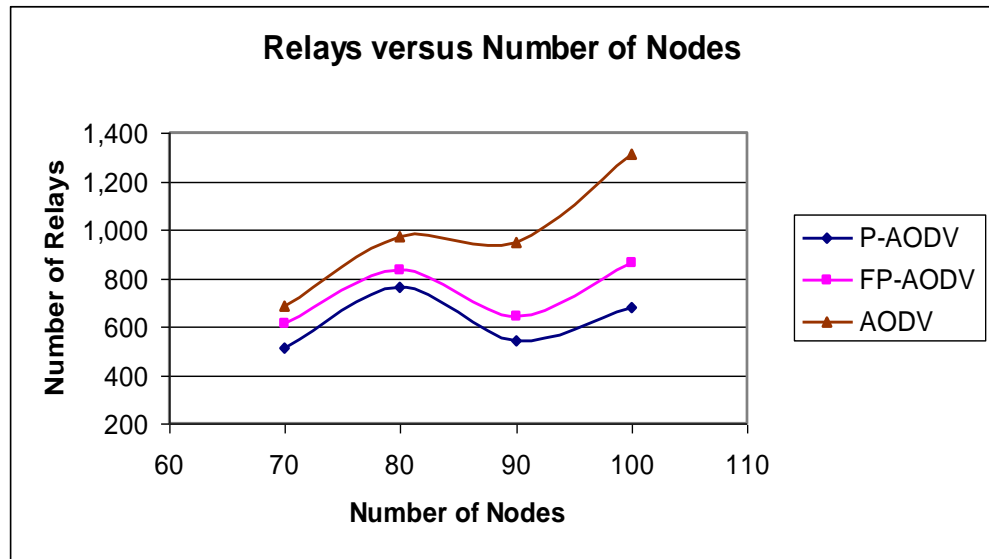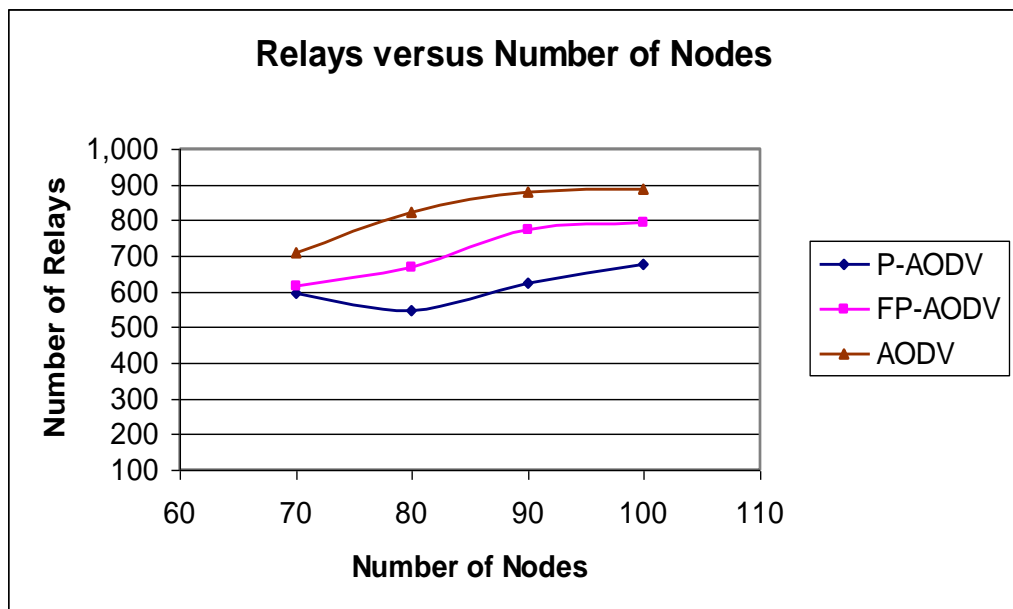and blind flooding schemes for the Manhattan Grid (MG) mobility model scenario
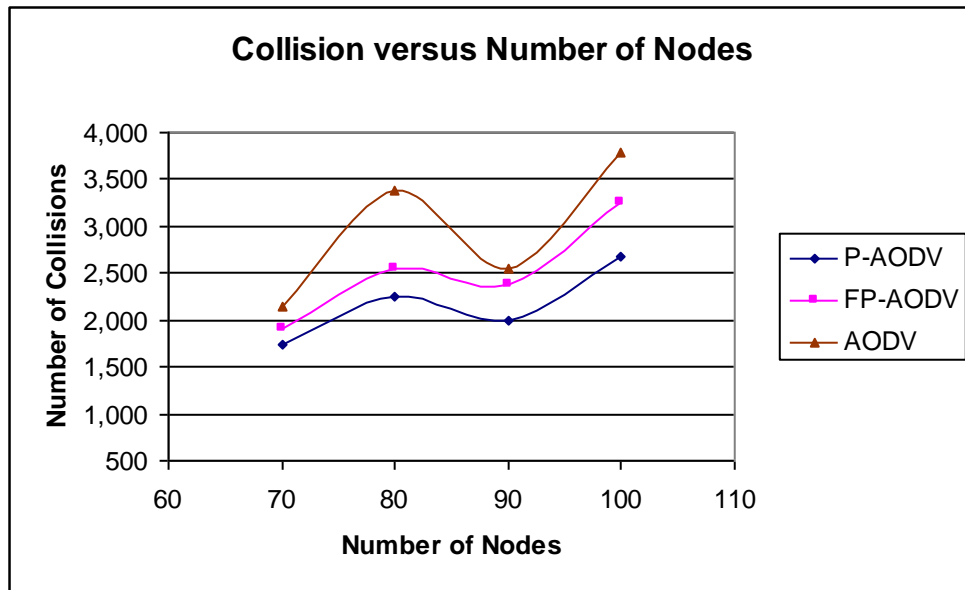
Figure 4-12: Comparison of collisions between the proposed dynamic probabilistic, fixed probabilistic and blind flooding schemes for the RPGM mobility model scenario

Figure 4.10 depicts collision results for different network densities. When the broadcast probability is dynamically calculated, the proposed dynamic probabilistic algorithm incurs fewer numbers of collisions than FP-AODV and blind AODV.

Moreover, similar behaviour is observed for the scenario of the Manhattan Grid (MG) mobility model (Figure 4.11). The proposed dynamic probabilistic, FP-AODV and blind AODV algorithms achieved less collisions compared to the scenarios of the RWP mobility model. This is due to the random movement pattern of the RWP mobility model, which is leaded to break the connection between the source and the destination nodes.

Additionally, Figure 4.12 shows the collision of the proposed dynamic probabilistic, FP-AODV and blind AODV algorithms under the RPGM model and different numbers

of nodes in the network. As shown in this figure, the proposed dynamic probabilistic

algorithm has lower collisions than the FP-AODV and blind AODV algorithms. This is

due to the P-AODV generating a less number of RREQs in the network, leading to

fewer collisions.

It is worth noting that under different mobility models the proposed dynamic

probabilistic algorithm outperforms both FP-AODV and blind AODV.

Figure 4.13 shows the number of collisions for a network with 100 nodes, under the

RWP mobility model with a variety of different connections of source-destination pairs

using 95% confidence interval and 50 times runs of simulation. In Figure 4.1 we show

performance with different number of connections. When number of connections

increases, more route requests fail to reach their destinations. In such cases, more route

requests are generated, leading to more collisions as a result of the increasing number of

control packets. It is clearly showed that the proposed algorithm shows the lowest

number of collisions amongst the AD-AODV.
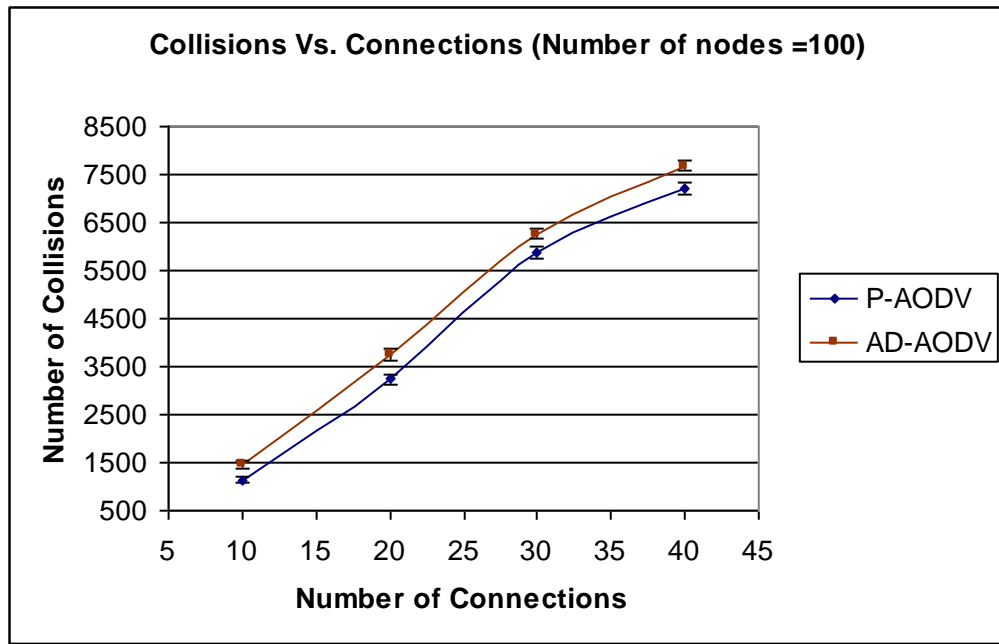
Figure 4-13: Comparison of collisions between the proposed dynamic probabilistic and adjusted

probabilistic

4.4 Summary

This chapter has related the performance evaluation of the proposed dynamic
probabilistic broadcasting scheme (P-AODV) where nodes move according to random
Waypoint (RWP), Manhattan Grid (MG) and Reference Point Group Mobility (RPGM)
models. The main reason for this is the constant change in network topology due to the
high degree of node mobility. Many protocols have been developed to accomplish this
task. Compared against the fixed probabilistic algorithm (FP-AODV), the performances
of the simulation results have shown that the proposed dynamic approach in terms of
SRB can achieve 31%, 31% and 34% under the RWP, MG and RPGM mobility models,
respectively, in low-density networks.

The simulation results have demonstrated that the proposed dynamic approach can generate fewer route rebroadcasts than FP-AODV and simple AODV approaches. It also incurs lower collisions than the FP-AODV and simple AODV approaches in all mobility scenarios.

Chapter 5

Enhanced Dynamic Probabilistic Scheme

5.1 Introduction

This chapter presents an enhanced dynamic probabilistic flooding algorithm that can dynamically adjust the rebroadcast probability at a given node according to its neighbourhood density. The algorithm is based on the same approach as that introduced in the chapter 3. However, the forwarding probability is further refined according to a pre-defined average number of neighbouring nodes distributed in the ad-hoc network for routing request packets (RREQs), to reduce the number of retransmissions as well as obtain a less number of collisions in the network.

As in dynamic probabilistic flooding (P-AODV), short Hello packets are used in the Enhanced dynamic flooding algorithm in order to gather information on 1-hop neighbours and update the current number of neighbours of a given node. The aim of this chapter is to describe the operation of Enhanced dynamic flooding algorithm and evaluate its performance against existing simple, adjusted probabilistic [1,10] and dynamic probabilistic flooding.

The rest of the chapter is organised as follows: Section 5.2 proposes the Enhanced dynamic probabilistic 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 The Enhanced Dynamic Probabilistic Broadcasting Scheme

Suitable use of a probabilistic broadcasting scheme in MANETs can reduce the number of rebroadcasts and thereby reduce the collisions and the chance of contention among neighbouring nodes. In this chapter, we propose an Enhanced dynamic probabilistic scheme that can dynamically adjust the rebroadcast probability as per the node's neighbourhood distribution using 1-hop neighbourhood information. This is based on locally available information and does not require the assistance of distance devices.

The information on 1-hop neighbours collected by means of exchanging short Hello packets is used to adjust the probability at a given node. If the number of neighbours is high, implying that the node is located in a dense area, the node could potentially receive a large amount of rebroadcasts from its neighbours. Description of the Enhanced dynamic probabilistic flooding algorithm is presented in Figure 5.1. The main operations of the algorithm are as follows. On hearing a broadcast packet (*pkt*) at *i*th node, the node rebroadcasts the packet according to a calculated probability with the average neighbour of nodes help in the network ($\overline{nbr}$) if the packet is received for the

first time if and the number of neighbours of ith node is less than the average number of neighbours ($\overline{nbr}$) typical of its surrounding environment.

Hence, if ith node has a low degree (in terms of number of neighbours), retransmission should be likely. If, on the other hand, the number of neighbours of ith node is greater than the average number of neighbours ($\overline{nbr}$) (i.e., ith node has a high degree), retransmission will be unlikely.

The average number of neighbours in the network is calculated for the selection of the value of p by using equation (5.1) [1, 10]. A is the area of an ad-hoc network, N the number of mobile nodes in the network and r is the radius of the transmission range of the node. The average number of neighbours can be obtained as shown below.

$$\overline{nbr} = \left(N - 1\right) \times 0.8 \times \frac{\pi r^2}{A} \qquad (5.1)$$

Procedure

Input Parameters:

pkt : Packet to relay by ith node.

$p(i)$: Rebroadcast probability of packet (pkt) of ith node.

$RN\,(i\,)$: Random number for ith node to compare with the rebroadcast probability p.

$S_{nbr}\,(i\,)$: Number of neighbouring nodes of ith node.

$\overline{nbr}$: Average number of neighbours (threshold value).

$nbrTable(i)$: Neighbour table for ith node.

Output Parameters:

Discpkt (*i*): Packet (*pkt*) will be discarded by *i*th node if it is already in its list.

Rbdpkt (*i*): Packet (*pkt*) will be rebroadcast by *i*th node if probability *p* is high.

Drpkt (*i*): Packet (*pkt*) will be dropped by *i*th node if probability *p* is low.

Calculation of broadcasting probability upon receiving a broadcast packet (*pkt*).

if a packet (*pkt*) is received for the first time at the *i*th node **then**

  {

    get *nbrTable(i)*

    if size (*nbr Table(i)*) == 0 **then**

    return (0)

    else   {

        If $(S_{nbr}(i) < \overline{nbr})$ **then**

*i*th node has a low degree:

$$P(i) := \prod_{i=0}^{S_{nbr(i)}} P * P_{\max}$$

    if $p(i) < p_{min}$ **then**

    $p(i) = p_{min}$
    end if
  return (*P(i)*)
  else
  *i*th node has a high degree:
    P(i) = 0.0 (drop the packet)
    end if
  end if
  Generate a random number RN over [0, 1].
  Relay the packet (*Rbdpkt* (*i*)) when (*P(i)*> *RN(i)*)
   else
      Drop packet (Drpkt)
end if
where   *pmax = 0.9* and *pmin= 0.4*

Figure 5-1: Enhanced dynamic probabilistic algorithm

5.3 Simulation Scenarios and Configuration

The GloMoSim network simulator (version 2.03) [70] has been adopted to conduct extensive experiments in the evaluation of the behaviour of the Enhanced dynamic probabilistic algorithm under different mobility models. Three AODV variations have been implemented: the first using adjusted probabilistic flooding [1, 10] method AD-AODV (AODV + fixed pair probability), the second based on dynamically calculating the rebroadcast probability for each node [84-86], called P-AODV (AODV + dynamic probability), and the third one is our enhanced dynamic algorithm (EDP-AODV). In our simulation, we use a 1000m × 1000m area with a different number of connections and 100 nodes. The network bandwidth is 2 Mbps and the Medium Access Control (MAC) layer protocol is IEEE 802.11[25, 50]. Other simulation parameters are shown in Table 5.1.

The main purpose behind the improved approach is to reduce the number of rebroadcasts in the route-discovery phase, thereby reducing network traffic and decreasing the probability of channel contention and packet collision.

Table 5.1: Simulation Parameters

Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	1000m×1000m
Transmission Range	250m
Mobile Nodes	100
Traffic Generator	Constant Bit Rate
Band Width	2 Mbps
Packet Size	512 bytes
Packet Rate	10 Packet Per Second
Simulation Time	900s

5.4 Performance Analysis and Evaluation

In this section, the performance of the Enhanced dynamic probabilistic broadcasting algorithm is evaluated. The performance of the Enhaced approach is examined by investigating and comparing it with simple AODV, adjusted probabilistic [1, 10] and dynamic probabilistic flooding [84-86] using the GloMoSim network simulator under different mobility models. The metrics for comparison include saved rebroadcast (SRB), average number of routing-request rebroadcasts and average number of collisions (as defined in Section 3.4, above).

5.4.1 Saved Rebroadcast (SRB)

Figures 5.2, 5.3 and 5.4 compare the saved rebroadcast (SRB) of adjusted probabilistic [1, 10], dynamic probabilistic [84-86] and enhanced dynamic probabilistic flooding under three different mobility model scenarios. Figure 5.2 depicts SRB for the RWP scenario, in P-AODV, AD-AODV and EDP-AODV, as a function of the traffic load that is varied by using different numbers of Constant Bit Rate (CBR) source-destination connections. The number of nodes is kept at 100, which move with a maximum speed of 10 m/s. The number of RREQ packets increases as the traffic load increases. This results in an increase in the broadcast activity of RREQ packets inside the network. The figure reveals that EDP-AODV significantly improves SRB compared to other routing protocols. Furthermore EDP-AODV has the highest SRB for all traffic loads and the performance advantage of EDP-AODV increases as the traffic load increases. The difference in performance in favour of EDP-AODV compared to P-AODV ranges from 20% to 22%, and from 30% to 28% compared to AD-AODV.

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Figure 5-2: Saved rebroadcast comparison between the proposed enhanced dynamic probabilistic, adjusted probabilistic and dynamic probabilistic flooding schemes for the RWP mobility model scenario

Figure 5-3: Saved rebroadcast comparison between the proposed dynamic probabilistic, adjusted probabilistic and dynamic probabilistic flooding schemes for the Manhattan mobility model scenario

Figure 5-4: Saved rebroadcast comparison between the proposed enhanced dynamic probabilistic,

adjusted probabilistic and dynamic probabilistic flooding schemes for the RPGM

mobility model scenario

Figure 5.3 depicts the performance of the three algorithms under the Manhattan mobility scenario when different connections of source-destination pairs are used. The SRB results reveal that EDP-AODV outperforms P-AODV [84-86] and AD-AODV [1, 10] at all source-destination connections when it is varied from 10 to 40 connections. For instance, EDP-AODV outperforms P-AODV in terms of SRB by 33% and AD-AODV by 37% when the number of connections is 10 source-destination pairs. When the traffic load increases, SRB increases slightly. For instance, SRB increases from 60% to 65% in EDP-AODV, from 33% to 51% in P-AODV and 29% to 35% in AD-AODV when the traffic load is increased from 10 to 40 connections pairs.

Figure 5.4 explores SRB in the three algorithms for various source-destination pairs where the nodes move under the RPGM mobility model at a maximum speed of 10 m/s in a network of 100 nodes. The figure reveals that EDP-AODV still delivers the best performance over the other algorithms. However, it can be seen that the three algorithms experience an increase in SRB as traffic load increases.

Figure 5.5 shows the number of relays in the EDP-AODV, P-AODV, AD-AODV and blind AODV algorithms under the RWP model and different numbers of connection pairs for a network with 100 nodes, where the nodes move at maximum speed of 10 m/s. As shown in the figure, the EDP-AODV algorithm has less relays than the P-AODV, AD-AODV and blind AODV algorithms at all traffic loads. It also shows that the number of route requests increases when the traffic load increases; this is due to the generation of a higher number of route requests when the number of connections in the network increases.

In Figure 5.6, we compare relays for the Manhattan mobility model at the same setting as that applied in Figure 5.5. The figure shows the enhanced algorithm incurring a lower number of relays. As a result, the route requests increase when the traffic load increases and the enhanced scheme can definitely outperform P-AODV, AD-AODV and blind AODV in these scenarios.
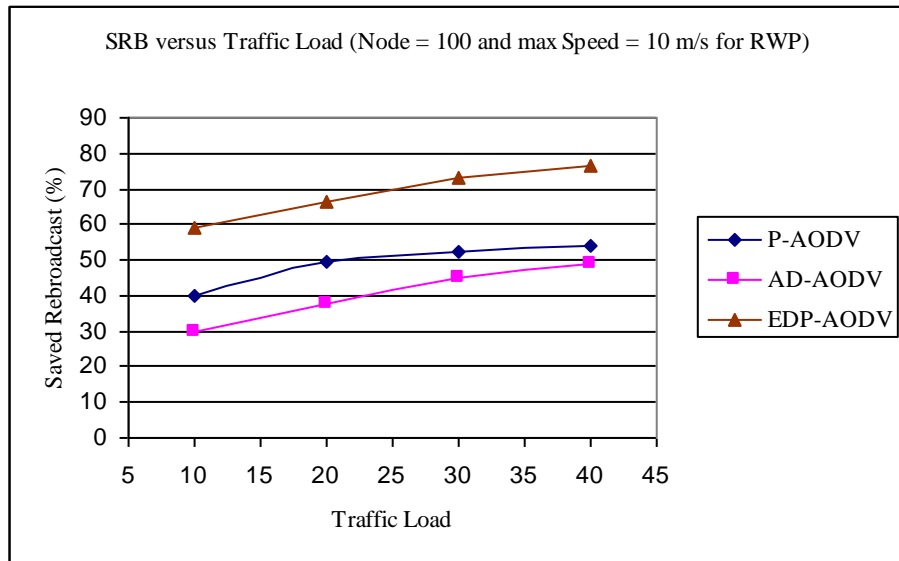
93

Figure 5-5: Relays comparison between the proposed enhanced dynamic probabilistic, adjusted

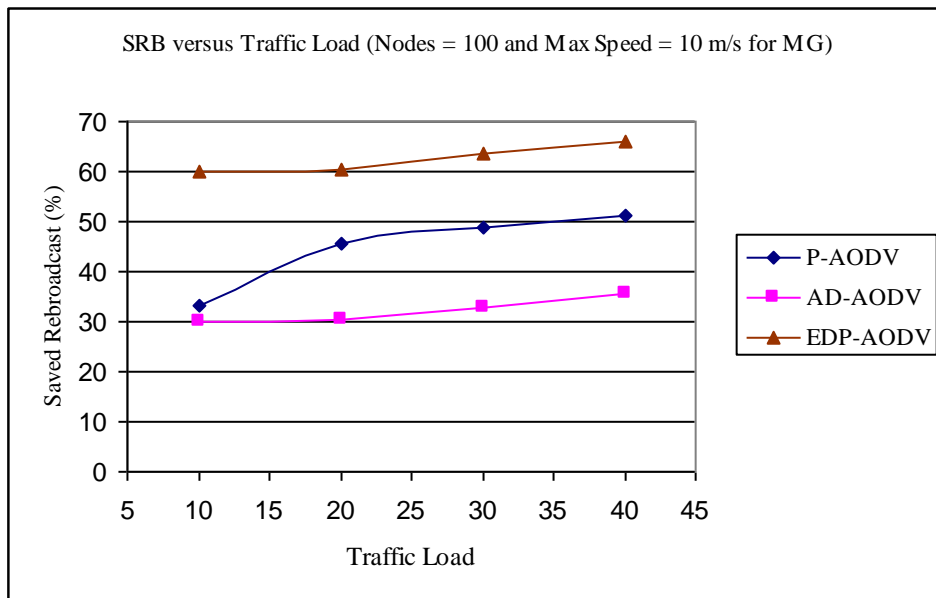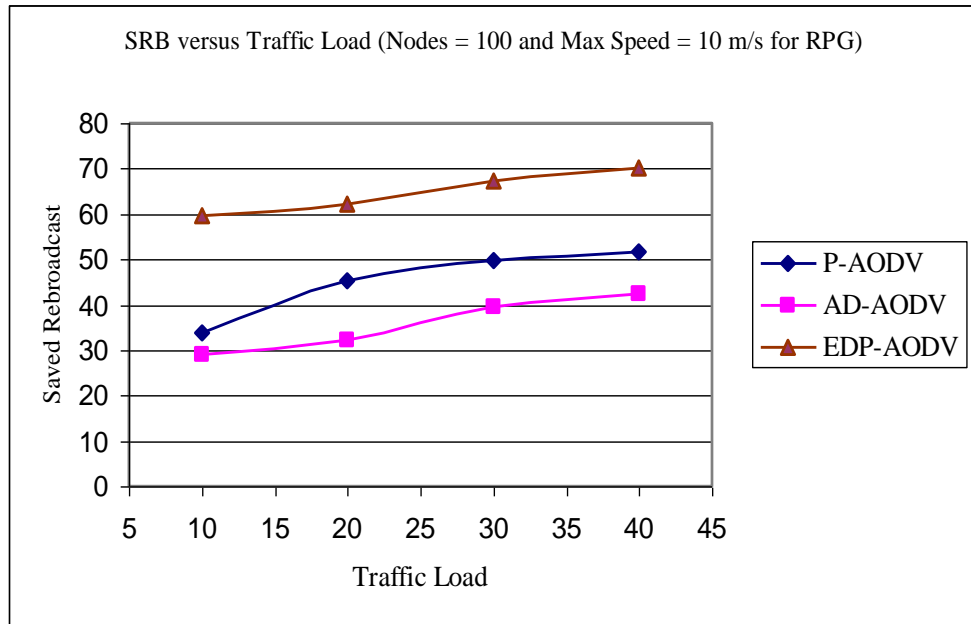probabilistic, dynamic probabilistic and blind AODV flooding schemes for the RWP

mobility model scenario.

Figure 5-6: Relays comparison between the proposed enhanced dynamic probabilistic, adjusted

probabilistic, dynamic probabilistic and blind AODV flooding schemes for the

Manhattan mobility model scenario

Figure 5-7: Relays comparison between the proposed enhanced dynamic probabilistic, adjusted

probabilistic, dynamic probabilistic and blind AODV flooding schemes for the RPGM

model scenario

Figure 5.7 shows the performance of four algorithms with the RPGM mobility model. Due to increasing the number of connections in the network with mobility, more route requests fail to reach their destinations. In such instances, more route requests are generated. The figure implies that the enhanced dynamic probabilistic approach can achieve fewer route requests than P-AODV, AD-AODV and blind AODV in this mobility model too.

5.4.2 Collisions

Figures 5.8, 5.9 and 5.10 represent a comparison of collisions between the enhanced (EDP-AODV), P-AODV, AD-AODV and blind AODV algorithms under RWP, MG and RPGM mobility models, respectively. Figure 5.8 explores collisions in the four

algorithms for various source-destination connection pairs where the nodes move under the RWP mobility model at a maximum node speed of 10 m/s in a network of 100 nodes. The figure reveals that EDP-AODV still incurs fewer numbers of collisions than P-AODV, AD-AODV and blind AODV. However, it can be seen that the four algorithms experience an increase in collisions as traffic load increases.
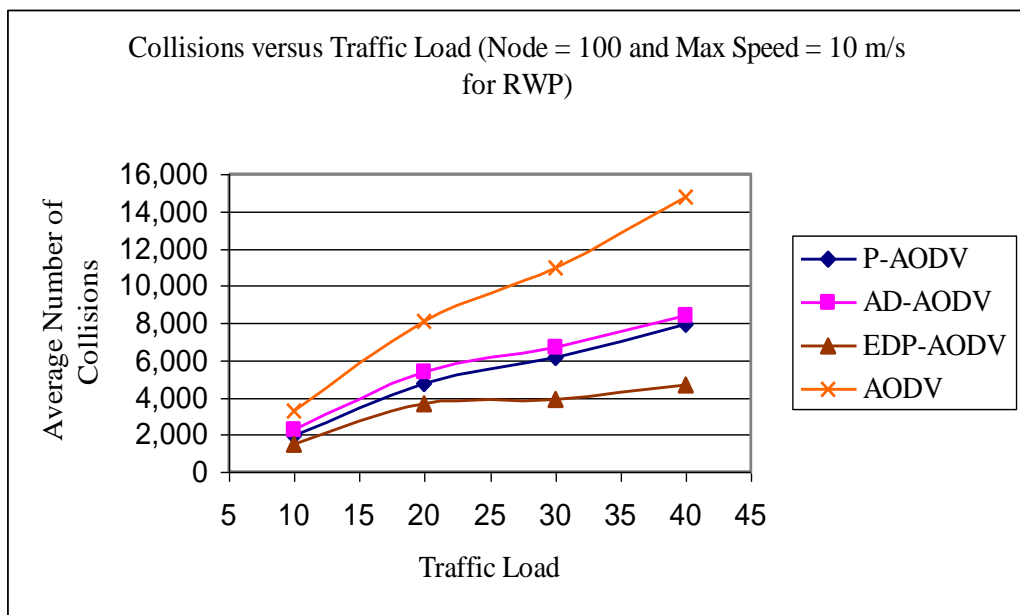
Figure 5-8: Collision comparison between the proposed dynamic probabilistic, adjusted pprobabilistic, dynamic probabilistic and blind AODV flooding schemes for the RWP mobility model scenario

Figure 5-9: Collision comparison between the proposed enhanced dynamic probabilistic, adjusted

probabilistic, dynamic probabilistic and blind AODV flooding schemes for the
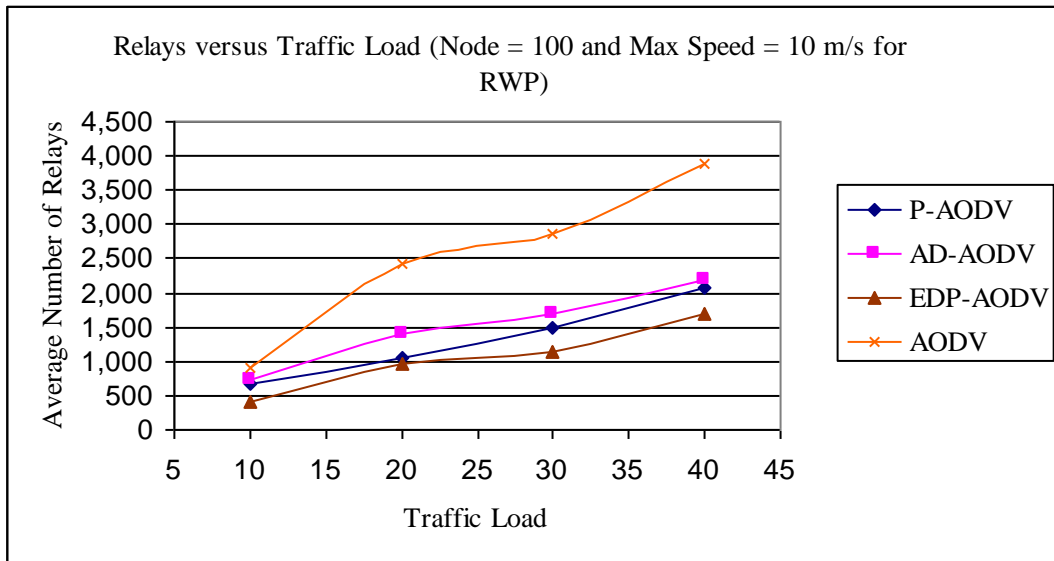
Manhattan mobility model scenario

Figure 5-10: Collision comparison between the proposed enhanced dynamic probabilistic, adjusted

probabilistic , dynamic probabilistic and blind AODV flooding schemes for the RPGM
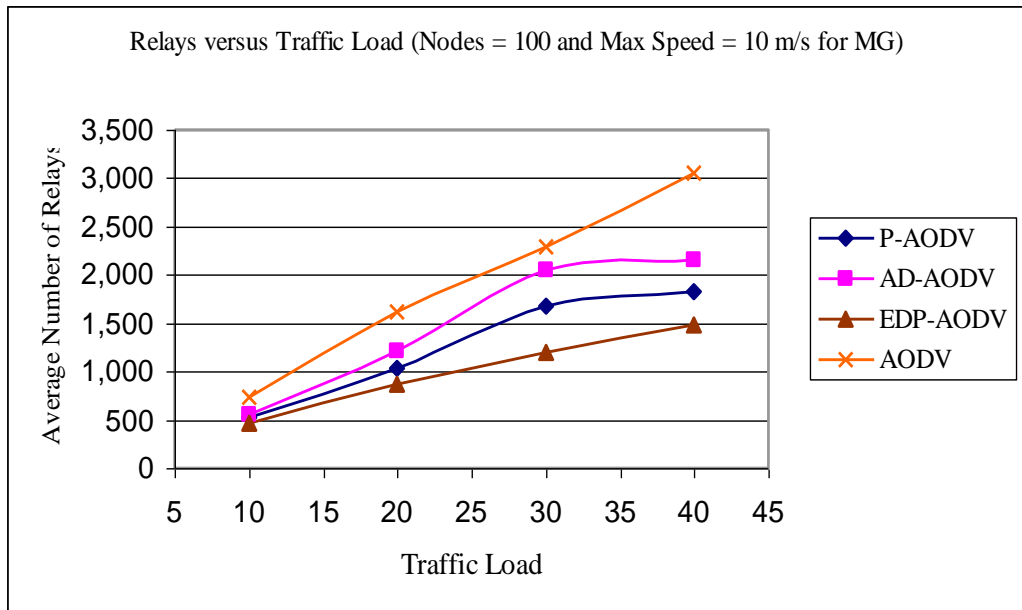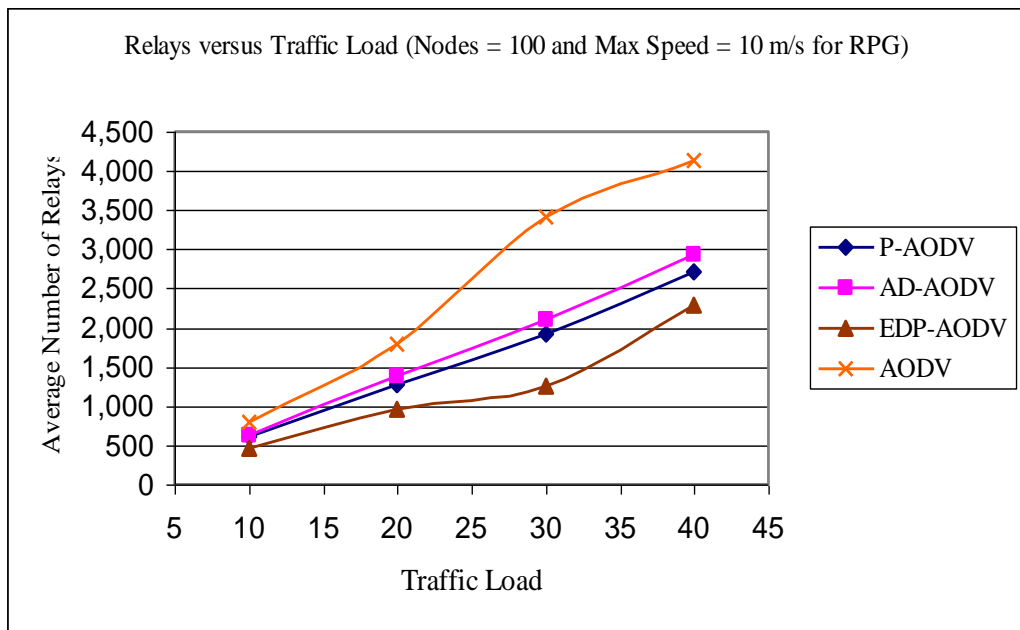
mobility model scenario

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Moreover, similar behaviour is observed for the scenario of the Manhattan mobility model (Figure 5.9). The enhanced algorithm achieves less collision compared with the P-AODV, AD-AODV and blind AODV algorithms in all scenarios. It also shows that the number of collisions increases when the traffic load increases, because when a more number of connections is applied, more route request are generated, leading to more collisions due to the increase in control packets.

Figure 5.10 also shows the collision of the enhanced algorithm and the P-AODV, AD-AODV and blind AODV algorithms under the RPGM model for the same simulation settings as in Figures 5.8 and 5.9. As shown in the figure, the enhanced algorithm has a lower collision than the P-AODV, AD-AODV and blind AODV.

5.4.3 Reachability

Figure 5.11 shows reachability results for different traffic loads varying from 10 to 40 connections of source-destination pairs. The network size is kept at 100 nodes under the RWP mobility model with the maximum speed of 10 m/s in the EDP-AODV, P-AODV [84-86], AD-AODV [1, 10] and simple AODV. As the figure shows, all algorithms for reachability results at all traffic load connections fell between 93.41% and 95.6%. It is clear that P-AODV has the best performance in terms of reachability compared to the other algorithms, because the EDP-AODV got high SRB than other techniques and many RREQ will prevent from rebroadcast to get the rout to destination which will affect the reachability.

Figure 5.12 shows the comparison between the enhanced algorithm and other algorithms in terms of reachability for the Manhattan Grid (MG) mobility scenario. As

shown in the figure, the reachability at all traffic load connections for all algorithms are relatively similar except for P-AODV, which outperforms the other algorithms. The figure shows that reachability decreases when traffic load increases, regardless of the routing protocol.
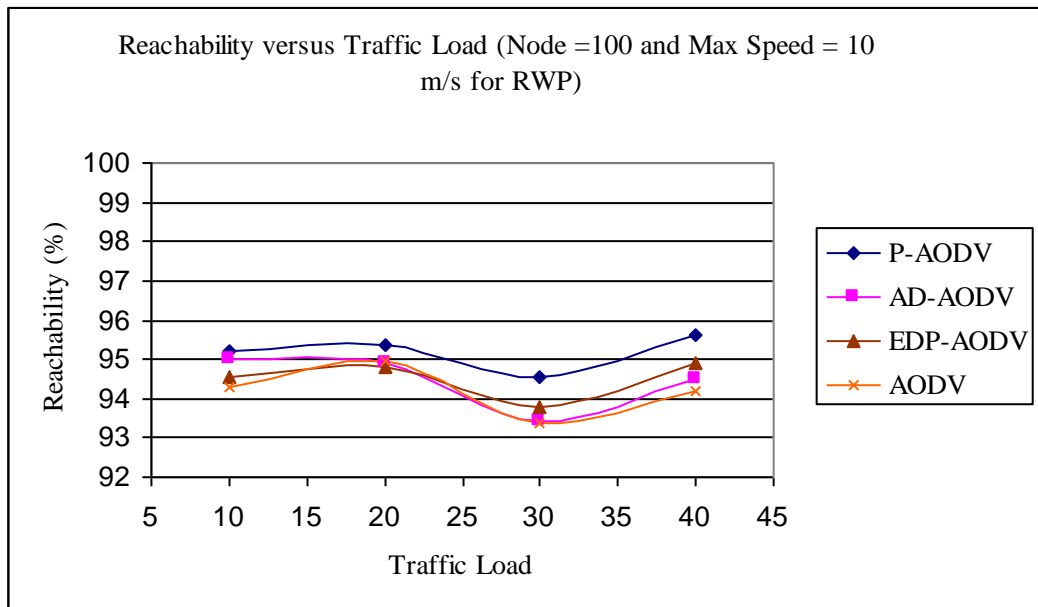
Figure 5-11: Comparison of reachability for the proposed enhanced dynamic probabilistic, adjusted probabilistic, dynamic probabilistic and blind AODV flooding schemes for the RWP mobility model scenario
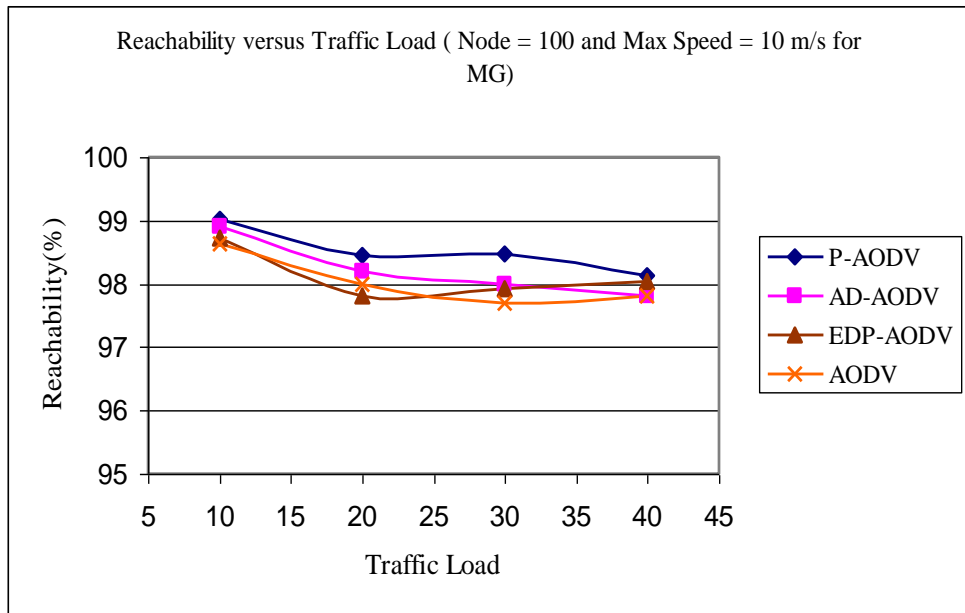
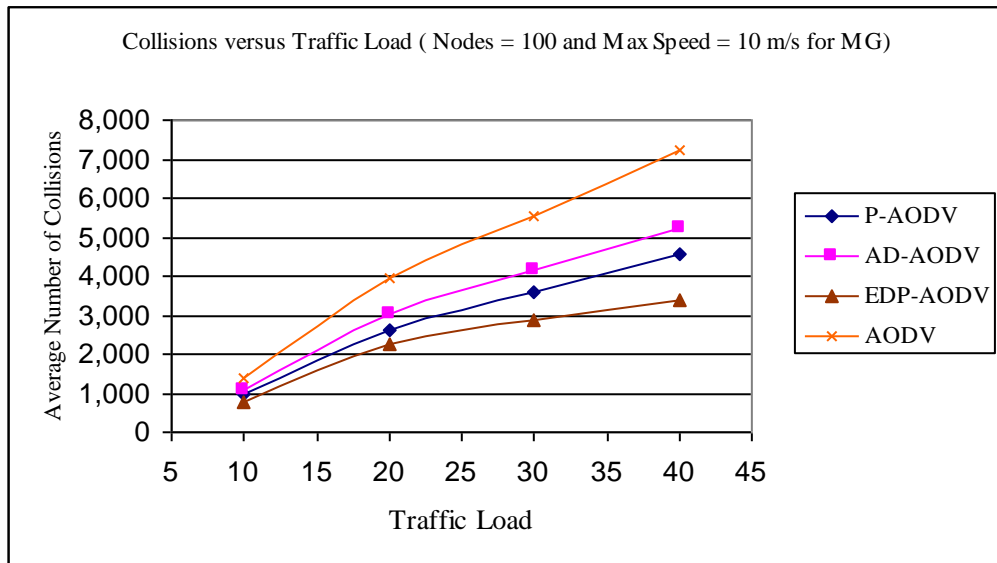Figure 5-12: Comparison of reachability for the proposed enhanced dynamic probabilistic, adjusted

probabilistic, dynamic probabilistic and blind AODV flooding schemes for the MG
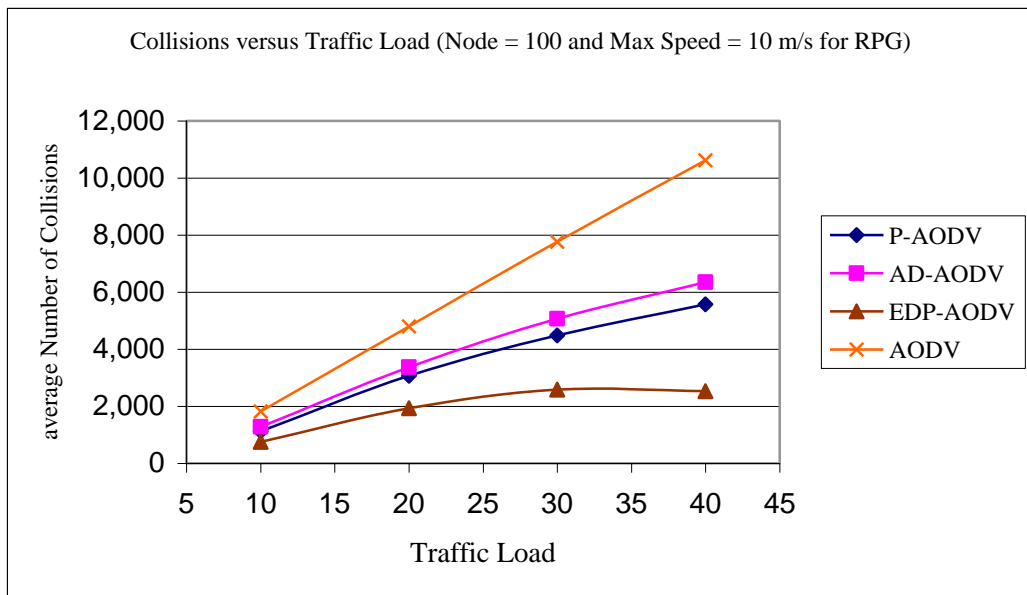
mobility model scenario

Figure 5.13 shows the comparison between the enhanced, adjusted probabilistic [1, 10], dynamic probabilistic [84-86] and simple AODV flooding algorithms in terms of reachability for the Reference Point Group Mobility (RPGM) scenario. As shown in the figure, the reachability at all traffic-load connections fall between 96.9% and 96.9%. Moreover, the figure shows that dynamic probabilistic flooding [18] (P-AODV) slightly outperforms other algorithms in terms of reachability. This is because the EDP-AODV achieves higher SRB, which lead to prevent RREQ to reach the destination and affects its reachability.
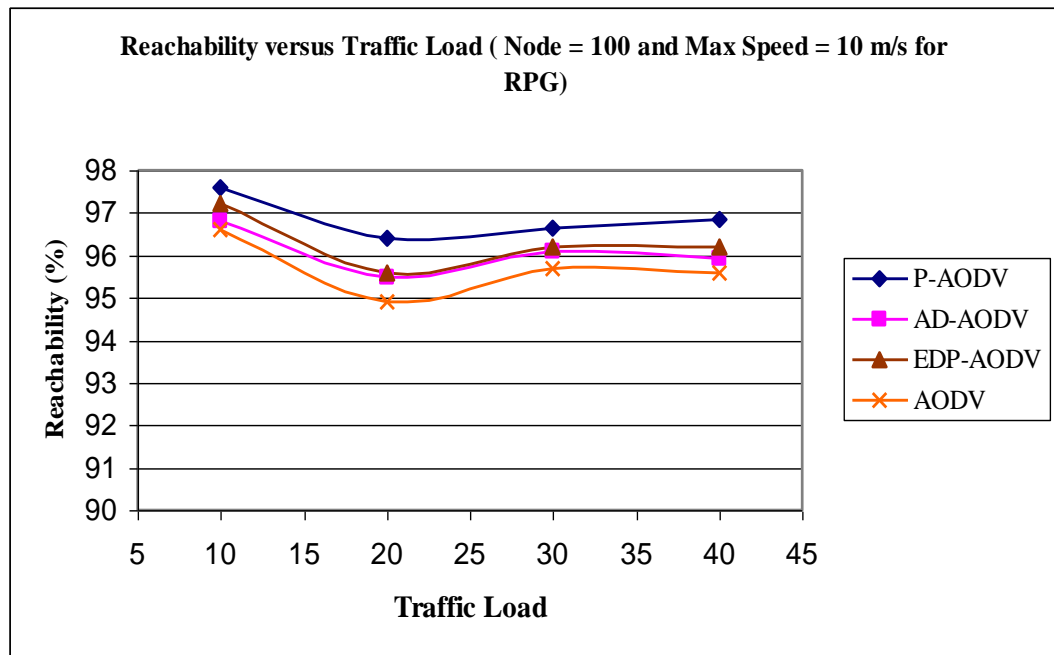
Figure 5-13: Comparison of reachability for the proposed enhanced dynamic probabilistic, adjusted probabilistic, dynamic probabilistic and blind AODV flooding schemes for the RPGM model scenario

5.5 Summary

This chapter has explained the enhanced probabilistic flooding scheme for MANETs where the rebroadcast probability is dynamically set according to the nodes' density areas with the help of an average number of nodes in the network. In order to improve the performance in the enhanced algorithm in terms of SRB while maintaining a reachability comparable to that achieved by other algorithms, the rebroadcast probability of nodes located in low-density areas is set higher than that for nodes located in higher-density areas. The new variant of AODV has been referred to as EDP-AODV for short.

This chapter has demonstrated that the dynamic selection of forwarding probabilities to network nodes depending on their density regions helps to reduce the number of rebroadcasts, in turn helping to reduce network traffic and decrease contention and packet collision.

Extensive simulation experiments under different mobility models have shown that EDP-AODV has the highest SRB over other algorithms under a variety of traffic conditions. In the RWP scenario, the difference in SRB performance in favour of EDP-AODV against P-AODV ranges from 20% to 22%, and from 30% to 28% against AD-AODV. Even under the MG and RPGM mobility models, EDP-AODV achieves higher SRB compared to other algorithms.

With the use of mobility, when the number of connections increases in the network, route breakages occur more frequently and as a consequence RREQ packets fail to reach their destinations. More RREQ packets are generated and retransmitted, leading to a high chance of collision due to the increase in the number of control packets inside the network. However, the results of simulation experiments have revealed that EDP-AODV manages to incur lower collisions and generate less route requests than P-AODV, AD-AODV and blind AODV in all mobility scenarios.

Chapter 6

Comparative Performance

Analysis

6.1 Introduction

Several techniques for dissemination in MANETs have been proposed in the previous chapters to reduce the number of collisions and achieve a high SRB. These include dynamic probabilistic broadcasting (P-AODV) and enhanced dynamic probabilistic broadcasting (EDP-AODV) schemes.

In chapter 3,5 a critical comparative study between the proposed algorithms and the previews work has been conducted using the different mobility modules ,in this chapter performance evaluation for the suggested algorithms will be presented under different mobility modules and the results demonstrated the merits and capabilities of the algorithms in the following sections.

6.2 Simulation Scenarios

In this section, the GloMoSim network simulator (version 2.03) [70] has been used to conduct extensive experiments for a performance comparison of P-AODV and EDP-

AODV algorithms under different the mobility models mentioned in Section 4.2.1. Three AODV variations were implemented: the first using an adjusted probabilistic flooding method [1, 10] called AD-AODV (AODV + fixed pair probability), the second based on dynamically calculating the rebroadcast probability for each node [84-86], called P-AODV (AODV + dynamic probability), and the third is the enhanced dynamic algorithm (EDP-AODV). Tables 6.1 and 6.2 show the parameters used in the simulation.

Table 6.1 Simulation Parameters for P-AODV

Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	1000m × 1000m
Transmission Range	250m
Mobile Nodes	70,80,90 and 100
Traffic Generator	Constant Bit Rate
Band Width	2 Mbps
Packet Size	512 Bytes
Packet Rate	10 Packet Per Second
Simulation Time	900s

Table 6.2 Simulation Parameters for EDP-AODV

Simulation Parameter	Value
Simulator	GloMoSim v2.03
Network Range	1000m × 1000m
Transmission Range	250m
Mobile Nodes	100
Traffic Generator	Constant Bit rate
Band Width	2 Mbps
Packet Size	512 Bytes
Packet Rate	10 Packet Per Second
Simulation Time	900s

6.3 Performance Comparison

The parameters used in the following simulation experiments are listed in Tables 6.1 and 6.2 for different numbers of connections and variants of mobile nodes to achieve a performance comparison for the proposed P-AODV and EDP-AODV algorithms and to show the effect of different mobility models on the proposed techniques. AD-AODV is also implemented for comparison. The metrics for comparison include saved rebroadcast (SRB), average number of routing request rebroadcasts, average number of collisions and reachability (as defined in Section 3.4, above).

6.3.1 Saved Rebroadcast (SRB)

Figure 6.1 explores a confidence of saved rebroadcast (SRB) of the dynamic probabilistic and adjusted probabilistic [1, 10] algorithms at 95% where the four traffic loads have been applied to the network and where system size is kept to 100 nodes under the RWP mobility condition with a maximum speed of 10 m/s and 50 runs of the simulation. Our algorithm (P-AODV) can significantly improve SRB at different traffic loads compared to the adjusted probabilistic algorithm [1, 10]. For instance, our algorithm achieves 36% in terms of SRB in low connections and 54% in high connections, while the adjusted flooding (AD-AODV) scheme achieves 29% in low connections and 48% in high connections. The figure also shows that SRB increases as the traffic load increases. This is because, when the number of connections in the network is increased, more route-request packets will be generated and some nodes might be prohibited from rebroadcasting a packet if its probability value is higher than

the set threshold, and hence there is an increase in the number of savings made by nodes in terms of re-broadcasting.
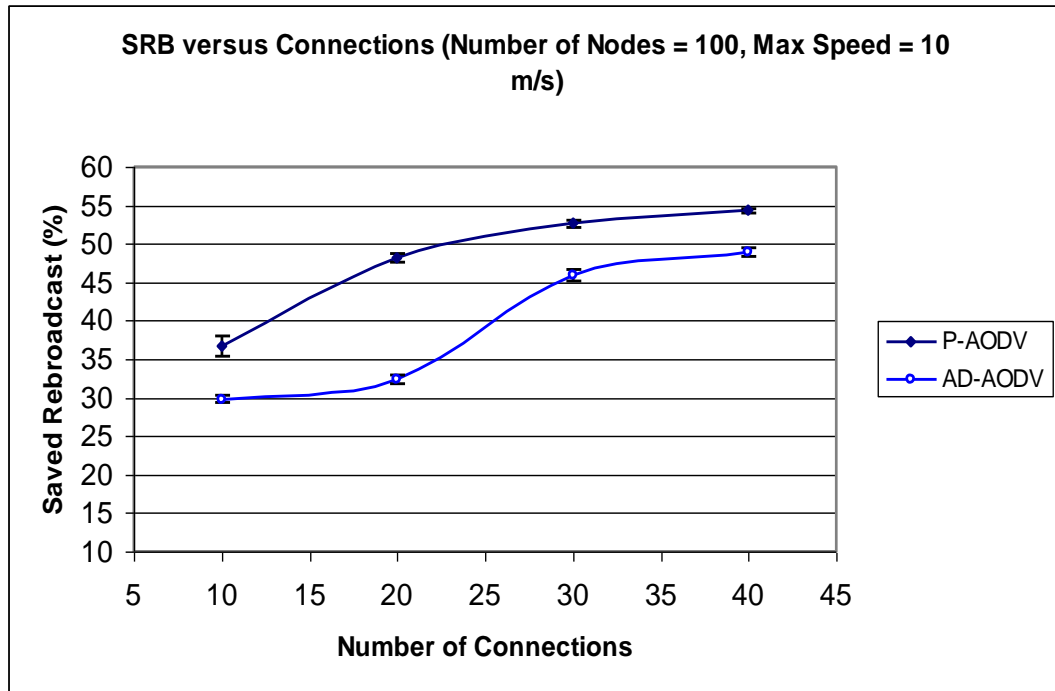
Figure 6-1: Saved rebroadcast comparison between the proposed dynamic probabilistic and adjusted probabilistic flooding schemes

Figures 6.2 and 6.3 depict the comparative performance of SRB results for P-AODV and EDP-AODV algorithms respectively under different mobility models. Figure 6.2 shows the SRB performance when the nodes move under RWP, MG and RPGM mobility models at the maximum speed of 10 m/s and in a combination of different network sizes (from 70 to 100). It is clear that under the RPGM mobility model scenario the dynamic probabilistic algorithm (P-AODV) achieves better SRB than the RWP and Manhattan mobility model scenarios. This is due to the random behaviour of the RWP and Manhattan mobility models. For example, when network density is 90 nodes, the

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SRB for P-AODV under RPGM is 38%, whereas it is 32% and 31%, respectively, under MG and RWP mobility models.

Figure 6-2: Comparison of saved rebroadcast for the proposed dynamic probabilistic flooding scheme under RWP, RPGM and MG mobility models

Figure 6.3 compares the SRB of the enhanced dynamic probabilistic algorithm (EDP-AODV) under RWP, MG, and RPGM mobility models with the mobility condition at the maximum speed of 10 m/s and a different number of CBR connections for a network with 100 nodes. The results reveal that SRB for EDP-AODV under the RWP mobility model scenario is higher than under the MG and RPGM mobility model scenarios for all the CBR connections. This is due to the different characteristics of the mobility pattern of each model. For example, the SRB of EDP-AODV under RWP is 59% in low traffic load and 76% in high traffic load compared to MG and RPGM

models. However, it can seen that under the three mobility models the EDP-AODV experiences increases in SRB as traffic load increases.

Figure 6-3: Comparison of saved rebroadcast for the proposed enhanced dynamic probabilistic flooding scheme under RWP, MG and RPGM mobility models

Figure 6.4 demonstrates the comparative performance of relay results for the P-AODV algorithm under RWP, MG and RPGM mobility models. The entire network and traffic configurations are also the same as those of the previous experiments in Table 6.1. It is also clear that under the RWP mobility model scenario the dynamic algorithm achieves a lower number of relays than the RPGM and Manhattan mobility model scenarios.

Figure 6-4: Comparison of relays for the proposed dynamic probabilistic flooding scheme under RWP,

MG and RPGM mobility models

Figure 6.5 explores the number of relays in the enhanced dynamic algorithm (EDP-AODV) under RWP, MG and RPGM mobility models. The entire network and traffic configurations are also the same as in the previous parameters shown in Table 6.2. As a comparison, the relays are calculated for the EDP-AODV with various CBR connections. As shown in Figure 6.5, it is of note that the EDP-AODV under the Manhattan mobility model incurs a lower number of relays compared to RWP and RPGM models.

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Figure 6-5: Comparison of relays for the proposed enhanced dynamic probabilistic flooding scheme

under RWP, MG and RPGM mobility models

6.3.2 Collision

In this section, we present two simulation experiments to compare the performance of both P-AODV and EDP-AODV algorithms in terms of collision using different mobility models (RWP, MG and RPGM).

Figure 6.6 shows the collisions of the P-AODV under the RWP, MG and RPGM mobility models with different numbers of mobile nodes. From the figure, we can observe that under the Manhattan Grid (MG) mobility model the P-AODV algorithm has significantly less collisions compared with RWP and RPGM mobility models. Collision increases as the number of nodes in the network increases.
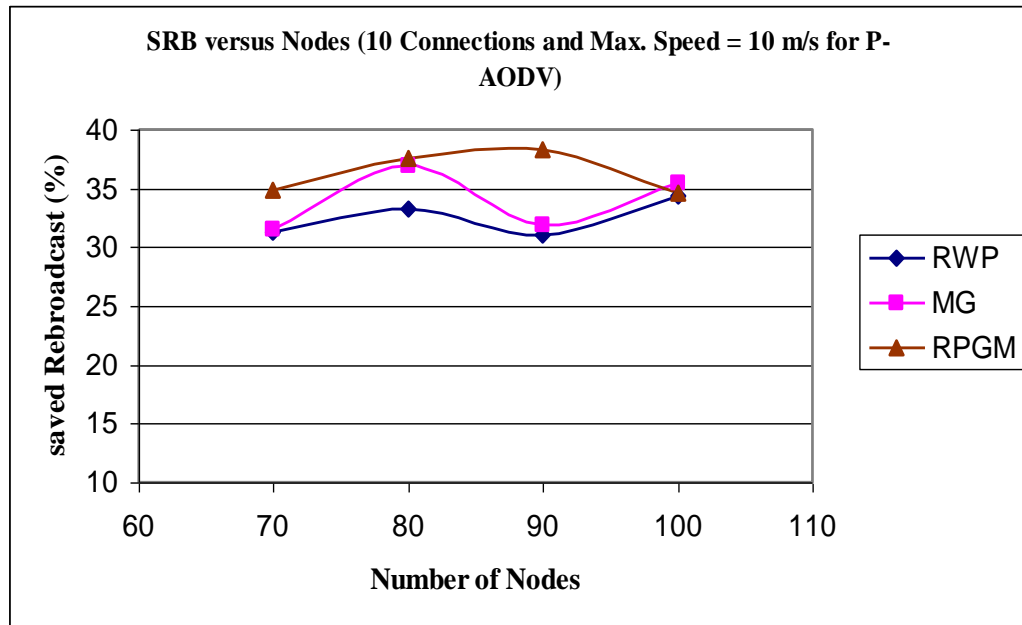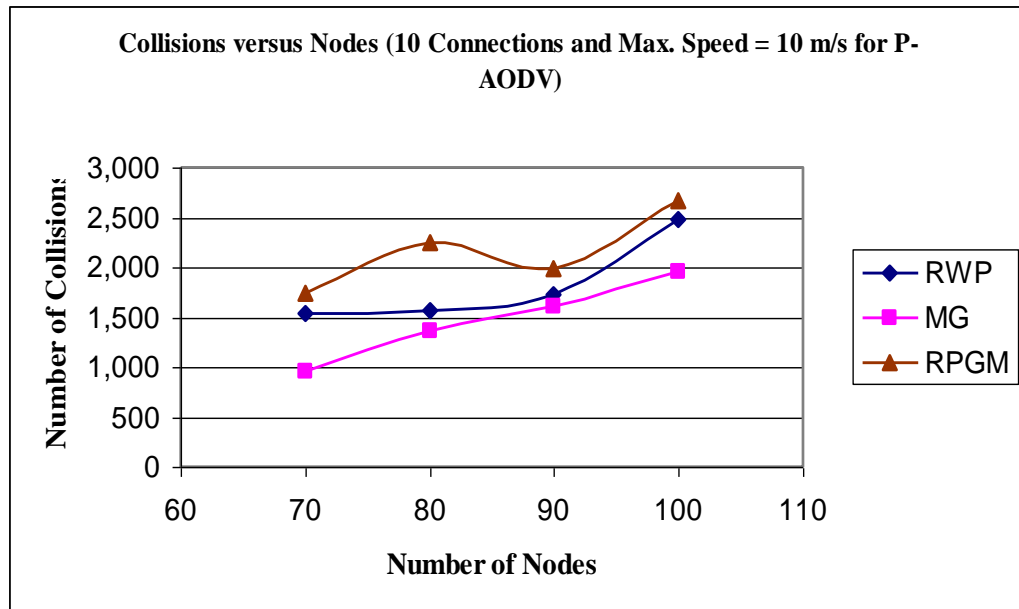
Figure 6-6: Comarison of collision for the proposed dynamic probabilistic flooding scheme under

RWP, RPGM and MG mobility models

Figure 6.7 compares the collisions for the EDP-AODV algorithm under RWP, MG, and

RPGM mobility models where the nodes move at a maximum speed of 10 m/s for a

network with 100 nodes and different numbers of source-destination connections. The

results reveal that EDP-AODV under RPGM mobility model scenario performs with a

lower number of collisions compared to MG and RPGM mobility models scenarios for

all the CBR connections. However, collision increases when the traffic load increases

regardless of what kind of mobility model is used.
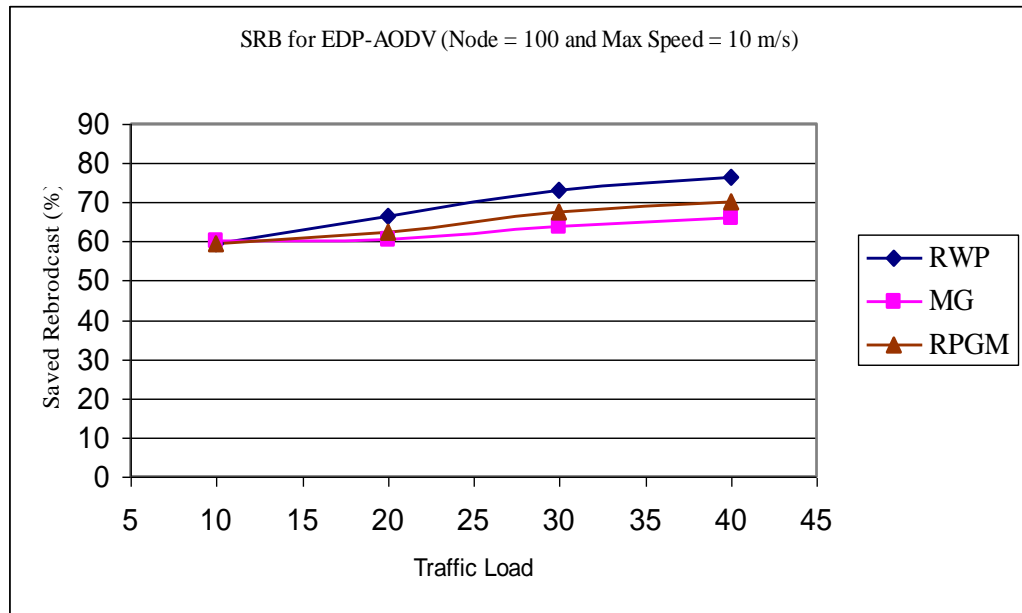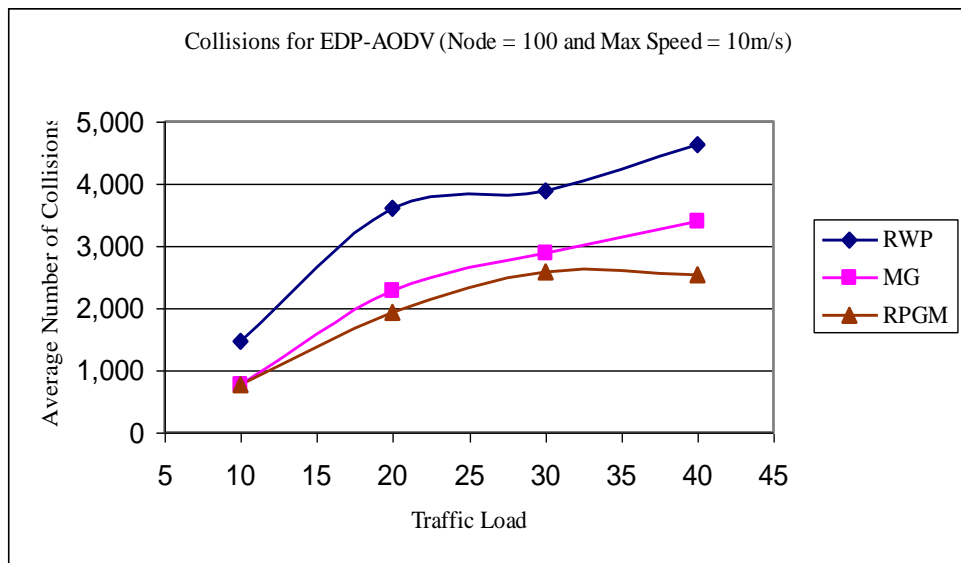
Figure 6-7: Comparison of collisions for the proposed enhanced probabilistic flooding scheme under RWP, MG and RPGM mobility models

6.3.3 Reachability

Figure 6.8 shows the comparison between RWP, MG and RPGM mobility models in terms of reachability for the enhanced probabilistic flooding algorithm (EDP-AODV) for a network with 100 nodes where nodes move at a maximum speed of 10 m/s and with different connections of source-destination pairs. Figure 6.9 clearly shows that the reachability for the algorithm EDP-AODV under the MG mobility model scenario achieves better reachability than under the RWP and RPG mobility model scenarios. Furthermore, the EDP-AODV under the MG mobility model has the highest reachability, which is almost uniform (above 97%) for all traffic loads.
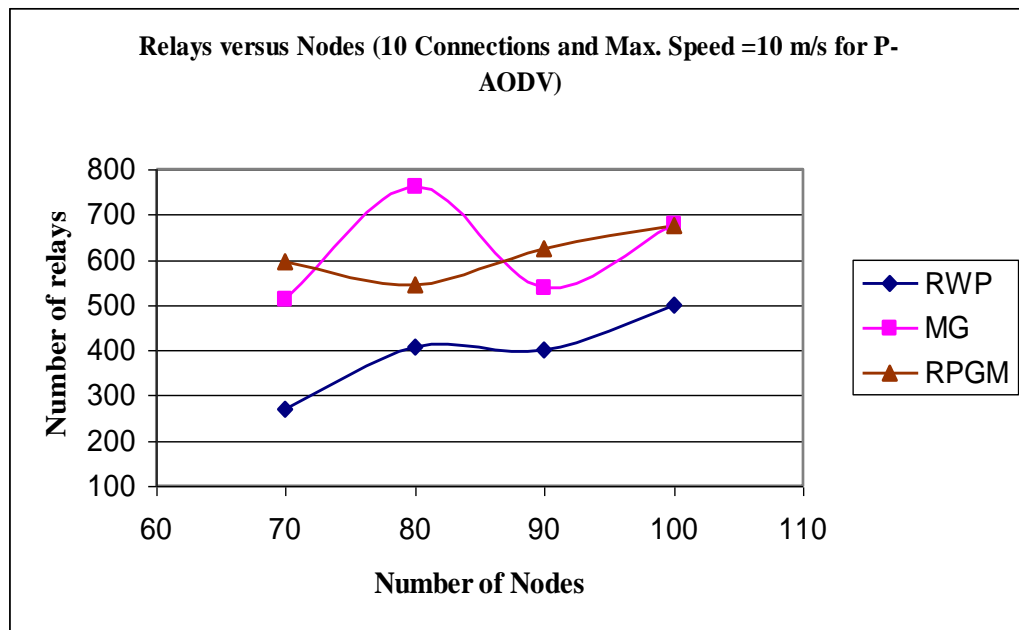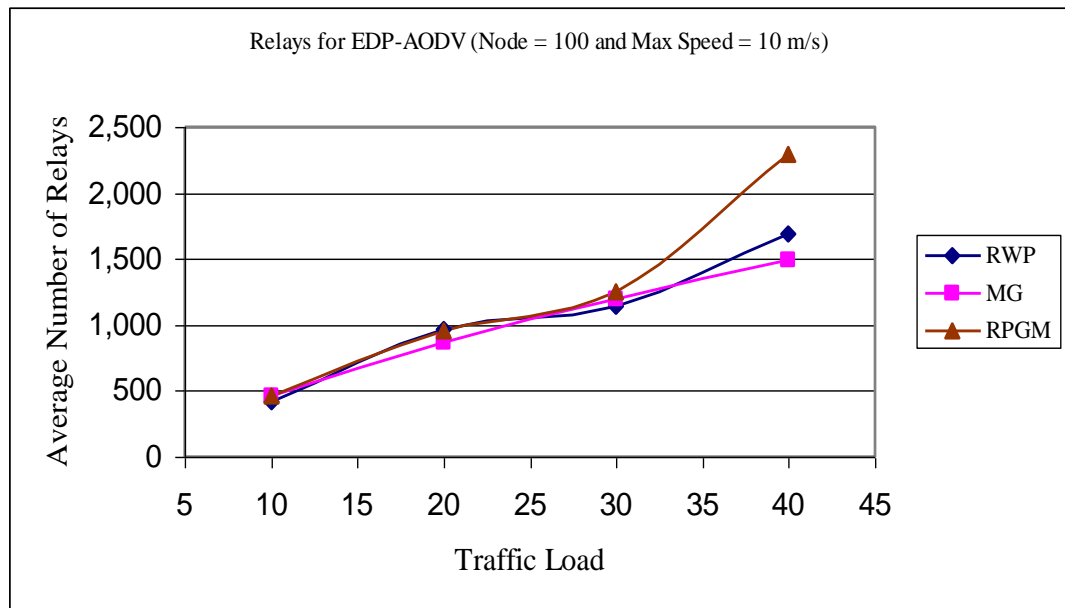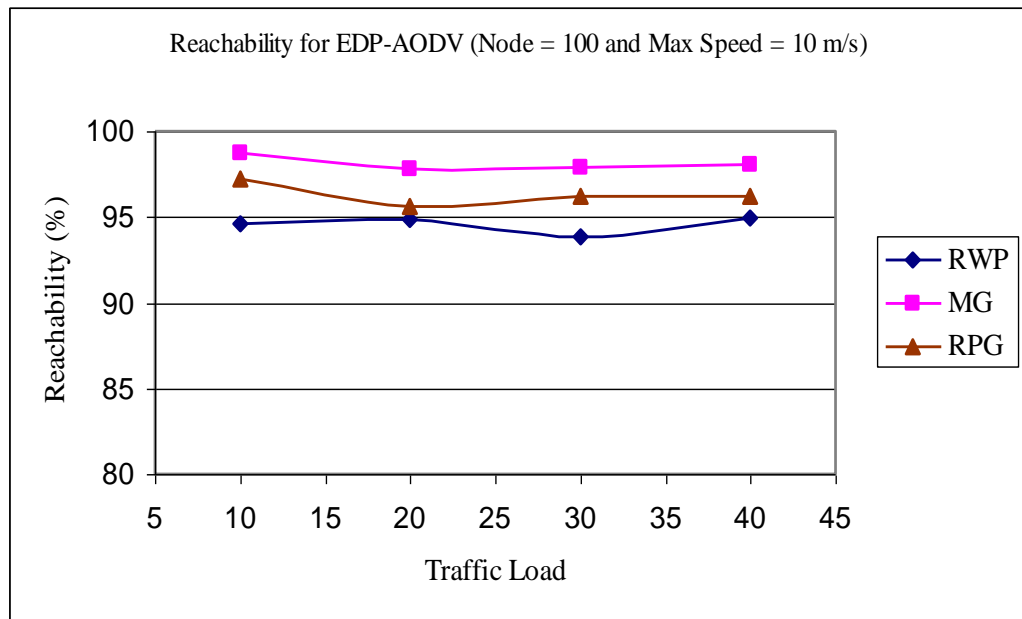
Figure 6-8: Comparison of reachability for the proposed enhanced probabilistic flooding scheme under

RWP, MG and RPGM mobility models

6.4 Evaluation of the P-AODV and EDP-AODV algorithms

This section presents an evaluation of the proposed techniques (P-AODV and EDP-AODV) comparing with simple AODV, FP-AODV and AD-AODV techniques in terms of deployment, scalability, complexity, cost and compatibility . From the simulation results with different simulation scenarios (sections 3.4, 4.3 and 5.4) of the proposed algorithms and the simple AODV, FP-AODV and ADP-AODV, the proposed algorithms and the compared algorithms can be deployed by applying them on other routing protocol such as DSR also can be deployed in industrial and commercial. The proposed algorithms have more scalability than the compared algorithms since their performance results (SRB, Collision, Relays and Reachability) are better than their

corresponded results in the compared techniques. Finally the proposed algorithms are compatibly better than the compared algorithms due to their scalability.

6.5 Summary

In this chapter, a performance comparison was presented to analyse RWP, MG and RPGM mobility models and their effect on P-AODV and EDP-AODV algorithms.

In terms of SRB, simulation results have shown that under RPGM mobility model scenarios the proposed dynamic probabilistic algorithm (P-AODV) achieves better SRB than under the RWP and Manhattan mobility model scenarios, whereas under the RWP mobility model scenario, the EDP-AODV achieves higher SRB than under the MG and RPGM mobility models scenarios. P-AODV achieves 38%, whereas only 32% and 31% are achieved, respectively, under MG and RWP mobility models in high network density. Compared to MG and RPGM models, the EDP-AODV under the RWP mobility model scenario achieves 59% in low traffic loads and 76% in high traffic loads.

In terms of collision, the P-AODV and EDP-AODV under MG and RPGM models, respectively, perform with lower collision compared to other mobility models, while in terms of reachability, the EDP-AODV under the MG mobility model outperforms the RWP and RPGM models. For example, the reachability under the MG mobility model compared to other mobility models is above 97% for all traffic loads.

Chapter 7

Conclusions and Future Work

7.1 Conclusions

This thesis has presented an investigation into the design and development of new dynamic probabilistic broadcasting flooding algorithms for Mobile Ad-hoc Networks (MANETs) that can overcome the limitations of previous flooding methods and deliver improved support for MANET applications.

Contributions to this investigation can be summarised as follows:

The WLAN networks have been reviewed including their types, advantages/disadvantages, 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 extreme redundant retransmission, collision and contention.

This thesis has classified existing broadcast algorithms into two main categories: proactive and reactive schemes. In the first category, proactive schemes, [48, 54, 55, 59, 87], 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 schemes [34, 55, 56, 63], 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 when 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. One of the main advantages of this kind of algorithm is that it is simpler and easier to implement than its deterministic counterpart.

One of the main aims of this thesis is to improve the performance of existing probabilistic broadcasting flooding techniques in order to reduce the broadcast storm problem. To achieve this aim we proposed a new probabilistic algorithm, referred to as dynamic probabilistic broadcasting flooding (P-AODV), which has been incorporated in the Ad-hoc On-demand Distance Vector (AODV) protocol, one of the better-known and widely studied routing algorithms in recent years. Each node dynamically sets the rebroadcast probability according to the number of its neighbouring nodes' information.

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 was evaluated by comparing it against simple (AODV), fixed probabilistic (FP-AODV) and adjusted probabilistic (AD-AODV) flooding approaches under a static scenario and Random Waypoint (RWP) mobility model scenario. The performance results have shown that the proposed scheme outperforms the FP-AODV, AD-AODV [1, 10] and AODV in terms of SRB, while keeping the reachability high. It also demonstrated lower collision, less relays and lower

broadcast latency than the FP-AODV, the AD-AODV [1, 10] and the simple AODV in all scenarios.

Extensive simulation experiments have been conducted to investigate and analyse the performance of the proposed dynamic probabilistic scheme and compare it to simple AODV and FP-AODV under different mobility models. Performance results have revealed that the proposed scheme outperforms the FP-AODV in terms of SRB. The results obtained also demonstrated lower collision compared with both FP-AODV and simple AODV, as well as a lower number of relays in all mobility scenarios.

In order to achieve high SRB while keeping reachability acceptable, we presented a new algorithm, referred to as enhanced dynamic probabilistic flooding (EDP-AODV), which is a further refinement over our first proposed algorithm. While in the first algorithm the broadcasting probability is calculated dynamically according to the information about the number of neighbouring nodes, in the second algorithm the rebroadcast probability also calculated dynamically, but based on the average number of nodes in the ad-hoc networks. Extensive simulation experiments were used to investigate the performance of the enhanced probabilistic flooding scheme and compare it to the simple AODV and AD-AODV schemes and the proposed P-AODV scheme under different mobility models. The performance results have demonstrated that the enhanced scheme EDP-AODV outperforms the simple AODV and AD-AODV schemes as well as the proposed P-AODV scheme in terms of SRB, collision and relays, whereas in terms of reachability the P-AODV outperforms the EDP-AODV.

Finally, an intensive comparative performance analysis for both algorithms P-AODV and EDP-AODV has been presented using RWP, MG and RPGM mobility models. This comparative analysis demonstrated the performance of the algorithms under the different mobility models and showed which performed better under each mobility model in terms of SRB, collision and number of relays.

7.2 Future Work

Other directions for future work might include the following:

An investigation into the effects of other important system parameters which have not been used in this research, For example, the transmission range of nodes could be investigated with regard to setting the rebroadcast probability, and by examining the regulation of the transmission radius of nodes, whether it might be possible to maximise SRB whilst maintaining a low number of rebroadcast.

Many research studies [9, 17] have recently 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.

Further research could be dedicated to the investigation of the performance merits of the dynamic probabilistic broadcast algorithms for other routing protocols, such as Dynamic Source Routing (DSR) [15, 16], under different mobility model scenarios.

Finally, the performance evaluations of MANETs have been conducted mostly through simulations experiments, and to date there has been relatively little activity in the use of analytical modelling to analyse MANETs' performance. It would be interesting if a mathematical model were developed to investigate the interaction between important parameters affecting the performance of dynamic probabilistic algorithms and summarise more accurately the performance behaviour analysis of these algorithms.

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