Dynamic Probabilistic Routing Discovery and Broadcast Schemes for High Mobility Ad-hoc Networks

by

Mustafa Bani Khalaf

A thesis submitted in partial fulfilment of the requirements

of

Edinburgh Napier University

for the award of Doctor of Philosophy

School of Computing

June, 2013

ABSTRACT

Mobile Ad-hoc Networks (MANETs) have lately come to be widely used in everyday applications. Their usability and capability have attracted the interest of both commercial organizations and research communities. Recently, the Vehicular Ad-hoc Network (VANET) is a promising application of MANETs. It has been designed to offer a high level of safety for the drivers in order to minimize a number of roads accidents. Broadcast communication in MANETs and VANETs, is essential for a wide range of important services such as propagating safety messages and Route REQuest (RREQ) packets. Routing is one of the most challenging issues in MANETs and VANETs, which requires high efficient broadcast schemes.

The primitive and widely deployed method of implementing the broadcast is simple 'flooding'. In this approach, each node 'floods' the network, with the message that it has received, in order to guarantee that other nodes in the network have been successfully reached. Although flooding is simple and reliable, it consumes a great deal of network resources, since it swamps the network with many redundant packets, leading to collisions contention and huge competition, while accessing the same shared wireless medium. This phenomenon is well-known in MANETs, and is called the *Broadcast Storm Problem*.

The first contribution of this thesis is to design and develop an efficient distributed route discovery scheme that is implemented based on the probabilistic concept, in order to suppress the broadcast storm problem. The proposed scheme is called a Probabilistic Disturbed Route Discovery scheme (PDRD), and it prioritizes the routing operation at each node with respect to different network parameters such as the number of duplicated packets, and local and global network density. The performance of the proposed scheme PDRD has been examined in MANETs, in terms of a number of important metrics such as RREQ rebroadcast number and RREQ collision number. Experimental results confirm the superiority of the proposed scheme over its counterparts, including the Hybrid Probabilistic-Based Counter (HPC) scheme and the Simple Flooding (SF) scheme.

The second contribution of this thesis is to tackle the frequent link breakages problem in MANETs. High mobility nodes often have frequent link breakages; this potentially leads to re-discovery of the same routes. Although different probabilistic solutions have been suggested to optimize the routing in MANETs, to the best of our knowledge they have not focused on the problem of frequent link breakages and link stability.

Unlike other existing probabilistic solutions, this thesis proposes a new Velocity Aware-Probabilistic (VAP) route discovery scheme, which can exclude unstable nodes from constructing routes between source and destination. The main idea behind the proposed schemes is to use velocity vector information to determine the stable nodes and unstable nodes. A proper rebroadcast probability and timer are set dynamically according to the node stability. Simulation results confirm that the new proposed scheme has much better performance in terms of end-to-end delay, RREQ rebroadcast number and link stability.

The routing in VANETs is very critical and challenging in terms of the number of broken links and packet overheads. This is mainly due to the fast vehicles' speed and different vehicles' movement directions. A large number of routing protocols such as Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) have been proposed to deal with the routing in MANETs. However, these protocols are not efficient and cannot be applied directly to VANETs context due to its different characteristics. Finally toward this end, this thesis proposes new probabilistic and timer probabilistic routing schemes in order to improve the routing in VANETs. The main aim of the proposed schemes is to set up the most stable routes to avoid any possible link breakage. These schemes also enhance the overall network performance by suppressing the broadcast storm problem, which occurs during the route discovery process. The proposed schemes also make AODV protocol suitable and applicable for VANETs. Simulation results show the benefit of the new routing schemes in terms of a number of metrics such as RREQ rebroadcast number, link stability and end-to-end delay.

To my Parents

To my lovely wife

To all my brothers, sisters, and friends

For their endless support, encouragement and love

Acknowledgments

I would like to express my very great appreciation to Dr Ahmed Al-Dubai for his valuable and constructive suggestions during the planning and development of this research work. His willingness to give his time so generously has been very much appreciated. I would like also to express my deep gratitude to Professor Buchannan, my second research supervisor, for his patient guidance, enthusiastic encouragement and useful critiques of this research work.

I would like to convey my great thanks to Edinburgh Napier University, and Scottish Funding Council for financial support and for granting me a scholarship to pursue my further studies at doctoral level.

Finally, I take this opportunity to express my profound gratitude to my beloved parent and brothers for their moral support and patience during my study. I would like to seize this opportunity to express my dearest gratitude to my wife, for her love, patient and encouragement. Without her being beside me, this research will not be finished on time.

Publications during the course of this research

- **CONFERENCES:**

- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai and Mourad Abed, New Velocity Aware Probabilistic Route Discovery Schemes For Mobile Ad-hoc Networks, Proceeding of the 20th international conference on Software, Telecommunications and Computer Networks (SOFTCOME 2012), Split, September 2012.
- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai and William Buchanan, A New Efficient Distributed Route Discovery for Wireless Mobile Ad-hoc Networks, proceeding of 11th Wireless Telecommunications Symposium (WTS), London, 2012.
- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai and William Buchanan, A New Adaptive Broadcasting Approach for Mobile Ad-hoc Networks, Proceeding of 6th IEEE Wireless Advanced (WiAD), pp.1-6, London, 2010.
- Muneer Bani Yassein, Mustafa Bani Khalaf, Performance Comparison of Smart Probabilistic Broadcasting of Ad-hoc Distance vector (AODV), Proceedings of the 25th UK Performance Engineering Workshop (UKPEW), Leeds, 2009.
- Muneer Bani Yassein, Mustafa Bani Khalaf, Performance Evaluation of Multiple Probabilities of Ad-hoc On Demand Distance Victor Protocol (AODV), Proceedings of the 4th International Conference on Information Technology, ICIT, Jordan, 2009.
- Muneer Bani Yassein, Mustafa Bani Khalaf, Smart Probabilistic Broadcasting in Mobile Ad-hoc Network, Proceeding of the IEEE International conference on Communications, Propagation and Electronics, Jordan, 2009.

- **JOURNALS:**

- Muneer Bani Yassein, Mustafa Bani Khalaf and Ahmed Y. Al-Dubai, A new probabilistic broadcasting scheme for mobile Ad-hoc on-demand distance vector (AODV) routed networks, The Journal of Supercomputing, Vol.53, no.1, pp.196-211, 2010.
- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai, Stable Routing Discovery Scheme for Mobile Ad-hoc Network, Ready to submit to: Journal of Computer and System Sciences, Elsevier, 2012.

- **TECHNICAL REPORTS:**

- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai, Reliable and Stable Routing Schemes for Vehicular Ad-hoc Networks, School of Computing, Edinburgh Napier University, *Technical Reports*, January, 2012.
- Mustafa Bani Khalaf, Ahmed Y. Al-Dubai, Dynamic Direction Stable Routing Schemes for Vehicular Ad-hoc Networks, School of Computing, Edinburgh Napier University, *Technical Reports*, September 2012.

List of Figures

List of Tables

Abbreviations

AODV	Ad-hoc On Demand Distance Vector Protocol
AOMDV	Ad-hoc On demand Multipath Distance Vector Routing Protocol
CBR	Constant Bit Rate
DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communication
DSDV	Destination-Sequenced Distance-Vector Routing
GPS	Global Position System
ITS	Inelegant Transportation System
MANET	Mobile Ad-hoc Network
MAC	Medium Access Control
OLSR	Optimized Link State Routing Protocol
OSI	Open System Interaction
PDRD	Probabilistic Distributed Routing Discovery
PB-SD	Probabilistic Based-Speed and Direction Scheme
PMD	Physical Medium Dependent
PLCP	Physical Layer Convergence Procedure
PSS	Probabilistic Speed Scheme
RREQ	Route Request
RSU	Road Side Unit
SVAP	Simple Velocity Aware Probabilistic Route discovery
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
VANET	Vehicle Ad-hoc Network
V2R	Vehicle to Road side
V2V	Vehicle to Vehicle
LLC	Logical link control
WAVE	Wireless Access in Vehicular Environments
ZRP	Zone Routing Protocol

Chapter 1

Introduction

Wireless networks are divided into two types: wireless single-hop and wireless ad-hoc multi-hop networks. The communication between nodes in the single-hop network is established based on a fixed infrastructure of base stations, access points and servers which are deployed in advance. Figure 1-1 shows a simple example of a fixed wireless network. Nodes such as a smart phone or a tablet computer connect directly to a fixed wireless access point.

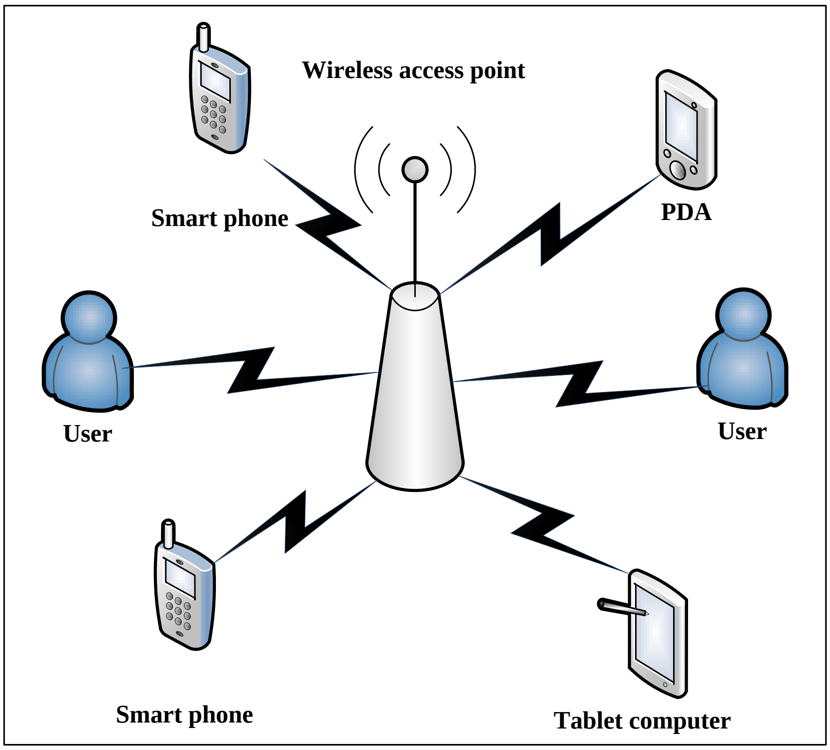

Figure 1-1 : Example of a fixed wireless network.

In the wireless ad-hoc network such as Mobile Ad-hoc Networks (MANETs), communication between nodes is established via other intermediate or forwarding nodes. The nodes in ad-hoc networks are dynamically formed with no need for an existing infrastructure or pre-configuration. MANETs can be deployed and operated without the need to rely on an infrastructure, which make them useful for various applications that run temporarily [1] [2]. Figure 1-2 shows a logical description of MANETs.

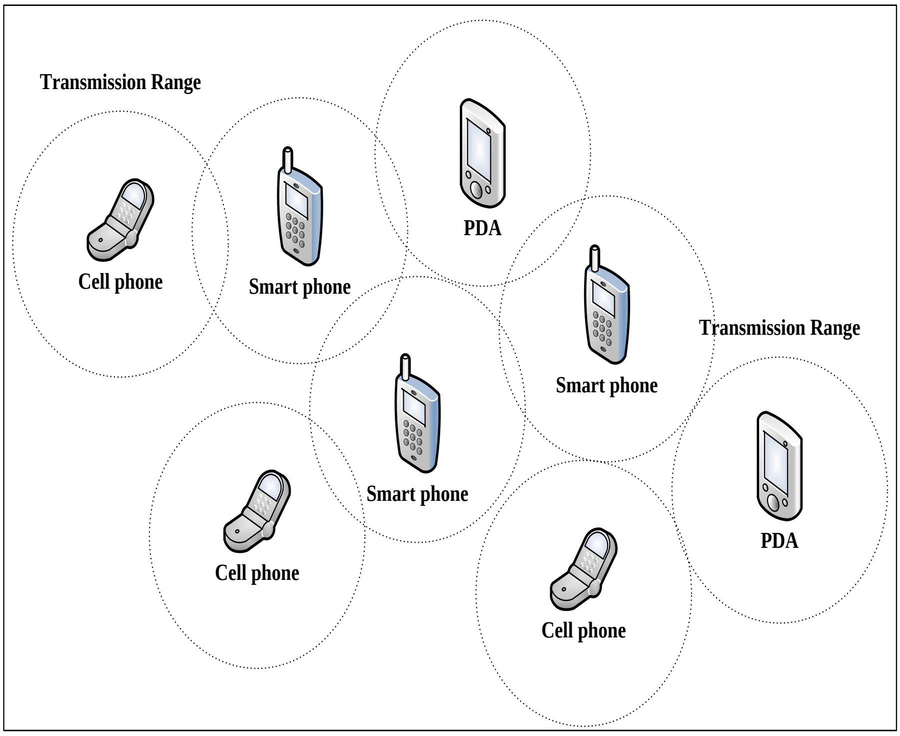

Figure 1-2: Example of a wireless mobile ad-hoc network.

MANETs technology have been a major avenue for many wireless and mobile network based applications in different fields including, but not limited to, industry, military, and public services as well as the emerging ones such as the intelligent transport systems (ITS) to enhance road safety, passenger comfort and logistics. Vehicle Ad-hoc Networks (VANETs) are one of the most common practical examples of MANETs, and they are the basic component of the ITS architecture. Over the last ten years, VANETs technology have been developed and used as a means to mitigate road accidents, and to provide more entertainment facilities to drivers on the road [3].

Nodes in MANETs move randomly and also they can arbitrarily connect to the network or disconnect from it. Vehicles in VANETs also connect arbitrarily, but vehicle movement and speed are very different, and are restricted by road constraints. Vehicles travel in the same or opposite directions, follow each other and move left or right according to road signs. Vehicles usually move at very high speed more than mobile devices that depend on human movement.

Broadcast communication has been the cornerstone of many VANETs and MANETs applications. It can be used to send information messages from either Road Side Unit (RSU) stations to vehicles, from a vehicle to all vehicles on the road, or to discover routes between vehicles. For instance, a given RSU station can broadcast a message about an accident at a specific road location. The first time a vehicle receives this message, it rebroadcasts it to its neighbours, in a multi-hop fashion, except the one it has received the message from. The vehicles may respond to this broadcast message by detouring to another road, and thus avoid the congestion scene-of-accident. As another example, when a source node needs to route data to a particular destination node, it broadcasts a Route REQust (RREQ) to all nodes in order to find the required destination. The primitive method of implementing the broadcast service is ‘flooding’. In this approach, each node ‘floods’ the network with the message which has been received, in order to guarantee that all nodes have received the message. The effect of using this method does not have a significant impact on a network, which has a limited number of mobile nodes. But in a large and scalable network such as VANETs and MANETs, the side effect of using flooding can dramatically decrease its performance.

Flooding approach produces redundant broadcasted messages, and increases collisions in transmission between vehicles and the competition on the shared wireless medium. This phenomenon is common in MANETs and is known as the *broadcast storm problem* [4] [5].

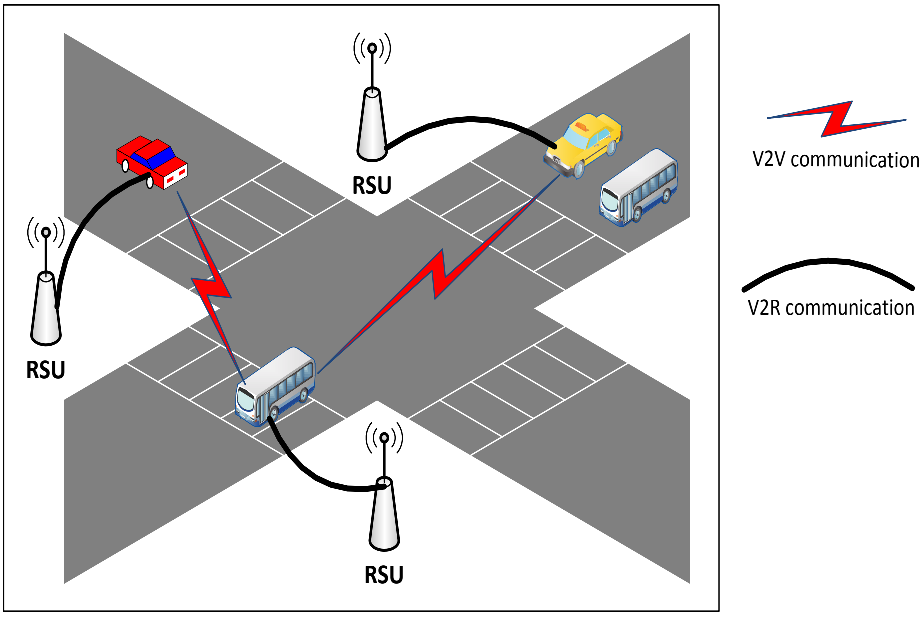

Figure 1-3 : Example of the communication between VANETs components.

The Dedicated Short Range Communication (DSRC) generation technology has been developed over the last decades to meet the new requirements of VANETs safety and non-safety applications. DSRC is also known as WAVE (Wireless Access in Vehicular Environments) [6] or IEEE 802.11p [7]. WAVE is the core part of DSRC and both terms are used, but DSRC is more common. Communication between vehicles in VANETs can be accomplished by two methods, depending on the use of DSRC. The first method is called a Vehicle-to-Vehicle (V2V) communication. In V2V, a vehicle sends a message to other vehicles on the road without Roadside Station Unit (RSU) assistance.

The second method is a Vehicle-to-Roadside (V2R) communication. In V2R, either the RSU station sends an information message to the vehicles, such as an announcement about weather conditions, or the vehicle sends a query message to RSU in order to find services, such as a parking space or a restaurant. Figure 1-3 shows the communication between the vehicles and the RSU.

1.1 Protocols Layers of MANETs

This section presents on the Open System Interconnection (OSI) reference model layers [8] for MANETs, and describes the functionality of each layer. Figure 1-4 represents protocols stack of MANETs including: the application, transport, network, data link, and physical layers. Communication between nodes in MANETs operates on the lower levels of OSI model, i.e. layers 1 to 3. The higher layers are only associated to the source and destination pairs.

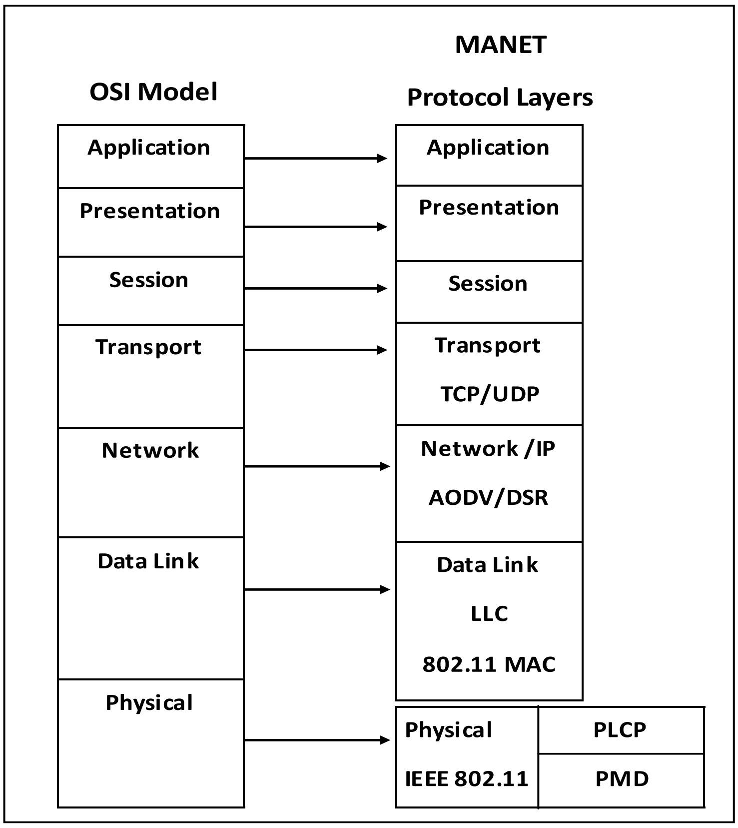

Figure 1-4: OSI reference model and MANET protocol layers.

In this section we discuss the first four layers as this thesis investigates the proposed routing schemes within these layers. However, the interested reader may refer to [9] for more details on the application layer (provides full end-user application process), presentation layer (provides data presentation and data integrity between devices) and session layer (manages the setting up and taking down connection between two end points).

The Transport Layer: the main aim of this layer is to provide a reliable end-to-end connection between source and destination node pairs. It provides several important services such as supporting data packet's integrity, flow control, and congestion control [8]. The transport layer consists of two important protocols: Transmission Control Protocol (TCP) [10] and User Datagram Protocol (UDP) [11]. TCP is designed to ensure reliable data delivery to a destination node by using acknowledgment and retransmission methods. In the constant, UDP is a connectionless protocol and provides no reliable or guarantee of a delivery. It is useful for video streaming and time-sensitive applications where error checking and correction is not important.

The Network Layer: it is responsible for all service to discovery and set up a route between source and destination node pairs. This includes, forwarding data packets and routing them through intermediate nodes, link repairing and maintenance [12].

The Data Link Layer: it comprises two sub layers: the Logical Link Control (LLC) layer and the Medium Access Control (MAC) layers [8]. The LLC layer is responsible for link maintenance, controls frame synchronization, flow control and error detection. The MAC layer is responsible to manage access to the shared wireless channel between nodes. So it is considered very necessary to prevent collisions and contentions among the node.

The Physical Layer: it is responsible for signal transmission over a physical link connecting devices together [13] [14]. The physical layer contains two sub-layers: the Physical Layer Convergence Procedure (PLCP) and the Physical Medium Dependent (PMD). PLCP prepares the frame received from the MAC layer into a format that PMD can retransmit. When PMD receives the frame from PLCP, it translates it into radio signals for transmission.

1.2 Characteristics of MANETs

MANET has several unique characteristics, which makes it very different from other types of wireless network [2] [15] [16]. These characteristics affect most network operations such as routing and broadcasting. Below is a description of the most important characteristics of MANET.

Multi-hop communication: In MANETs, nodes within the transmission range boundary of the source node are able to communicate with one hop transmission range. Nodes that are located further of source node transmission range set up communication channels with the help of the intermediate nodes. This type of communication is named *Multi-hop,* and related only to MANETs.

Infrastructure-less network: Nodes in MANETs are directly connected together without an access point or base station assistance. Each node operates as a server or as a router depends on the request that it has recently received. This characteristic makes MANETs very useful to applications such as disaster relief, search and rescue, and tactical operations where it is impossible to install a fixed infrastructure, or where the network is temporary or unavailable.

Resource-constrained and limited: Devices equipped with nodes in MANETs have limited resources and operate with limited capacity, in terms of energy, computational power and memory.

For instance, nodes use batteries as a source of power to perform their tasks such as sending or receiving messages. However, batteries sometimes run out of power as they have a finite lifetime.

1.3 Applications of MANETs

Due to its high flexibility, easy installation and quick configuration, MANETs has a wide range of applications which can be directly applied to many real life scenarios [17] [18] [19]. Below is a description of most common applications of MANETs.

General Purpose Applications: MANETs is useful in some military operations such as battlefields to exchange information between soldiers. MANETs is also used in some critical applications, such as in disaster recovery, or rescue operations where the communication infrastructure is frequently lost between nodes, and restoring it quickly is very important. Sharing files, sending documents and showing videos in meeting rooms, class rooms and conference avenues need a temporary network such as MANETs to set up a communication between mobile devices such as Personal Digital Assistants (PDAs) or laptops.

Vehicular Ad-hoc Networks: is the largest commercial application which has emerged from MANETs. VANETs is the main component of the ITS and provides a communication infrastructure for all its applications. Section 1.4 discuses general VANETs' applications.

1.4 Characteristics of VANETs

MANETs and VANETs have some shared characteristics in terms of mobility and density. However, VANETs still has distinct features which makes it very different from other types of MANETs. These features are listed in this section as follows.

- **Mobility**

Vehicles usually have a very high velocity more than mobile devices that depend on human movement. Vehicles' velocity also varies from a high velocity such as on highways, to medium or low within a city environment. In general, VANETs topology changes rapidly and frequently due to high vehicle mobility. For this reason, the lifespan of connections between vehicles expires quickly. Therefore, reconstructing a new one consumes network's recourses. The final part of this thesis is dedicated to designing a routing scheme able to consider vehicles' mobility conditions.

- **Density**

The topology of VANETs can be divided into three types, i.e., dense, regular and sparse types based on density estimation. Density is usually measured by an estimated number of vehicles on the road. In the case of dense types, a message can reach other vehicles with small number of hops. However, redundant retransmissions and contention between neighbours would make messages collide with each other. On the other hand, disconnection problems can appear in sparse types, due to the greater distance between vehicles. Messages sometimes could not reach vehicles, which are located outside the transmission range source boundary.

A number of additional different parameters can affect on VANETs density, such as the road length and the number of lanes per road. For example, assume that 100 vehicles are distributed randomly on a road with two lanes and of length 1km. Such a scenario forms a dense regime. But the same scenario with a road length of 3km can form a regular or a sparse regime. Density also varies from time to time. For instance, dense types during rush hours may become sparse types during non-rush hours.

- **Movement Patterns**

Vehicle movement is always restricted by road directions and boundaries. In general, vehicles travel in opposite directions, follow each other and move left or right according to road signs. The stability of communication link between vehicles depends on the direction of vehicle movement. Vehicles moving in the same direction are able to be connected for a long time period, while the link between vehicles moving in opposite direction is short-lived.

1.5 Applications of VANETs

VANETs have a wide range of applications which can be applied to many real life scenarios. Different classifications exist in literature [20] [21] [22] [23], each one only focusing on a particular applications group. In this section we provide a general categorization for the most VANETs applications.

- **Safety Applications:**

The main purpose of operating VANETs is to increase safety for vehicles and pedestrians on roads. In [24], safety applications are divided between cooperative forward collision, pre-crash sensing/warning and hazardous location V2V notification. More applications are considered as safety applications in [25], which include traffic signal sign warning, left turn assistance, assistance blind merge warning and pedestrian crossing information. Further safety applications can also be included such as information and warning functions (dissemination of road information such as surface conditions), communication-based longitudinal services (such as platooning vehicles for improving road capacity) and control co-operative assistance systems [26]. Safety applications can also be classified as safety-related and safety-critical [20].

In the former, each vehicle should receive the safety message with high security mechanisms. In the second, the safety message should reach other vehicles with minimum end-to-end delay. The author in [21] has classified safety applications as life-critical safety applications (high priority and latency is critical), and safety warning application (low priority and latency is not critical).

- **Non-Safety Applications**

A number of non-safety applications have been developed as part of the applications that VANETs can provide. Applications such as these can offer entertainment and increase comfort factors for all drivers on the road.

Traffic management and optimization, and logistic operation are one possible non-safety application. Drivers can receive information which informs them about current road conditions such traffic congestion on roadways and assist them in finding another detour [22] [25]. Electronic toll collection services allow drivers to make payment via wireless technology without waiting at a toll booth [22] [23]. To offer more entertainment options on roads, infotainment applications have been developed to help vehicles gain access to the internet, download media and make online payments [22] [24] [27].

1.6 Motivation

As mentioned above, network applications such as route discovery protocols and warning messages dissemination protocols relay basically on the broadcast concept. For instance, in the route discovery phase, the broadcast operation is used to flood the network with RREQ packets to establish a route between source and destination pairs. Although flooding achieves high reachability and guarantees that every node receives the RREQ packet, it still sufferers from high levels of redundant retransmission, which often leads to the broadcast storm problem. Flooding also consumes network resources for example increasing battery power consumption and decreasing the communication bandwidth [4] [28].

Broadcast contention and collision in dense networks occurs frequently because all nodes sharing the same wireless media. As a result, many RREQ packets are dropped and fail to find the required destination, which requires the source to resend the RREQ packet many times and thus increase the total end-to-end packet delay. *Hidden terminal problem* also appears in dense networks when the flooding technique is used to disseminate the RREQ packet to the entire network. It often occurs when more than two nodes within the sender transmission range rebroadcast simultaneously and they do not see each other [29].

So far, there have been significant research efforts focused on mitigating the broadcast problem [30] [31] [32], and reducing RREQ packet transmission redundancy in some routing protocols [33]. However some of the proposed schemes assume the existence of GPS at each node in order to reduce and control the RREQ packet overhead [31] [33]. One of the most promising solutions to reduce the communication overhead accompanying routing protocols without the existence of GPS is to develop an efficient distributed probabilistic route discovery scheme. It should be designed to limit the number of nodes that participate in forwarding the RREQ packets, while guaranteeing that it can achieve the same performance as the flooding scheme.

Although a number of probabilistic schemes are suggested for use in MANETs communications, most of them are inadequate to reduce the number of packet collisions, while still achieving a reasonable level of reachability. A fixed value of retransmission probability is assigned at each node in [5]. As shown in [34], a low value of retransmission probability leads to poor reachability in sparse networks, while a high value of retransmission generates more redundant retransmissions in dense networks. This problem often appears as the value of probability is set at each node regardless of its surrounding neighbour's information such as a node density. Therefore, retransmission probability should be adjusted according to the network density and should be different at each node.

A recent proposed solution to the broadcast storm problem is a hybrid solution incorporating advantages of the fixed probabilistic scheme and the counter-based scheme [35]. In this scheme, when a node receives a new packet, it initiates a Counter (*C*) which counts the number of times that the node receives the same packet.

If *C* reaches a predefined threshold *C* within a fixed timer, the node drops the packet. Otherwise, if *C* is less than Counter threshold C_{th}, the packet is rebroadcast with a rebroadcast fixed Probability *P*. Although the hybrid probabilistic counter-based scheme is the earliest solution, it is still vulnerable to the broadcast storm problem. A fixed probabilistic scheme problem appears in such hybrid solutions as all the nodes with same density degree are forced either to rebroadcast with same probability value or to cancel their transmission. In addition, most hybrid probabilistic counter based-schemes [36] [37] and counter based-scheme [5] [38], fail to avoid the simultaneous broadcast problem between nodes. A random fixed timer is initiated at each node without considering their local topological characteristics. As a result, many nodes decide to rebroadcast at the same time which causes broadcast collision problems. Furthermore, most probabilistic schemes also suffer from the simultaneous broadcast problem as no timer is used at all, and each node rebroadcasts immediately after it receives the packet.

Due to high node mobility frequent link breakages are one of the major problems that degrade network performance and lead to broadcast problem [39] [40].

This occurs when a node that is a part of a route, loses connectivity to its neighbours and is no longer able to communicate with them. The disconnected node then announces itself to inform the source node that a new route discovery session is needed. This case imposes extra overhead on the network and increases the arrival times of the packets. Most recent proposed probabilistic routing schemes alleviate the broadcast storm problem in MANETs protocols by prohibiting nodes from participating in route discovery based on some predefined thresholds. For example, in [34] [41] a node cancels its retransmission if it has a density degree above a predefined density threshold such as maximum network density. In [42], the rebroadcast probability is calculated based on the distance between sender and receiver.

The probability of the receiver cancelling its transmission is high if it is located at a distance close to the sender. Although the current suggested probabilistic routing schemes succeed in reducing routing overhead, they fail to avoid frequent link breakages problem. This is because nodes' velocity is not included as a factor in routing decisions, and some unstable nodes form part of the routes.

Ad-hoc On-Demand Victor (AODV) protocol is mainly designed to work with MANETs applications. A lot of optimization solutions have been suggested to enhance its performance within the context of MANETs [43] [44] [45]. Due to its effectiveness and reliability, some efforts have been dedicated to making AODV protocol suitable for VANETs [46] [47] [48]. However, the frequent link breakages problem in AODV protocol-based VANETs, has not been addressed so far within probabilistic routing solutions. Thus, this thesis presents solutions in order to fill the gaps and the limitations found in the literature.

1.7 Contribution

Motivated by the shortcomings mentioned in the motivation section regarding existing probabilistic routing solutions, this thesis presents new routing schemes based on the probabilistic concept that are able to overcome these shortcomings, and open new doors towards optimal routing strategies.

The flooding routing scheme is enhanced with traditional probabilistic routing schemes such as the fixed counter scheme and the fixed probabilistic scheme. Recently, further investigation demonstrates that a hybrid routing solution of fixed counter scheme and fixed probabilistic scheme outperforms the traditional solution [43]. However, both solutions are not efficient and suffer from the broadcast storm problem. This appears in traditional probabilistic schemes when a fixed counter or a fixed probability is set to take routing decisions blindly without considering neighbourhood information.

The hybrid probabilistic scheme [36], overcomes this shortcoming by making probabilistic routing decisions based on neighbourhood density. Nevertheless, the broadcast storm problem occurs when all of the nodes in a dense area or in a sparse area are assigned the same value of rebroadcasting probability. Furthermore, a random fixed timer value is used for all nodes regardless of the network density. This increases the chances of more than two nodes with the same transmission range broadcasting simultaneously, and as a result increases the number of packet collisions.

Towards this end, the first contribution of the thesis proposes a new probabilistic scheme, namely a Probabilistic Distributed Route Discovery scheme (PDRD). Node density and node degree in MANETs are distributed randomly, and they change frequently. It is crucial to set appropriate values for both timer and forwarding probability for each node with respect to its density degree.

In a dense region, nodes should wait longer and assign low forwarding probability to minimize the number of unnecessary retransmissions. But in a sparse region, nodes should rebroadcast immediately with minimum possible time waiting and with high forwarding probability to maintain a high level of connectivity. To meet these requirements, PDRD schemes is designed with a dynamic timer adjusted according to the global and local network density, and extended per packet received over a time interval. The rebroadcast probability value is also initialized based on network density, and readjusted per packet received. PDRD uses an appropriate mathematical equation to represent the exact relationship between nodes' density, timer and forwarding probability. The performance of the PDRD scheme is evaluated and compared with existing schemes; pure flooding and hybrid probabilistic schemes [36]. The simulation results show that PDRD scheme achieves significant results compared to its counterparts in terms of many important metrics such as collisions and routing overhead.

As stated in the contribution section, most existing probabilistic routing schemes are not aware of nodes stability when broadcast decisions take place. The second contribution proposes two new Velocity Aware Probabilistic Route Discovery schemes to overcome the frequent link breakages problem in MANETs. The new proposed schemes privilege nodes that have approximately the same velocity to build stable routes between source and destination pair. To the best of our knowledge, probabilistic link stability routing schemes are the first proposed schemes to optimize AODV protocol in MANETs.

In the first scheme namely Simple Velocity Aware Probabilistic Route discovery scheme (SVAP), nodes are classified into two types based on their velocities. A node is classified as a reliable node if it has a similar velocity to the source node.

But the node is classified as an unreliable node if it has a different velocity to the source node. The reliable nodes should set a high counter threshold value, and a high forwarding probability value. On the other hand, the unreliable nodes should set a low counter threshold vale, and a low forwarding probability value. This gives the reliable nodes a better opportunity to build routes, and as a result reduces the link breakages problem. Simulation results show, that the new proposed routing scheme outperforms the flooding scheme, fixed probabilistic scheme and fixed counter scheme in most performance metrics such as link stability and routing overhead.

Although the SVAP scheme can reduce the number of broken links and keep the route connected as long as possible, it can be improved further. A fixed timer in the SVAP scheme is used in all nodes regardless of their reliability, which could allow some unreliable nodes to be part of the established routes. To fill this gap, an Advance Velocity Aware Probabilistic (AVAP) route discovery scheme is proposed, which employs two different timers to distinguish between the reliable nodes and the unreliable ones.

A short timer is initialized at the reliable nodes to enable them to quickly retransmit a received RREQ packet before the unreliable nodes. On the other hand, a long timer is initialized at the unreliable nodes to prevent them from participating in the route discovery process and cancelling their retransmission. Simulation results show that the AVAP scheme achieves superior performance in terms of link stability, collision rate and end-to-end delay compared to the SVAP scheme.Routing in VANETs is more complicated than routing in MANETs, and traditional AODV protocol does not operate effectively.

As stated above, there has been a much of research on optimizing AODV protocol with probabilistic route discovery scheme including the schemes mentioned above in the context of MANETs. However, there has been little activity to make AODV protocol suitable for VANETs. In an effort to fill this gap, the final contribution in this thesis proposes two new stable probabilistic routing discovery schemes for VANETs. The first scheme is called the Probabilistic Speed Scheme (PSS), which uses a probabilistic mathematical function that allows vehicles with the same speed (i.e. reliable vehicles) to participate in the routing discovery process regardless of their direction of movement. The second scheme is called the Probabilistic Based-Speed and Direction Scheme (PB-SD), which uses a timer mathematical function that allows vehicles with the same speed and direction (i.e. most reliable vehicles) to participate in the routing discovery process. Both schemes are incorporated into AODV protocol, evaluated within a VANETs context, and compared to the traditional AODV. To the best of our knowledge, this is the first investigation that shows how the probabilistic broadcast concept can be used to make AODV stable and suitable for a VANETs environment.

Extensive simulation results reveal that the PSS scheme and the PB-SD scheme based AODV protocol achieve significant results in terms of routing overhead and end-to-end delay, compared to the traditional AODV protocol that employs the simple flooding scheme.

1.8 Thesis Statement

Traditional AODV protocol that employs the simple flooding scheme suffers from the broadcast storm problem. Although several probabilistic routing schemes have been suggested to solve this problem, most of them do not solve the problem effectively.

Furthermore, some routing schemes require nodes to be equipped with additional hardware such as GPS to limit the routing process to a specific geographical area.

Current suggested probabilistic routing schemes fail to solve the frequent link breakages problem in traditional AODV protocols, which is a main cause of the broadcast storm problem. AODV protocol with current probabilistic solutions including our solutions, achieves a good performance in MANETs. However, AODV protocol still does not suit VANETs without proper modifications to its routing function.

This research asserts the following key statements of this thesis:

- ***T1:*** A new **Probabilistic Distributed Route Discovery Scheme** (PDRD) is proposed, which is suitable for MANETs applications that do not rely on the existence of the GPS. The proposed scheme also has significant features which can handle the broadcast storm problem effectively. The global and local network densities are included when calculating both the rebroadcast probability and the waiting time. It can also avoid the simultaneous broadcast problem by extending the timer per each packet received.
- ***T2*:** All the previous probabilistic routing schemes are dedicated to solving the broadcast storm during the route discovery process only. In this thesis we utilize the probabilistic concept to develop new probabilistic routing schemes called **Velocity Aware Probabilistic** (**VAP**) route discovery schemes, to solve the frequent link breakages problem and guarantee that all constructed links are stable in MANETs. Node velocity is anticipated as a key parameter to control the routing function among the nodes. Nodes that move with the same velocity are called reliable nodes and should be assigned a high probabilistic routing decision,

while nodes that move with different velocities are called unreliable nodes and should be assigned a low probabilistic routing decision. A cosine angle is calculated between a sender and a receiver, and compared with a predefined cosine angle threshold, to identify whether the receiver is a reliable node or an unreliable node.

- ***T3:* New stable probabilistic route discovery schemes** are proposed for VANETs, as routing in VANETs is very difficult and different compared to MANETs. Unlike other proposed schemes, these schemes use vehicles' speed information and direction to calculate for each vehicle the probabilistic rebroadcast and the waiting time. These schemes change the primitive flooding routing function in the traditional AODV protocol and make it workable within VANETs topology.

1.9 Thesis outlines

The rest of the thesis is organized as follows:

Chapter 2 accommodates background and previous research efforts relating to broadcasting and routing schemes in MANETs and VANETs. It starts with a description of broadcast operation. This is followed by a section including a general categorization of broadcasting and routing schemes in MANETs and VANETs, and several optimizations on the traditional flooding broadcast. Finally, it discusses the network simulator, mobility model, research assumptions and the performance evaluation metrics.

Chapter 3 introduces the Probabilistic Distributed Route Discovery (PDRD) scheme that dynamically adjusts the forwarding probability and timer at a node according to the local and global network density.

Chapter 4 presents the new Simple and Advance Velocity Aware Probabilistic routing schemes (SVAP and AVAP). Both SVAP and AVAP use the vector unit information of the sender and the receiver to find the most stable nodes and adjust the forwarding probability value and the timer accordingly.

In **Chapter 5**, stable probabilistic route discovery schemes for VANETs are proposed. These schemes incorporated AODV protocol to make it suitable for VANETs topology.

Finally, **Chapter 6** summarizes the results obtained in this research and outlines some possible directions for future work.

Chapter 2

Background and Literature Review

The key objectives of this chapter are to provide the background information necessary to understand the subsequent chapters and are organized as follows:

- Describing broadcast operation, problems and applications.
- Reviewing and categorizing the most relevant works including broadcasting and routing schemes in MANETs and VANETs.
- Describing the network simulator and mobility models used in this study.
- Outlining the research assumptions and the performance evaluations metrics.

2.1 Broadcasting in MANETs

Broadcast is defined as a process whereby a node disseminates a message to all other nodes within its communication range. The message then traverses to the other nodes in the network in a multi-hop manner through intermediate nodes. *Flooding* is the simplest scheme to run at each node to guarantee that the message reaches all the nodes in the network. However, the primitive flooding scheme consumes network resources, reduces network performance, and causes the broadcast storm problem which is discussed later in this chapter. Therefore, to design and implement an efficient flooding broadcast scheme is very important in MANETs.

In MANETs, each node completes the broadcasting phase at the physical layer based on two different models: the *one-to-one* broadcast model and the *one-to-all* broadcast model [49] [50].

In the first broadcast model, each node sends a message to only one neighbour by using narrow beam uni-directional antennae, or receives it based on its unique frequency. In the second broadcast model, transmission by a node reaches all nodes within its transmission range distance by using omni-directional antennae. The one to-all broadcast model is widely studied in the literature, and most of the suggested broadcast solutions have been implemented based on its requirements. This is due to most current mobile devices being equipped with omni-directional antennae, and new emergent applications require their availability. Therefore we assume that one-to-all broadcast is the model we use in this study.

The remaining part of this chapter is organised as follows. Section 2.2 describes in detail the broadcast storm problem. Sections 2.3 and 2.4 list broadcast applications and broadcast scheme in MANET. Section 2.5 lists broadcasting schemes in VANETs. Section 2.6 and section 2.7 discuss AODV operations and AODV in VANETs. Assumptions of this study are listed in section 2.9. Section 2.10 shows the performance metrics that is used in this thesis. Finally, Section 2.11 concludes the chapter and presents a brief introduction to the next chapter.

2.2 The Broadcast Storm Problem

Broadcast storm problem occurs when a flooding scheme is used with uncontrolled settings. It is a combination of three problems; duplicate transmission, channel contention, and message collision. They could appear together or apart during the message disseminating process. We illustrate this problem through the following scenario in Figure 2-1.

Duplicate transmission: this usually occurs when a node retransmits a message that its neighbours have already heard.

This message is useless and dropped by all the neighbours. For instance, node A broadcasts a message to nodes B, C and D. Once node B receives the message; it rebroadcasts it to nodes C and D, which have already received it. Hence, nodes C and D drop it immediately.

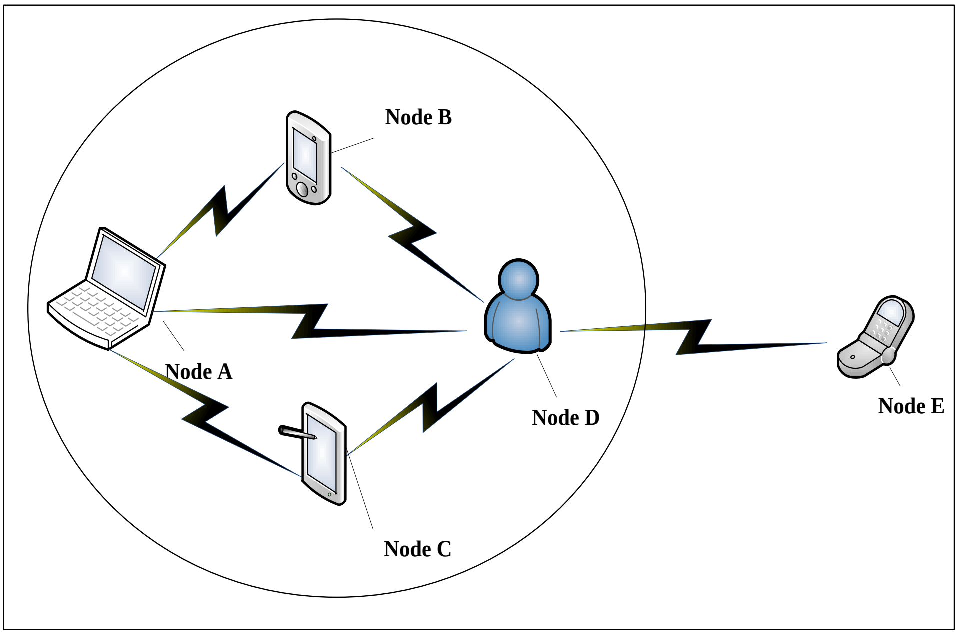

Figure 2-1: Example of the broadcast storm problem.

Channel contention: in the same example, assume that node B decides to rebroadcast the message that it received from node A. At the same time node C decides to rebroadcast it. Node C waits for a random slot time as it knows that the channel is now busy because of node B. Node C could severely contend the shared physical channel of node B, which increases time delay in the dissemination of data packets.

Message collision: simultaneous transmission between nodes C and D is more likely to occur as no acknowledgment mechanism is used in the flooding scheme. Nodes C and D compete to rebroadcast the message as both share the same wireless channel. Hence, message collision could occur between nodes C and D, and does not reach other nodes such as node E.

2.3 Broadcast Applications

Several important applications in MANETs benefit from using broadcasting to disseminate both utility or information messages, and it has very important use at the network layer. We summarize general broadcast applications as follows.

Routing Discovery:

Routing in Ad-hoc networks require a broadcasting mechanism to set up a route between any two nodes. For example, AODV [51] and DSR [52] protocols use broadcasting in the route discovery phase through flooding the network with RREQ packets. Broadcasting can also be used to propagate error packet regarding a broken link as in TORA protocol [53].

General Safety Applications:

Recently, broadcasting has been used in many safety applications, typically those related to VANETs. For instance, a Road Side Unit (RSU) broadcasts a message about an accident that has just occurred to inform other vehicles to avoid using this road and to take another detour. The RSU unit also broadcasts messages containing information about the weather/humidity, and the nearest gas stations/restaurants, so it can help drivers on the roads. Broadcasting is an essential operation for several applications that are related to the new generation of smart cities environment [54]. For instance, it is used in security services such as anti-thieve protection, and to help citizens in living and roaming such as offering services for elderly people.

2.4 Broadcast Schemes in MANETs

Over the last ten years several broadcast schemes have been proposed for MANETs [55] [56] [57] [58] [59]. In this section, we provide a brief description of some of the most relevant works, and make a general classification which aims to better understand them.

In general, broadcast schemes fall into four classifications; probabilistic broadcast schemes, deterministic broadcast schemes, position-based broadcast schemes, and hybrid-based broadcast schemes.

Table 2-1 shows a comparison study for different broadcast schemes in terms of various important mercies such as contention, collision, congestion, performance, reliability.

Table 2-1: Comparison of broadcast schemes

Schemes	**Reliability**	**Rebroadcast**	**Collision**	**Contention**
Simple Flooding Scheme	Very high	Redundant	Severe	Very high
Probabilistic Scheme	Moderate	Controlled	Moderate	Low
Distance Based Scheme	Moderate	Controlled	Low	Moderate
Location Based Scheme	High	Efficient	Low	Moderate
Hybrid Scheme	High	Controlled	Low	Low
Deterministic Scheme	Moderate	Controlled	Moderate	Moderate

The table shows that although simple flooding is reliable, it incurs very high contention and collision. Hybrid scheme achieves a high reliability, low transmission contention and collision.

2.4.1 Probabilistic Broadcasting

The probabilistic broadcast scheme is one of the most important and simple solutions to the broadcast storm problem. It simply allows a node to rebroadcast the message with a certain value of probability P and discard it with $1-P$.

The selection of the value of P is crucial and several works have been done so far to find an appropriate measurement to adjust it according to different conditions. Below is a discussion about different suggested ideas on how the value of P should be selected.

2.4.1.1 *Fixed-Probabilistic Broadcast Scheme (FPB)*

FPB is the first probabilistic approach and is considered as the basis for all later dynamic probabilistic schemes. In FPB every node receives a broadcast message for the first time, rebroadcasts it to all nodes in the network with a certain value of probability P, regardless of the density level of the current node. The authors in [4] have shown that the best value of P in terms of high reachability and saved rebroadcast is approximately equal to 0.07%.

2.4.1.2 *Fixed -Density Probabilistic Broadcast Scheme (F-DPB)*

The F-DPB [60] uses two values of P instead of using a fixed value of P, and adjusts these values according to neighbourhood information. In F-DPB a node rebroadcasts a packet with a high probability if the packet is received for the first time, and the number of neighbours of node N is less than the average number of typical neighbours of its surrounding environment. Hence, if node N has a low degree (in terms of the number of neighbours), retransmission should be likely. Otherwise, if node N has a high degree its rebroadcast probability is set low. A further improvement to this scheme is proposed in [34] and operates as follows: when a broadcast packet is received by a node for the first time, it is rebroadcast according to a probability which depends on the neighbourhood information. The packet is re-broadcast with probability P_1 if the node is located in a sparser area. Similarly, it is re-broadcast with probability P_2 if the node is located in a medium density area.

Finally, in a dense area, the node rebroadcasts the packet with a lower probability P_3. Sparse, medium and dense areas are determined according to minimum, average and maximum threshold values which have been calculated through extensive simulations.

2.4.1.3 *Density-Aware Probabilistic Broadcasting Scheme (D-APB)*

In this scheme [61], the value of probability *P* is determined by the ratio information collected from nodes' neighbours (neighbours density) and the constant parameter *K*. The value of *K* is proposed as an efficiency parameter to achieve high broadcast reachability, but it is not adjusted according to any network parameters.

2.4.1.4 *Fixed-Counter Broadcast Scheme (F-CBS)*

In the fixed counter scheme [5], when a node receives the message, a fixed timer is initialized with a Fixed Counter (*FC*) to count the number of duplicated messages which are received during the timer. The node increases *FC* per message received until the timer has expired. After that, the node compares its *FC* with a pre-defined max counter threshold C_{max}. The node will cancel its retransmission if $FC > C_{max}$, as it assumes that all nodes may have received the same packet. Otherwise the node will retransmit it. In this approach, some nodes will not rebroadcast in a high density network, while in a sparse network all nodes have a high chance to rebroadcast.

2.4.1.5 *Adjusted Fixed-Density Counter Broadcast Scheme (AF-DCBS)*

In this scheme [62] three density counter thresholds are used to control the broadcast decision at each node. A small value of the counter should be assigned if the node is located in a dense area. On the other hand, the node should be assigned a large value of the counter if the node is located in a sparse area. This simple adaptation helps to minimize the amount of rebroadcasting in a dense area, and maximize the level of reachability in a sparse area. The density information is collected as it was in [34].

2.4.2 Position Based-Broadcasting

The basic scheme of position broadcasting in MANETs is suggested in [4]. A further improvement to this scheme is investigated in [30]. In this scheme the sender and receiver nodes should know their own opposition by using geo-location technique such as GPS devices. This scheme works as follows: upon the reception of a new packet, the node initializes a random waiting time and calculates the Expected Additional Coverage (*EAC*) that the node can cover. When the waiting timer expires, if the *EAC* is less than a predefined $EAC_{\min}$, the node will not rebroadcast the packet, as this does not cover a new region. Otherwise the node rebroadcasts it.

The distance broadcast scheme works in the same way as the location scheme, but instead of calculating *EAC*, the distance between the receiver and the sender is considered instead. This scheme was suggested first in [4], and many other schemes have been built upon its concept [63]. In this scheme, a node decides whether to rebroadcast a packet only if the distance between the source and receiver exceeds a certain fixed Distance Threshold *Dth*. Each node upon receiving the message initializes a fixed timer and calculates distance (*d*) between itself and the sender. If the $d < Dth$ the packet will not be rebroadcasted by this node.

2.4.3 Deterministic Based-Broadcasting

In this category nodes are not equipped with GPS as position information or a distance measurement is not required at each node.

In deterministic schemes, groups of forwarder nodes are selected in advance, which should rebroadcast the broadcast packet. In the other hand, probabilistic schemes allow each node to rebroadcast based on a pre-assigned forwarding probability.

2.4.3.1 *Flooding-Self Pruning Scheme (F-SPS)*

Lim and Kim [64] have suggested a simple neighbour knowledge-based scheme, which called flooding-self pruning. In this scheme each node periodically exchanges the knowledge of its one-hop neighbours which can be collected by using a “HELLO” packet. When the node broadcasts a message it appends its list of one-hop neighbours to the header of each broadcast message. Each node that receives this message compares its neighbours list with its sender’s neighbours list. The receiver refrains from broadcasting if no additional node can be covered, otherwise it rebroadcasts the message.

The scheme in [65] improves the self-pruning scheme as each node includes the knowledge of its neighbours within a two-hop radius instead of a one-hop radius. The “HELLO” packet technique is used to collect neighbourhood information between nodes. Then the node decides whether it can cover new nodes by rebroadcasting the broadcast packet or not.

2.4.3.2 *Dominant Pruning Scheme (DPS)*

In this each node collects its two-hop neighbour’s knowledge, which are collected via “HELLO” packets, and uses a greedy set cover algorithm to alleviate the broadcast storm problem [66]. The sender explicitly appends to the broadcast packet a list of forwarding nodes that are responsible for rebroadcasting the packet. When the receiver receives the broadcast packet, it checks the packet header to decide whether it is one of the forwarding nodes or not.

2.4.3.3 *Multipoint Relaying Scheme (MRS)*

The Multipoint Relaying Algorithm (MRA) is suggested to reduce redundant retransmission by limiting the number of rebroadcasting processes to a small set of relay nodes.

Each relay node keeps a record for two-hop neighbours' knowledge collected via "HELLO" packets [32]. In this scheme the relay nodes (which are defined as a set of one-hop neighbours) are only allowed to rebroadcast if they can cover a set of two-hop neighbours. Selecting an optimal set of multipoint relays at each node is a NP-complete problem and a heuristics technique should be used with the availability of neighbourhood information.

2.4.3.4 *Cluster-Based Scheme (CBS)*

In a cluster-based scheme [56], the network is partitioned into several groups of clusters. Each group has a Cluster Head (CH) with gateways nodes responsible of rebroadcasting the message and select forwarding nodes on behalf of the cluster. Each host has a unique ID; a host with a local minimal ID will select itself as a cluster head. If a node receives a message from a neighbour that announced itself as CH, it will send a message (to all its neighbours) declaring itself a non-CH node, to enable more clusters to be created (note that two CHs are not direct neighbours in the algorithm). Thus each node broadcasts its clustering decision after its neighbours with a lower ID have already done so. Non-CH nodes that hear two or more CHs will declare themselves as gateway nodes.

2.4.4 Hybrid-Based Broadcasting

The schemes under this classification combine the advantages of two or more different broadcast schemes in order to introduce an optimal broadcasting one to suppress the broadcast storm problem.

For instance, the fixed probabilistic scheme is used with the fixed counter scheme as in [36], and an advanced probabilistic based distance scheme is proposed in [67]. This section reviews and describes those schemes.

2.4.4.1 *Position Aware-Counter Based Scheme (PA-CBS)*

This scheme [30] combines the advantages of the position scheme and the counter scheme. Each node has two pre-defined Fixed Counter (*FC*) values and two Expected Additional Coverage (*EAC*) threshold values. Each node, upon receiving a broadcast packet calculates the new additional coverage that can be covered. If the new additional coverage is less than EAC_1 the node will not rebroadcast. Otherwise the new additional coverage is larger than EAC_2 and a shorter timer is assigned for those nodes with a small *FC* value.

2.4.4.2 *Angle Aware-Probabilistic Based Scheme (AA-PBS)*

A dynamic angle aware probabilistic broadcasting scheme is proposed in [68], to address the broadcast storm problem. The rebroadcast probability in this scheme is adjusted dynamically based on the cover angle concept. The proposed scheme operates as follows: when a node *X* receive a new broadcast message *M*, then node *X* stores it in the received packet list called *RCV_LIST* and initializes a random timer *t*. If *X* receives the same copy of the message *M* before *t* expires, it is stored in the *RCV_LIST*. When *t* expires, the node *X* estimates the cover angle for each stored message *RCV_LIST*, sums up the non-overlapping cover angles, calculates the rebroadcast probability value for the node *X*, and then take the rebroadcast decision.

2.4.4.3 *Distance Aware-Counter Based Broadcast Scheme (DA-CBS)*

DA-CBS combines the advantages of the distance scheme and the counter scheme. A distance threshold (D_{th}) is used in *DIS_RAD* to distinguish between the interior nodes and the border nodes. The border nodes do their rebroadcast first as they initialize a Short Random Assessment Delay (*SRAD*), while the interior nodes initialize a long *RAD* (*LRAD*) to increase their opportunity to receive more duplicated packets from the border nodes. This is because the border nodes can cover larger additional coverage than the interior nodes [69].

2.4.4.4 *Distance-Based Dynamically Adjusted Probabilistic Broadcast Scheme (D-DAPS)*

DDAP has been suggested in [67], which introduces the concept of distance into the probabilistic scheme. The scheme uses an exponential timer and probabilistic formula to initiate at each node a distance delay time and a distance probability value. So, a node is that located further from the source node waits a short time and rebroadcasts with a high probability. On the other hand, a node that is located closer to the sender waits a long time and rebroadcasts with a low probability, or its rebroadcast could be cancelled.

2.4.4.5 *Energy Aware -Distance Broadcast Scheme (EA-DBS)*

In this scheme [63] instead of using the distance threshold, the Reception Signal Strength (*RSS)* at each node is considered. When a node receives a message for the first time, it calculates the RSS of the message and compares it with the *Border_Threshold*, which represents the power of nodes that are far from the source node and close to the border. If the minimum signal strength is larger than *Border_Threshold*, the node drops the message. Otherwise it initiates a waiting time which is calculated according to the received power *Power_Delay*, or to a random delay chosen between intervals of [0, *Power_Delay*].

2.4.4.6 *Probabilistic Counter-Based Broadcast Scheme (PCBS)*

PCBS uses a packet counter to estimate the neighbourhood density for each node in the network [35]. A high packet counter value means that the node is in a dense area, while a low packet counter value entails that the node moves in a relatively spars area.

In this scheme, each node keeps a counter for every new packet received within the *RAD* period. The node increases the counter if it receives the same copy. After the *RAD* expires, if the counter value exceeds a predefined threshold, the node cancels its retransmission. Otherwise, it rebroadcasts with a predefined fixed rebroadcast probability *P*.

2.4.4.7 *Adjusted Probabilistic Counter-Based Broadcast Scheme (APCBS)*

APCBS [70] is a further improvement to PCBS. In this scheme, rebroadcast probability is set according to the number of duplicated packets in the same manner as in PCBS. Each node counts the number of the identical received packets (i.e. *c*) within a random timer. After timer expiration, the node uses the ratio between the total numbers of received packets (i.e. *c*) within the timer and the predefined Counter threshold *C*, to rebroadcast the packet with a value of mathematical exponential probabilistic function unlike PCBS, which uses a predefined fixed rebroadcast probability *P*.

2.5 Broadcasting in VANETs

Broadcasting in VANETs as a concept is similar to that in MANETs. But its implementation is considered more complex and difficult in VANETs, since vehicles' movement follows road directions, signs and broadcast sometime is only relevant to a specific geographic area.

For instance, when an accident occurs vehicles that move on the same side of the accident only should be made aware of it, while vehicles that move in the opposite direction should not. Hence, broadcast schemes in VANETs should be designed to cope with road layout, and manage disseminating messages to the target vehicles.

Several solutions regarding cope broadcasting in VANETs have been proposed in the literature [71] [72]. Each one has adopted a different solution to optimize network performance and mitigate the broadcast storm problem. In general, broadcast schemes in VANETs fall into two categories:

Hybrid probabilistic broadcast schemes, and position broadcast schemes. The following sections provide a summary of the latest known proposed schemes.

2.5.1 Hybrid Probabilistic Broadcasting Schemes

The main idea behind proposed probabilistic schemes is to reduce the number of transmissions and the probability of message collision. Most of the proposed probabilistic schemes in VANETs are hybrid, since pure probabilistic schemes do not achieve good performance. The concept of vehicle position is added to the probabilistic broadcast scheme to make it suit broadcast requirements in VANETs. Below is a summary of some of the existing hybrid probabilistic broadcast schemes in VANETs with a brief description.

2.5.1.1 *Weighted Probabilistic-Persistence Broadcasting Scheme (WP-PBS)*

In this scheme [71] when the node *j* receives a packet from node *i*, node *j* waits a period of time WAIT-TIME and checks the packet ID and rebroadcasts with probability P_{ij} if it receives the packet for the first time; otherwise, it discards the packet. The rebroadcast probability is adaptively calculated according to the distance from the sender. When the timer expires the node rebroadcasts the RREQ packet with the least value of probability as in the following formula:

$$P_{ij} = \frac{D_{ij}}{R} \tag{1}$$

where D_{ij} is the distance between the sender and the receiver, and R is the average transmission range. To prevent the packet dying out the node should wait a further time and rebroadcast with a probability equal to one.

2.5.1.2 *Slotted One-Persistence Broadcast Scheme (SO-PBS)*

In this scheme [71], when a node receives a broadcast packet, it checks the packet ID and waits a time slot $Ts_{ij,}$ which is adaptively calculated according to the relative distance to the sender. The node then rebroadcasts the packet with a probability equal to one, if it receives it for the first time, and has not received any duplicates before its assigned time slot. Otherwise, it discards the packet. Ts_{ij} is calculated as in the following formula:

$$\mathrm{Ts}_{\mathrm{ij}} = \mathrm{S}_{\mathrm{ij}} \times \tau \tag{2}$$

where τ is the estimated one-hop delay, which includes the medium access delay and the propagation delay, and S_{ij} is the assigned slot number which can be expressed as follows:

$$S_{ij} = N_s \left[1 - \left[\frac{\min(D_{ij}, R)}{R} \right] \right] \tag{3}$$

where N_s is the number of time slots. By using the above formula, a short waiting time is assigned for the nodes located further from the sender and their broadcasts reach new nodes and cover a new additional area.

2.5.1.3 *Slotted P-Persistence Broadcast Scheme (SP-PBS)*

This scheme [71] is similar to the SO-PB scheme and operates as follows: when a node receives a packet, it waits a time slot Ts_{ij} before rebroadcasting on operation to count the number of duplicated packets. Upon the expiration of Ts_{ij}, the node checks the packet ID and rebroadcasts with the pre-assigned probability P, if this is the only packet ID it receives and if it has not received any duplicates before its assigned time slot. Otherwise, it discards the packet. In this scheme, to prevent the message from being lost, each should buffer the message for an extra period of time (e.g., [N, - 1] x *WAIT-*

TIME + *d* ms) and rebroadcast the packet with probability one if no nodes in the neighbourhood rebroadcasts it.

2.5.1.4 *Optimized Slotted One-Persistence Broadcast Scheme (OSO-PBS)*

The SO-PB scheme [72] suffers from a synchronization problem that can occur when more than two vehicles have the same time slot and start rebroadcasting simultaneously. This increases the number of collisions and decreases the packet delivery ratio. Hence, the Optimized Slotted One-Persistence Broadcast Scheme (OSO-PB) is proposed to tackle this problem. In OSO-PB scheme the Ts_{ij} is assigned for each vehicle with respect to its direction. For instance, a warning message about an accident is more useful to the upstream vehicles than to the vehicles that move in the opposite direction. Therefore, a long time slot is assigned to the opposite direction vehicles, while a short time slot is assigned to upstream vehicles. In this way the number of message collisions is reduced and the packet delivery ratio as a result is increased.

2.5.1.5 *Network Topology P-Persistence Scheme (NTP-PS)*

The NTPP scheme [73] is similar to the SO-PB scheme as it attempts to control flooding by buffering the message with a distance-based density timer, and rebroadcasting it also with distance-based density probability. The NTPP scheme privileges the transmission to the furthest vehicle immediately if its ID is marked as the potential transmitter, while other vehicles calculate their rebroadcast probability P_{tr} as:

$$P_{tr} = \frac{1}{2}\left[\left(\frac{\min(R_{RSS}, R_{\max})}{R_{\max}}\right) + (1 - \frac{\lambda_s}{\lambda s_{maz}})\right] \quad (4)$$

where R_{RSS} is the calculated inter distance between the sender and the receiver, that is collected based on the average received signal strength.

R_{max} is the maximum transmission range equipped by vehicles. λ_s and λs_{max} is the maximum vehicles density in a jammed traffic scenario. The non-potential transmitters also calculate their waiting time by the same logic of calculating P_{tr}. The waiting time T_w is defined as follows:

$$T_w = (1 - \frac{\min(R_{RSS}, R_{\max})}{R_{\max}})(\frac{\lambda_s}{\lambda s_{\max}})\tau \quad (5)$$

Where $\tau = 2T + \delta$ is twice the packet's transmission time plus the propagation delay time δ for the message to reach the range R_{max}.

2.5.1.6 *Probabilistic Inter-Vehicle Geocast Scheme (P-IVGS)*

The basic IVG scheme [74] suffers from a spatial broadcast problem, which appears when all border vehicles have the similar or the same timer value. To mitigate this problem, P-IVG [75] has been proposed to introduce the concept of density probabilistic broadcasting to the IVG scheme. In the P-IVG scheme, when a vehicle receives a message, it first generates a Random Number RN between [0, 1]. If the RN is less than the $\frac{1}{density}$ factor, the vehicle initiates a timer. Otherwise, this vehicle is prevented from rebroadcasting. Density information is collected for each vehicle by broadcasting a beacon twice a second. This beacon contains the vehicle's information (speed, location, etc.), and is stored in a database at each neighbouring vehicle. The number of beacons determines if the vehicle is in a high density, medium density or low density area.

2.5.2 Position-Based Broadcasting

Position based methods privilege transmission to vehicles that cover a new additional area, or new vehicles.

The proposed schemes under this classification use GPS devices to obtain a vehicle position to determine relay vehicles which have the best coverage. Some schemes use the vehicle signal strength instead of GPS when it is unavailable- to decide if the vehicle can act as a best coverage vehicle. Below is a description of the major schemes under this classification.

2.5.2.1 *The Last One Broadcast Scheme (TLOB)*

The TLOB scheme [76] is designed to broadcast a safety message effectively with minimum end-to-end delay and overhead. It assumes that each vehicle is equipped with a GPS, so every vehicle can easily obtain the geographical location of other vehicles within its communication range. When an accident occurs, the victimized vehicle starts broadcasting a warning message to all vehicles close to the accident. Upon receiving the warning message, each receiver vehicle does not rebroadcast it immediately, but runs the TLOB scheme to find the last vehicle which is able to send the warning message to new vehicles. Each vehicle knows the distance value between itself, the victimised vehicle and its surrounding neighbours, so the receiver vehicle can easily check if there is a neighbour vehicle further than it.

If the receiver vehicle is the last vehicle, it rebroadcasts the warning message immediately, while other vehicles wait for a time period to take the next rebroadcast decision. After the timer expires, the vehicle checks whether it has received the message from any surrounding neighbours. If no message was received the vehicle rebroadcasts it, otherwise the message is dropped.

2.5.2.2 *Least Common Neighbours Scheme (LCNS)*

The LCN scheme [77] is a selective flooding scheme for forwarding emergency messages by initializing a timer for each vehicle based on its common neighbours. This scheme aims to privilege rebroadcasting for only one candidate among the vehicles within the same radio communication.

It assumes that if the distance between the sender vehicle and any receiver vehicle is very small, the number of common neighbours increases. On the contrary, if the distance between them is very far the number of common neighbours decreases. Based on this rule, the vehicle that has the least common neighbours is furthest from the sender, and so the best candidate to rebroadcast the emergency messages. The best candidate also sets its timer value according to the number of common neighbours. In some cases, many candidates rebroadcast simultaneously since they have the same common neighbours. To solve this problem, the LCN scheme uses a random function to adjust the timer value to the vehicles that have the same number of common neighbours.

2.5.2.3 *Street Broadcast Reduction Scheme (SBRS)*

The SBR scheme [78] is a novel scheme proposed not only to mitigate the broadcast storm problem in VANETs, but also to speed up delivery of the warning message notification and increase its reachability. In the SBR scheme, vehicles operate in two modes: warning mode, and normal mode.

Warning mode vehicles are responsible for broadcasting warning messages among the vehicles to inform them of their status. Such warning messages broadcast periodically every T_w seconds and have the highest priority at the MAC layer. On the other hand, the Normal vehicles mode helps to disseminate the warning message to other vehicles in the street periodically every T_b seconds. They are also responsible for sending beacons including information such as their positions and speeds, etc. The beacons have lower priority than the warning messages and are not rebroadcast by other vehicles. The SBR scheme allows the receiver vehicle to rebroadcast, only if the received message is a warning message, received for the first time, and the distance between it and the receiver is larger than the distance threshold or both vehicles are in different streets. Otherwise, the message is discarded, as it is either a duplicated message, a beacon message, it does not cover additional coverage area, or it is in the same street.

2.5.2.4 *Location-Based Flooding Scheme (L-BFS)*

Emergency Warning Message (EWM) methods-based location and counter broadcast schemes have been proposed in [79], to suppress the broadcast storm problem, and achieve better network connectivity and message reachability. A random back-off delay timer function that has a Gaussian distribution is adjusted based on the vehicle position with regard to the previous forwarder. The lower mean value of the probability distribution function of the delay timer means that the vehicle is very close to the previous forwarder, and it has a high priority to forward the received packet. *Max_count* threshold is used to control the rebroadcast decision and minimize redundant forwarding. Each vehicle upon receiving a packet initializes a Counter and counts the number of duplicated packets received within a delay period. If the counter value is less than the *Max_count* retransmission by the current vehicle should be cancelled.

2.5.2.5 *Position-Based Adaptive Broadcast Scheme (P-BABS)*

This scheme [80] is designed for the purpose of delivering an emergency message by the appropriate candidate with minimum end-to-end delay. The PABS scheme uses position, direction, and velocity information of sender and receiver vehicles to identify one candidate to relay the emergency message to other vehicles in the street. The PABS scheme states that vehicles are not relevant to the place of accident, and vehicles that do not cover a new additional area should not act as a candidate vehicle. Hence, each vehicle calculates the time delay for each received message based on the spacing distance and velocities of the sender and the receiver vehicles, in order to give a shorter time delay for the further vehicle.

2.6 Routing in MANETs

Many Ad-hoc routing protocols have recently been proposed to address routing problems in MANETs. Such protocols fall into three routing classifications based on routing strategy: *proactive, reactive and hybrid*. This section reviews the routing protocols in MANETs.

2.6.1 Proactive Protocols

In proactive protocols, each node stores routing information about all of its neighbours regardless of its usefulness. Due to the frequent change of the network topology, each vehicle updates its routing table information constantly even, if no data available should be sent. An advantage of proactive protocols is route availability, which enables the source to immediate route data and thus avoids initial route discovery delay. However, periodic updating of the routing table imposes extra overhead for highly dynamic Ad-hoc networks. Destination-Sequenced Distance-Vector Routing (DSDV) [81] and Optimized Link State Routing Protocol (OLSR) [82] are examples of proactive routing protocols.

2.6.2 Reactive Protocols

On the contrary, in reactive protocols route discovery starts only "on-demand" or when needed. A source attempts to find a route to a destination if routing information is not stored in the routing table. Routing overhead in reactive protocols is less compared to proactive protocols as the routing table at each vehicle is updated only on-demand rather than periodically. The most common examples of reactive protocols are AODV [51] and Associatively-Based Routing (ABR) [83].

2.6.3 Hybrid Protocols

Hybrid protocols combine the advantage of reactive protocols scalability and proactive protocols stability, such as Zone Routing Protocol (ZRP) [84]. A vehicle/node using the hybrid protocols divides its neighbours into two zones: “intra-zone” and “inter-zone”. Intra-zone uses reactive protocol to establish a route to destination networks, and inter-zone uses proactive protocol to update routing table information at each vehicle only when the topology of the network is changed.

2.7 Ad-hoc On-Demand Distance Victor (AODV) Protocol Overview

AODV is one of the most important reactive routing protocols and it is widely used in MANETs [85] [86]. This type of protocol establishes routes between vehicle s only on-demand when there is a need to route data packets. Each vehicle keeps routing information for its neighbours, only if it is part of the currently used route. Hence, AODV incurs small overhead, as not all routes in the network are updated. The next section explains the two most important operations in AODV.

2.7.1 Route Discovery Operation

Broadcast storm is the major problem for the route discovery operation as the uncontrolled flooding broadcast scheme sets up routes. This problem appears when a source node needs to send data packets to a particular destination node and does not have a valid path to reach it. The source floods RREQ packets through the network and starts to find the destination with the assistance of intermediate nodes. When intermediate node receives the RREQ packet for the first time, it checks first whether it is the destination node, it is non- destination node but has a valid route to the destination node, or it is non-destination node and does not have a valid route to the destination node. In the first case, the destination sends back a Route Reply (RREP) packet to the source node through the routes that the RREQ packets visited and the route discovery process stops. In the second case, the node rebroadcasts the RREQ packet to all reachable nodes within its wireless transmission range, and sends RREP packets to its preceding nodes. In the third case, the vehicle simply rebroadcasts the RREQ until it finds the required destination and establishes the path successfully.

2.7.2 Route Setup and Route Maintenance Operations

The source node starts to send data via the minimum hop distance route recently established to the destination node. Some of the route nodes that relay date to the destination move faster than the source node and in the opposite direction. Such nodes do not stay long with the source communication range and cause link breakage. The node that breaks the link invokes *Route Maintenance* phase and sends Route Error (REER) to inform its neighbours that the route to destination is no longer available.

The brooked link is repaired locally if it is near the destination, by broadcasting RREQ packets to downstream nodes. Upstream nodes buffer packets during the local repair process until they receive a RREP packet to announce that the broken link is valid again. Unsuccessful local repair requires the intermediate nodes to send RRER packets back to the source. The source node reinitiates a new route discovery phase, if there is no ready valid route to use in its routing table to the destination [51].

2.8 AODV in VANETs

Several optimization solutions have been suggested to modify basic AODV protocol routing functions, in order to make it suitable for VANETs [46] [47] [48]. Below is a brief description of some recent work relevant to this research.

In [46], the authors argued that the traditional AODV routing protocol does not suit VANETs topology. Hence, AODV-VANET is proposed to enhance the AODV routing discovery phase by considering the mobility characteristics of VANETs.

AODV-VANET finds the best route between pairs of source and destination vehicles, in terms of reliability and stability. When the source vehicle starts broadcasting RREQ packet to find the required destination, it adds its speed, acceleration and direction information to the RREQ packet. When a vehicle receives the RREQ packet it uses the previous vehicle mobility information with its mobility information to calculate the accumulated weight of route toward the destination. Once the destination is found, a RREP packet is sent upstream with accumulated weight and possible routes. The source then selects the most reliable and stable route, which has the minimum total route weight between different possible routes. AODV-VANET is enhanced in [47] through considering the expiration time factor of the existing route. The idea is that a new alternative route toward the destination should be discovered before the existing route has expired, so the source vehicle can use it immediately.

In [48] the author also used the same mobility information in [46] with two different methodologies to develop a stable AODV protocol for VANETs. Firstly, the source vehicle calculates the link weight between itself and all of its neighbours. Then based on a *number_bound* threshold, the source vehicle selects all neighbours or some of them with the smallest link weight value. Secondly, the source vehicle uses route expiration time or total route weight to select the most stable route, if it has many possible routes to the destination. Although this approach obtains good performance in terms of high packet delivery ratio and low link breakage, but the *number_bound* threshold is not selected based on either experimental trials or mathematical equations.

A High Mobility Ad-hoc On-demand Multipath Distance Vector Routing Protocol (HM-AOMDV) is proposed in [87] for VANETs, which uses the vehicle 's Mobility Factor (*MF*) to search for more stable and reliable route among all of the available routes.

AOMDV is an extension of the traditional AODV, which keeps multipath toward the destination with no routing loop and link-disjoint paths [88]. The *MF* is calculated at each vehicle and sent with the RREP packet to the source. Then the route with largest *MF* is more stable than other possible routes and is used to route data.

Recently probabilistic schemes are used with traditional MANETs and VANETs routing protocols to obtain a high communication performance. Yet most of the probabilistic schemes focus only on using different network density parameters to reduce the routing overhead during the route discovery phase without considering route stability. For instance, the probabilistic routing decision in [41] [45] is taken according to the network density, and in [36] is taken with regard to the number of duplicated packets. Although such scheme succeed in reducing the routing overhead and mitigating the broadcast storm problem, to the best of our knowledge there has been investigation into utilizing the probabilistic scheme with vehicle mobility information to find stable and reliable routes in VANETs.

2.9 Assumptions

Several simulation experiments have been conducted, to evaluate the performance of the proposed routing schemes. The following assumptions have been considered in the simulation environment and have been widely used in other similar existing studies in MANETs [89] [90] [91] [92].

- All of the simulated nodes are equipped with IEEE 802.11e transceivers, and have the same transmission range length.
- During the simulation time all of the nodes are kept constant, and have sufficient power until the simulation time ends. Hence, the network is assumed to be connected all the time, but sometimes network partition is possible, typically in a spare network where the nodes usually are located far from each other.

- Any node in the network can initiate a route discovery session, participate in the routing operation, or forward data packets to the destination via intermediate nodes.

Furthermore, some assumptions will be mentioned in the next chapters where needed.

2.10 Performance Metrics

Performance metrics are used to measure the efficiency and accuracy of both the proposed broadcast schemes and routing schemes, and they are also useful for comparative study. Several performance metrics have been used in the literature [7, 22, 43, 45]. In this study, performance of the proposed routing schemes is measured using the following performance metrics:

- ***End-to-end Delay:*** Represents the average time period that starts once the source transmits a data packet and ends when it is delivered to the destination.
- ***RREQ Rebroadcast Number:*** Represents the total number of RREQ packets that each node generates and rebroadcasts during the period of simulation time.
- ***Route Stability:*** Represents the total number of broken links during the simulation time. Small numbers of broken links indicate that the routing scheme is successful in constructing stable routes.
- ***RREQ Collision Number*:** Represents the average number of RREQ packets dropped and which fail to reach the destination nodes in the network.
- ***Packet Delivery Ratio:*** Measures the ratio of data packets successfully delivered to their destinations to those generated by the constant bit rate (CBR) source.

2.11 Summery

This chapter has discussed broadcast operation in MANETs, broadcast problems and broadcast applications. The chapter has then reviewed the most relevant broadcast schemes that are proposed to handle the broadcast storm problem including probabilistic- based broadcast schemes, deterministic-based broadcast schemes, position-based broadcast schemes and hybrid-based broadcast schemes. Broadcast operation in VANETs has also been discussed in this chapter. Various broadcast schemes that have been proposed for VANETs have also been reviewed in this chapter including hybrid probabilistic schemes and position schemes.

The chapter has also listed the three major routing strategies in MANETs; proactive routing, reactive routing and hybrid routing. The chapter has shed light on the routing discovery process in AODV protocol as the most important and common example of the use of broadcasting operation.

The chapter then provides some solutions that make AODV protocol workable within a VANETs environment. The Network Simulator and the mobility models which are used to evaluate the proposed routing schemes have been briefly described. Finally, the chapter has outlined the performance evaluation metrics and assumptions that used in this study.

Routing discovery process in AODV protocol imposes a major problem when flooding scheme is used. In MANETs, not all nodes are necessary to participate in routing discovery process to find the required destination. The next chapter will describe a new efficient probabilistic route discovery scheme that is able to enhance AODV protocol. The new scheme is used with AODV protocol instead of flooding scheme.

Chapter 3

A New Probabilistic Distributed Route Discovery Scheme for Mobile Ad-hoc Networks

---

The key objective of this chapter is to present and discuss the new probabilistic routing scheme, and it is organized as follows:

- Explaining in detail the new Probabilistic Distributed Route Discovery scheme (PDRD), its components and steps.
- Evaluating the performance of PDRD under different network conditions.
- Concluding the chapter and providing a brief summary.

3.1 Introduction

In conventional ad-hoc on demand distance vector routing protocol AODV [51], when a node starts to send a data packet to a specific destination, it first checks whether it has a valid route or not. The valid route is then used immediately by the source if it has already been established. Otherwise, the source initiates a route request session and broadcasts a Route Request (RREQ) packet to its neighbours. All neighbours that receive the RREQ packet blindly rebroadcast it, which causes the broadcast storm problem.

Although several probabilistic solutions have been proposed, such as the fixed probabilistic scheme [4] [34] , the fixed counter scheme [5], or hybrid schemes [68] to tackle the flooding problem, developing efficient and a distributed probabilistic solution is still a challenging issue. In MANETs if all the nodes are assigned the same threshold value or the same rebroadcast probabilities, this can degrade the network performance.

For instance, using small threshold values and small rebroadcast probabilities will help to reduce number of rebroadcast RREQ packets, but this may lead to poor reachability especially in sparse networks. Alternatively, using large threshold values and rebroadcast probabilities in sparse networks are very important, but it can cause broadcast storm problem in dense networks. Consequently, routing schemes should be able to maintain a reasonable balance between saving and reachability to prevent a node located in a dense network to rebroadcast a received packet, while allowing a node located in a sparse network to rebroadcast a received packet. To reduce the duplicate retransmission problem in dense areas (i.e., when the number of nodes is very high), low retransmission threshold values should be assigned to each node. On the other hand, to maintain a good connection in sparse areas, a high retransmission threshold values should be assigned to each node. To achieve this aim, in this chapter a new probabilistic distributed route discovery scheme is suggested. Its methodologies are capable of managing routing process in both dense and sparse types.

The remaining part of this chapter is organised as follows. Section 3.2 describes a new Probabilistic Route Discovery Scheme. Section 3.3 presents network simulator and mobility model. Sections 3.4 presents performance results of the effects of node mobility, and network density on the performance of probabilistic flooding schemes. Finally, Section 3.5 concludes the chapter.

3.2 A new Probabilistic Route Discovery Scheme

The new Probabilistic Distributed Route Discovery scheme (PDRD) runs in three phases. In the first phase a proper forwarding probability is initialized based on the neighbourhood and the network density information. In the second phase, a proper time slot is also initialized based on neighbourhood and network density information. Finally, the readjustment of the forwarding probability value, and the extension of the time slot take place to balance sending RREQ packets in dense and sparse types . The following sections explain each phase.

3.2.1 Network Density Estimation

In MANETs, node density varies from low to high density, as the nodes spread randomly and the topology changes frequently. Neighbourhood information is a simple and common approach to collect the network density information [5] [12] [32] [35] [36] [37]. This information is collected by broadcasting a "HELLO" message every second to construct a one-hop neighbours table for each node. This neighbours table represents the local neighbourhood information. Assume that node N_i has neighbours X_1, X_2, X_3 …..X_k, and N_{local} is a local density parameter of the node N that is calculated as follows:

$$N_{local} = \sum_{k=1}^{k} X_k \tag{6}$$

The value of N_{local} for each node varies depending on the network density degree. N_{local} does not provide a complete and full estimation of the network density status. Hence, global network density information N_{global} is required for the density estimation. Assume that N is the number of nodes in the network, and X_k is the number of neighbours at the node N_i. N_{global} is defined as follows:

$$N_{global} = \sum_{k=1}^{N} \frac{X_k}{N} \tag{7}$$

3.2.2 Timer Function

If the source’s neighbour receives the RREQ for the first time, the neighbour initialises a random waiting time which is adjusted according to the network density.

In dense network, a waiting time should be set longer as many relay nodes receive the same message and try to rebroadcast it. Using density as a factor in calculating the waiting time for each node can reduce the possibility for having more than one node to rebroadcast at the same time. As a result, the simultaneous broadcast problem between nodes and packet collision can be reduced. The following formula is used to set the timer in the proposed scheme.

$$DT_i = (0,1 - e^{-(\frac{N_{local}}{N_{global}})}) \times t \quad (8)$$

where DT_i refers to the node initial Density Timer, N_{local} is the local number of one-hop neighbours for the node, N_{global} is the maximum global possible network density, and t is a random delay number between [0,10^{-3}]. This interval value is simulation-based and is adopted to reduce both the number of rebroadcasted nodes and the packet collision rate. The same value is also used in [14] [15]. We have conducted extensive simulation scenarios to find the approximate value for N_{local} and N_{global} as in Table 3-1. The timer function uses the exponential function equation as the value of its output reflects the ideal density relationship. Figure 3-1 shows that as the number of local network density N_{local} increases, the initial density timer value DT_i increases proportionally.

Table 3-1: Sample of the values of that used in the equations.

No.of Nodes	Network Size	N_{local}	N_{global}	DT_i	DP_i
50	500m x 500m	6	8	52 x10^{-5}	0.47
100	750m x 750m	57	64	58 x10^{-5}	0.41
200	1000m x 1000m	46	60	23 x10^{-5}	0.64
300	1000m x 1000m	70	95	51x10^{-5}	0.48

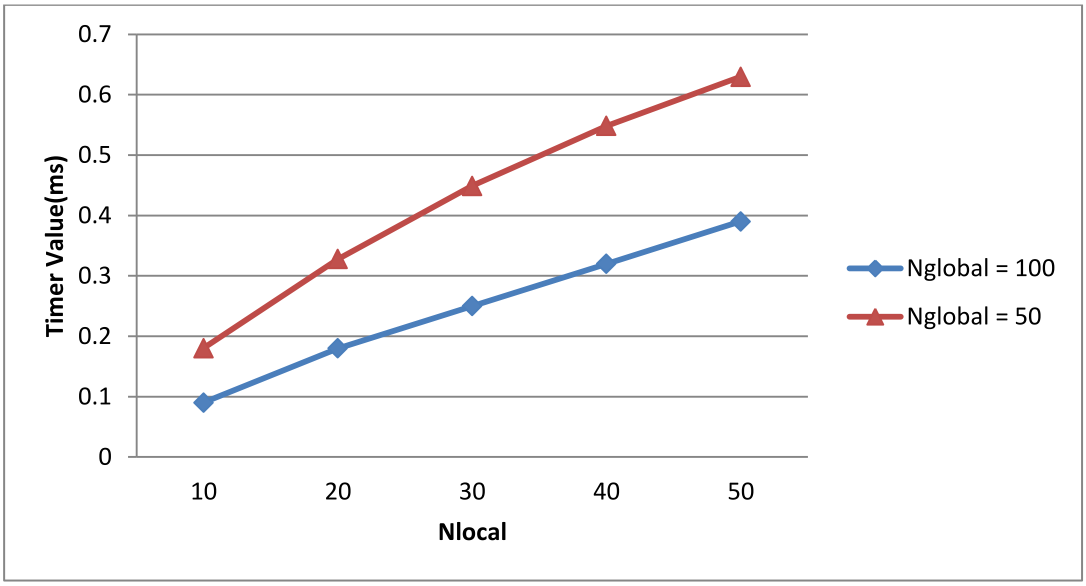

Figure 3-1: Value of Timer VS. number of local neighbours Nlocal.

3.2.3 Probabilistic Function

Similarly, a rebroadcast probability for nodes that relay the RREQ packet should consider the nodes density during the rebroadcast calculation. When the network density is high, where the number of possible relay nodes is increased, the value of the rebroadcast probability should be set to low. Otherwise, the large number of relay nodes with high probability causes the broadcast storm. Upon receiving the RREQ, each relay node calculates its initial Density rebroadcast Probability DP_i by using the following formula:

$$DP_i = RAND\ (0, e^{-(\frac{N_{local}}{N_{global}})}) \quad (9)$$

Figure 3-2 shows the inverse relationship between network density and rebroadcast probability.

Nodes with more neighbours should rebroadcast with a low probability to minimise the number of duplicated retransmissions, while nodes with a few neighbours should rebroadcast with a high probability to achieve high rebroadcasting reachability. It can be clearly observed from the figure that if the number of neighbours increases, the rebroadcast probability value decreases and vice versa.

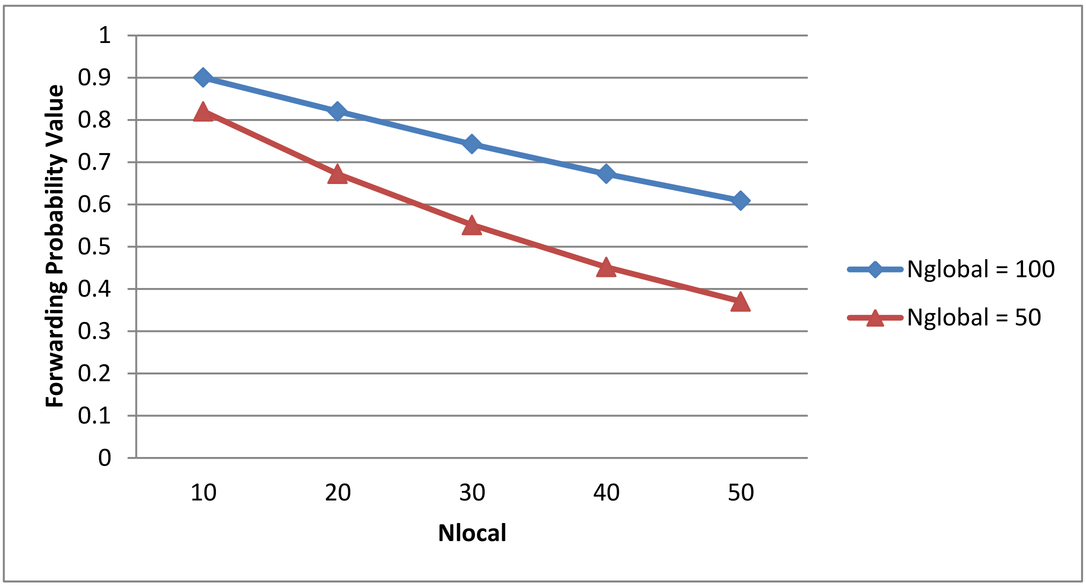

Figure 3-2: Value of Forwarding Probability V.S number of local neighbours Nlocal.

3.2.4 Timer Extension and Recalculating Probability

Every time the timer expires, the relay node checks whether it has received duplicated RREQ messages during the waiting time DT_i. If this is the case, this indicates that more than one neighbour have already performed the rebroadcast operation. In such a case, PDRD extends the timer to maximise the probability for each node to receive more duplicated RREQ packets, thus decreasing its probability to participate in the rebroadcasting process. The following formula is used to extend the timer:

$$DT_i+1 = DT_i\ (N_C-1) \quad (10)$$

where DT_{i+1} is the next waiting time interval, and N_C is the number of received RREQ packets copied within the DT_i interval. The next value of the density rebroadcast probability DP_{i+1} is calculated using the following formula:

$$DP_{i+1}= DPi/\ (N_C-1) \quad (11)$$

We refer to equations 11 and 12 in lines 4 and 5 in Figure 3-3. To avoid facing the infinity problem while extending the timing process, we set two control parameters. The first is a waiting Timer Counter (*TC)* to count the number of times each node extends its timer. The second is a Waiting threshold W_{th}, which represents the maximum number of times that each node has to wait. Note that W_{th} is a designed network parameter that should be set according to the neighbourhood density. In other words W_{th} should be set high and low in a dense network and a sparse network, respectively. Hence, we use the number of copy parameter N_c to adjust the value of W_{th} as it provides a good indication of neighbours density status. The extension of the timer process is terminated if the number of *TC* reaches the above W_{th} threshold. Step 12 and step 13 in Figure 3-3 represents the extension of the timer and the readjustment of rebroadcast probability.

Figure 3-3 describes the logical steps of the PDRD scheme and it works as follows. Upon receiving a RREQ packet for the first time, a node initializes a density timer and a density probability which are randomly chosen by using the equations (8) (9) (Lines 3-6). During the waiting time, the node increments the counter N_c for each duplicated RREQ received.

The PDRD scheme allows the node to extend its timer, and reduce the next rebroadcast probability per duplicated RREQ packet received (lines 8-15). The extending and reducing process stop when the waiting timer counter exceeds the waiting time threshold (line 7). When the while loop has terminated, the scheme generates a Random Number between (0, 1), and compares it with the last Density Probability *DP* value. If the generated random number is less than *DP*, the node forwards the RREQ packet to its neighbours (lines 19-21). Otherwise the packet is dropped.

Scheme: Probabilistic Distributed Route Discovery (PDRD)

Input: $\mathbf{N_{LOCAL}}$, $\mathbf{N_{GLOBAL}}$, Density Timer (DT_i), Density Probability (DP_i)
Output: The Rebroadcast Probability Value (P).

1:$\mathbf{N_{LOCAL}}$ ←Get_Number_OneHopNeighbour ()
2:$\mathbf{N_{GLOBAL}}$← Get_Maximum_NetworkDenisty()
3:IF (RREQ Packet Received for the First Time) = **TRUE** {
4: Initialize Density Timer: DT_i=(0,1- e-(N_{LOCAL}/N_{GLOBAL}))* t
5: Initialize Density Probability: DP_i = RAND (0,e- (N_{LOCAL}/N_{GLOBAL}))
6:END_IF
7:WHILE (DT_i != Expeired) {
8:Get_Number_Copy () {NC=NC+1, Wth=NC}
9 : END_WHILE
10:WHILE ($TC < W_{TH}$) {
11: IF (The Same RREQ Packet Received) = **TRUE**{
12: Timer Extension (){DT_i+1 = DT_i (N_C-1)}}
13: Probability_Readjusting (){DP_i+1= DP_i/N_{C-1}}
14: Increase Wating Timer Counter : TC = TC+1}
15: END_IF
16: END_WHILE
17: RN←Random_Number(0,1)
18: IF $RN<DP$ = **TRUE**
19: Rebroadcast_RREQ()
20: ELSE
21: DROP_RREQ()
22: END_IF

Figure 3-3 : Logical steps of the PDRD scheme.

3.2.5 Illustrative Example

An illustrative example for PDRD is provided in Figure 3-4. For instance, in Figure 3-4 if Source *S* needs to open a connection to the Destination *D*, it will initiate sending an RREQ packet to all of its neighbours within its transmission range. Nodes 1, 2, 3, 4, 5 and R1 will receive this transmission.

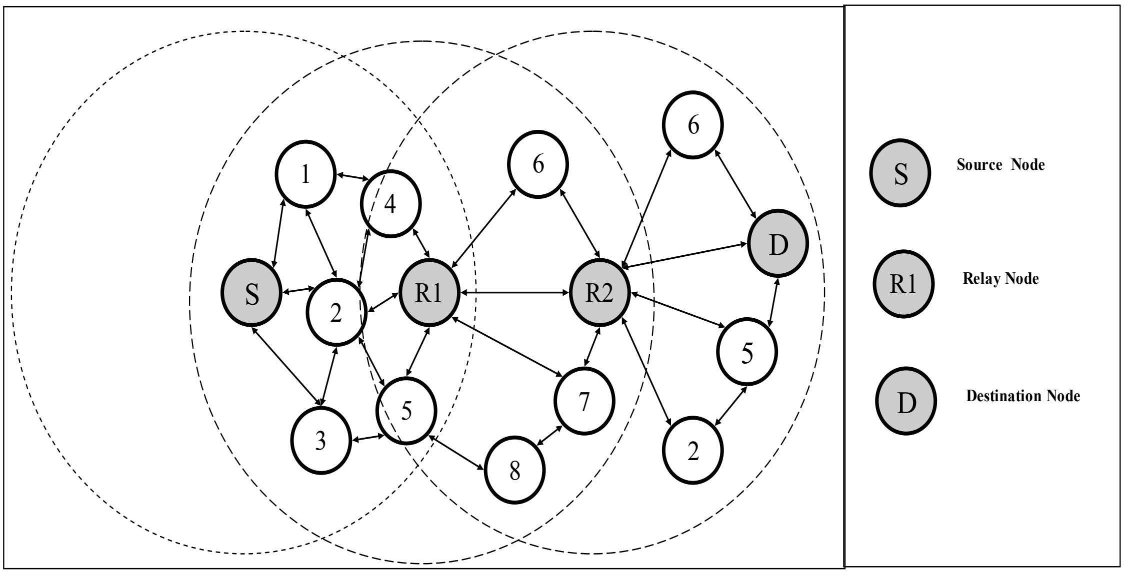

Figure 3-4: Example of PDRD scheme.

All of these nodes, i.e., 1, 2, 3, 4 and 5, after receiving the RREQ packet for the first time, execute the PDRD scheme to optimize the rebroadcast process during the route discovery operation. First, nodes 1, 2, 3, 4, 5 and *R1*, upon receiving the RREQ packet from the source node *S*, will wait the whole period of DT_i before deciding to rebroadcast again or discard the RREQ packet, if they obtained it from other nodes. Suppose that node *R1*'s timer expires first compared to the other nodes, for example, if it is located in a sparse area. Nodes 1, 2, 3, 4 and 5 receive duplicated RREQ packets from node *R1*, while nodes 6, 7, 8 and *R2* receive RREQ for the first time from *R1*. Therefore, those nodes execute the PDRP scheme again, and nodes 1, 2, 3, 4 and 5 extend their timer DT_{i+1} and decrease retransmission probability DP_{i+1}, as the RREQ message has already been received by those nodes.

The timer extension process and the re-adjustment of the value of DP_{i+1} will stop if the timer extension number (i.e. T_C) exceeds the maximum number of waiting time (i.e. W_{th}) that is allowed at each node. Similarly, assume that the timer of node 8 expires first; all of its neighbours run the PDRD scheme again to suppress any unnecessary retransmissions. Finally, the optimal route that PDRD creates is S->R1->R2->D.

3.3 Network Simulator and Mobility Models

Network simulation is one of the most important existing evaluation methodologies, which have been widely used for network analysis, design, and implementation. Several network simulators are available for both academic studies and commercial uses. For instance, ns-2 [93], GloMoSim [94], OPNET [95], QualNet [96] and OMNeT++ [97]. Ns-2 is the most popular one and most of the works on MANETs mentioned in this thesis use ns-2 for the performance evaluation. Hence, it is used in this study to evaluate the performance of the suggested routing algorithm in MANETs and VANETs. It is an open source tool designed by researchers at Berkeley University, and implemented based on C++ language. It provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless networks. Ns-2 is used along with OTCL script to control network parameters and topology.

Nodes' movement and behaviour in MANETs is described as random, arbitrary, and not restricted to direction. Two different mobility models are used to test and evaluate routing schemes in MANET's environment: trace and synthetic models [98]. Trace models these are mobility patterns represents real-world environments. Although, trace provides accurate information, it is considered time consuming and it is not suitable for research studies. On the other hand, synthetic models attempt to create a realistic mobility pattern of mobile nodes in MANETs without the need for traces.

Different synthetic entity mobility models are developed for Ad-hoc networks such as group mobility model which simulate battle field environment [98], community mobility model which represents human movements within communities and different communities [99], and random way mobility model [100].

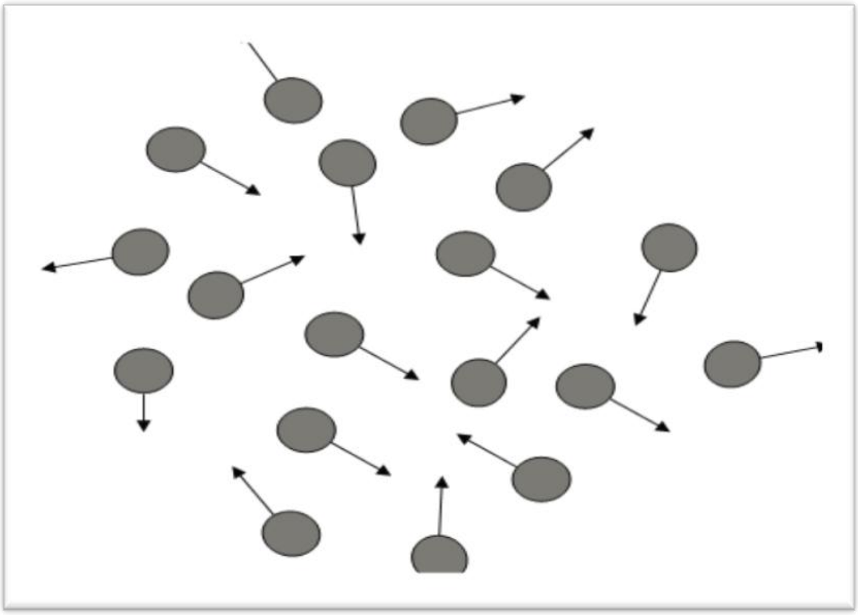

Figure 3-5 : Example of random way point model.

To mimic such a movement of mobile node in MANETs, the random way mobility model as in Figure 3-5 is used in this study as it is the most popular one and several academic research consider it for carrying out experiment results [4] [34] [61] [62].

In this model, nodes place randomly over a defined flat area with different dimensions. Each node moves towards a random destination with a uniform speed distribution between (0, S_{max}), where S_{max} is the maximum speed parameter. When the node reaches the destination, it pauses for some time, selects another destination and repeats the same process. The random way point model is used to evaluate the performance of PDRD and VAP schemes.

On the contrary, as vehicles' movement and behaviour is restricted by the road directions and boundaries, the random way model is not suitable to represent VANETs topology. Several mobility generators are developed for the purpose of studying the vehicles' behaviours on the road within a city environment such as SUMO (Simulation of Urban MObilit) [101], VanetMobiSim [102] and CityMob model [103].

SUMO is an open source generator, designed to generate large road networks. It can simulate different vehicle types, multi-lane streets and collision free vehicle's movement. VanetMobiSim is developed to create a realistic vehicular motion pattern. It can generate a network layout with multi-lane streets and traffic signs at intersections. It can also support mobility models such as Intelligent Driving Model with Intersection Management (IDM/IM), Intelligent Driving Model with Lane Changing (IDM/LC) and an overtaking model (MOBIL). CityMob [103] is a multi-mobility pattern generators designed to create different mobility models in VANETs, and to investigate their impact on inter-vehicle communication performance. It creates three urban mobility models scenarios; the simple model, the Manhattan model, and the downtown model.

The simple model creates a topology consisting only of vertical and horizontal lines with no semaphores. Vehicles move straight-forwarding and do not change direction. The Manhattan model uses a grid topology with square identical uniform blocks size. It represents a city with horizontal and vertical streets. All of the streets are two-way with one lane in each direction. Unlike the simple model, vehicles are able to change direction and stop at semaphores. The downtown model adds traffic density to the Manhattan model. In the downtown model vehicle density increases, and not uniformly distributed vehicle speed decreases. On the other hand, vehicle density in the outskirts decreases and vehicles move faster than in the downtown areas. Due to its simplicity, the City Mobility (CityMob) model is used in this study to evaluate the performance of the probabilistic stable routing discovery schemes for VANETs.

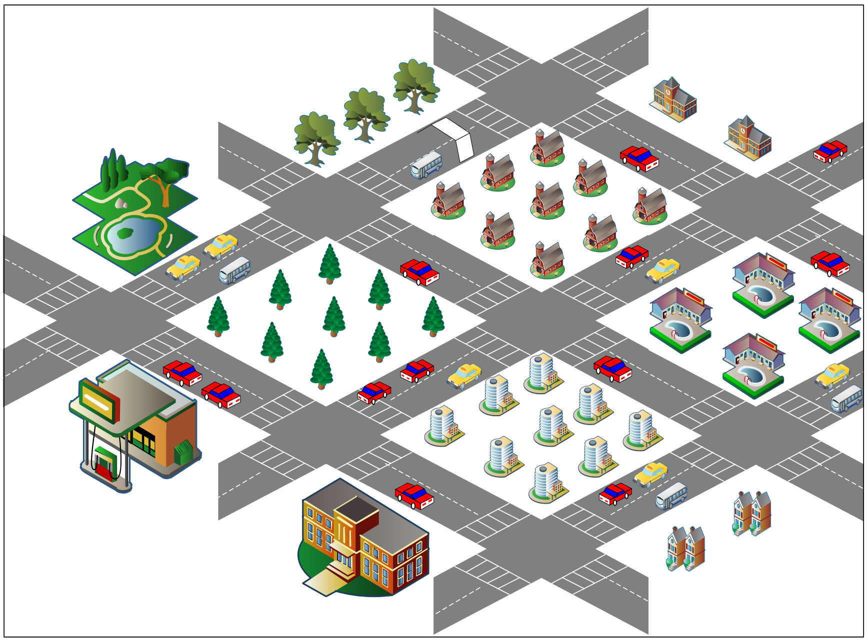

Figure 3-6 : Example of a city scenario for VANETs.

It also generated a mobility model that represents the required simulation environment, which can be easily and directly used with ns-2.34. An example of city environment is shown in Figure 3-6. The interested reader can refer to [104] for further details and other examples of VANETs' mobility generators.

Figure 3-7 shows a flowchart of the simulation processes. First, the mobility generators generate the mobility model, i.e., the random way model or city model that will be used in the simulation. The traffic generator creates a traffic pattern that determines packet size, number of connections, and packet sending rates. Both mobility trace and traffic trace are included in the TCL script which contains the rest of the parameters. Then ns-2 is invoked by the TCL script and simulation process is started until the end of the simulation time. The performance results are then obtained from a trace file contains all the network events.

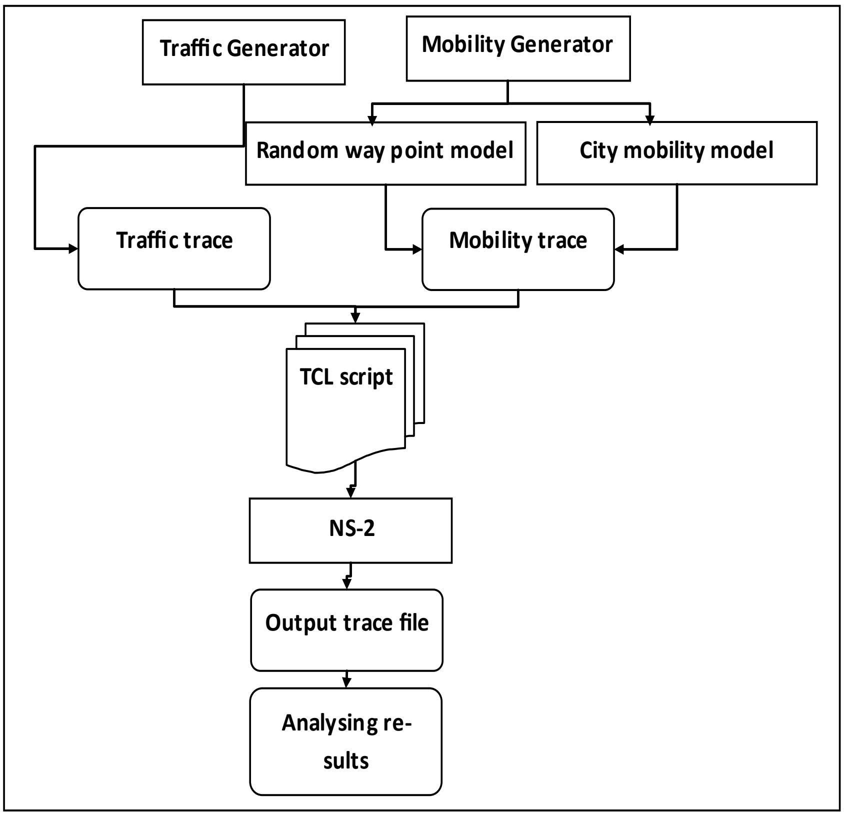

Figure 3-7: Simulation Environment flow

3.4 Performance Evaluation

To evaluate and compare the performance of the routing schemes discussed above, we used NS-2.34, the simulation platform designed by researchers at Berkeley University [93]. For each data point in the figures, at least 30 experiments are used, each one representing different network topology with 95% confidence intervals. The random waypoint model [100] is used as the mobility model. In this model, mobile nodes move freely and randomly without boundary restrictions. The application layer at each node generates CBR traffic. Standard transmission range of 250m is selected. To keep the nodes move all the time, node's pause time is set to 0. Interface queue length, bandwidth and the packet size are set according to the default values that are exited in the AODV protocol.

Node speed is set to 20m/s in order to mimic vehicles' speed in the city environment. All of the parameters exist in Table 3-2. It is worth stating that we have used almost the same parameters as in [36]. Due to its high capability in MANETs, AODV routing has been adopted in our experiments. PDRD, SF, and HPC have been examined within the context of AODV routing protocol. In our experiments, we refer to our proposed scheme as AODV-PDRD and we investigate its performance, in comparison with both AODV-SF [51] and AODV-HPC [70]. The HPC scheme uses an exponential function to calculate rebroadcast probability values. AODV-HPC is discussed in chapter two, section 2.4.4.7. The simulation scenarios consist of two different settings. First, the impact of network density is tested by spreading a different number of nodes over a topology area of 1000m x 1000m. The second simulation scenario measures the effects of the number of connections on the performance of the routing scheme by changing the number of connections for each scenario.

Table 3-2 : Summery of the parameters used in the simulations.

Parameter	**Value**
Transmitter range	250m
Bandwidth	2Mbit
Interface queue length	50 messages
Simulation time	900 sec
Pause time	0 sec
Packet size	512 bytes
Topology size	$1000 \times 1000 \; m^2$
Node speed	20 m/sec
Number of nodes	20-200 nodes
Number of connections	1-40
Data traffic	CBR
Mobility model	Random Way-Point
Number of trials	30 trials

3.4.1 SCENARIO 1: Impact of Network Density

In this scenario the network density varies from low (20 nodes) to high (200 nodes) placed in a network area of size 1000m x 1000m. Each node has a random maximum speed of 20m/s. Traffic load is set to 20 flows for each scenario with 8 data packets/second.

- **RREQ Rebroadcast Number**

The RREQ rebroadcast number represents the number of nodes that receive a RREQ packet and rebroadcast it successfully. To study the effect of varying network density on the number of generated RREQ packets incurred by AODV-PDRD and AODV-SF, we calculated the number of disseminated RREQ packets for each scheme. Figure 3-8 shows that as the number of nodes increases the number of RREQ packets increases, as many nodes receive and rebroadcast the same RREQ packet. In contrast, AODV-PDRD generates a minimum number of RREQ packets. Figure 3-8 depicts that the RREQ number of AODV-PDRD is reduced by approximately 65% and 35% compared to AODV-SF and AODV-HPC respectively.

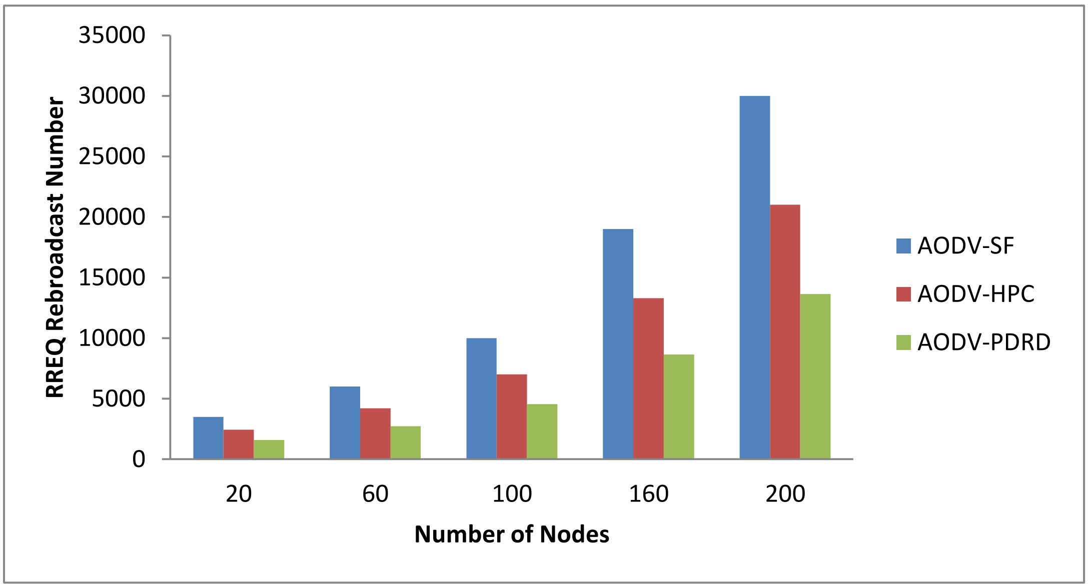

Figure 3-8: shows RREQ rebroadcast number vs. number of nodes incurs by all the proposed schemes.

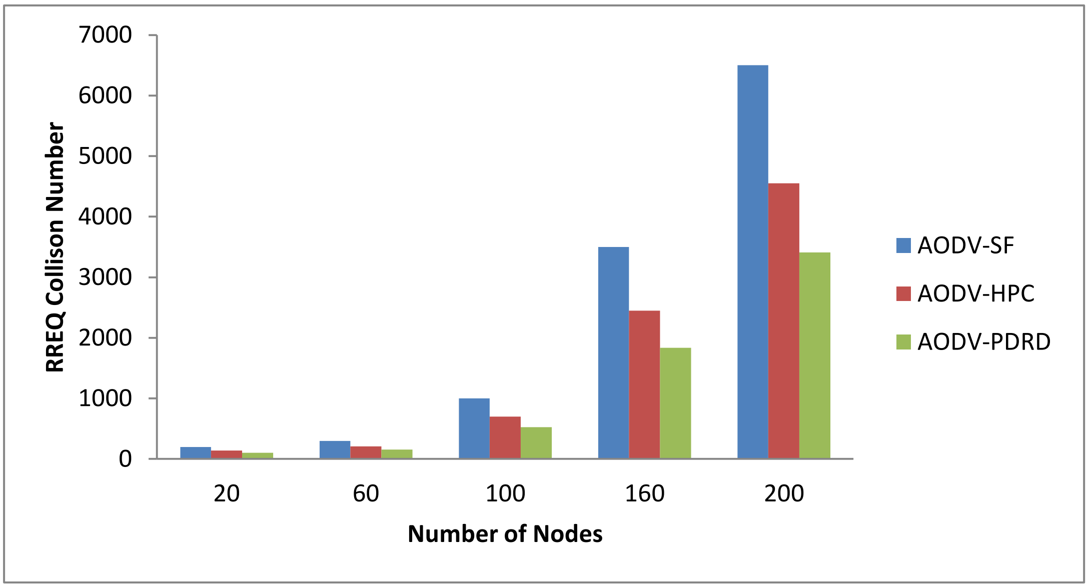

Figure 3-9 : shows RREQ collision number vs. number of nodes generated by all the proposed schemes.

- **RREQ Collision Number**

To measure the impact of using AODV-PDRD and other routing schemes on minimizing channel contention, we calculated the RREQ collision rate that is generated by each scheme. Figure 3-9 shows that the collision rate increases for each scheme as the number of nodes increases. Notice that when the density increases the number of candidates that rebroadcast RREQ increases. As a result, collision of RREQ packets increases. The AODV-PDRD reduces the possibility of having more than two nodes to rebroadcast at the same slot time. As a result, the broadcast collision problem is suppressed. The figure also depicts that the collision rate of AODV-PDRD is reduced by approximately 45% compared to AODV-SF and 25% compared to AODV-HPC.

- **Packet Delivery Ratio**

Packet delivery ratio measures the percentage of data packets that successfully arrive at the destination to the total data packets that have been sent by the source. Figure 3-10 shows the effect of network density on the performance of all three schemes.

It can be seen in the Figure 3-10 that as the network density increases the packet delivery ratio decreases. This is because to in dense networks the number of nodes that receive and resend the RREQ packets increase, which in turn increase the usage of wireless bandwidth and decreases the packet delivery ratio. Figure 3-10 shows that AODV-PDRD has superior performance over AODV-SF and AODV-HPC. For example, at high network density (e.g. 200 nodes) the packet delivery ratio for the three schemes: AODV-PDRD, AODV-HPC and AODV-SF are 0.72, 0.66 and 0.6, respectively.

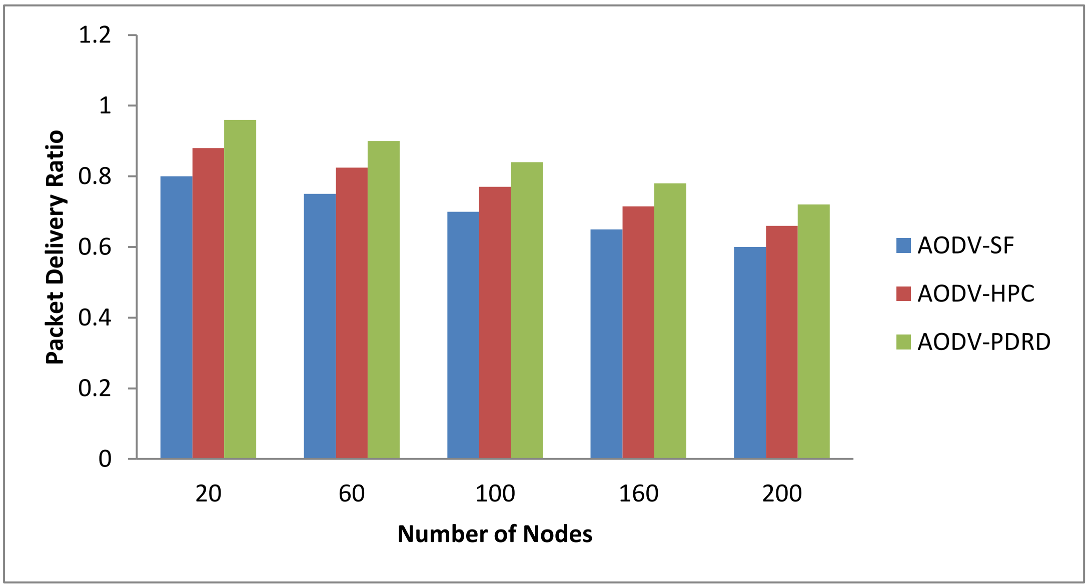

Figure 3-10: shows packet delivery ratio vs. number of nodes for each scheme.

- **End-to-end Delay**

Figure 3-11 represents the resultes of the average end-to-end packet delay incurred by all of the proposed schemes. In a dense network, the number of dropped packets increase due to the increased number of nodes that generet RREQ packets. This in turn, requires the dropped packets to be resent, or to wait longer in the interface queue.

As a result, the average end-to-end elay increases. For instance at very dense network points of 100 nodes and 200 nodes, the average end-to-end   delay increases from 0.2 sec to 0.3 sec in AODV-SF, and from 0.15 sec to 0.225 sec in AODV-DPRD.

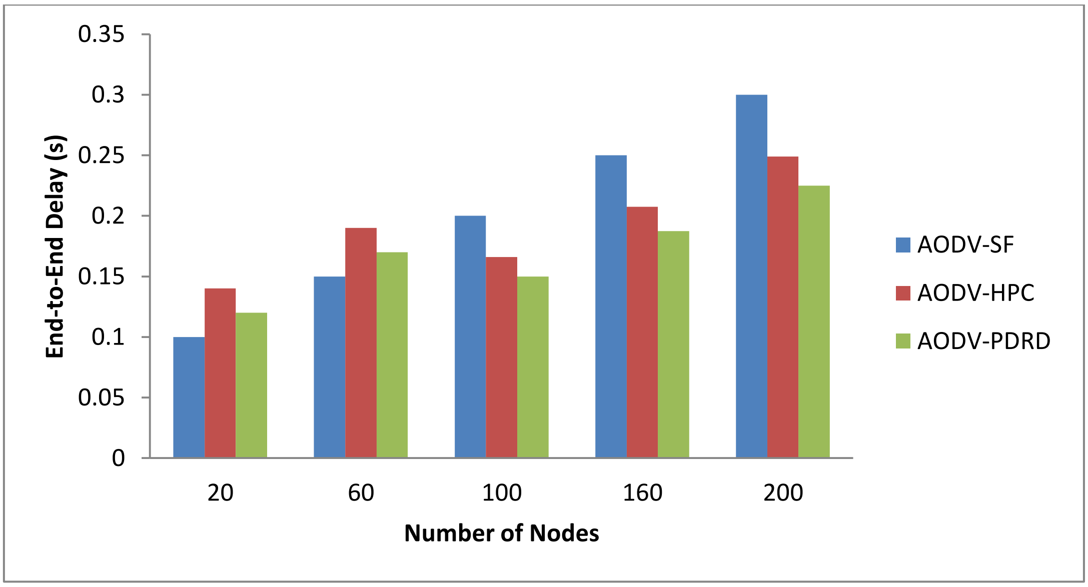

Figure 3-11: shows end-to-end delay vs. number of nodes for all the proposed schemes.

3.4.2 SCENARIO 2: Impact Number of Connections

Connection parameter represents the number of communication channels between source and destination pairs, which are used for sending data packets. In this scenario, each routing scheme is evaluated under different number of connections, varies from 1-40.

- **RREQ Rebroadcast Number**

Figure 3-12 depicts that the RREQ rebroadcast number generated by the routing schemes increases with the increase in the given load. This is because as the amount of flow increases, the number of connections between sources and destinations increases proportionally. In fact, to open any connection between the source and destinations, the RREQ packet should be initiated and rebroadcasted. For instance, when the number of connections increases from 5 to 40, the routing overhead generated by AODV-PDRD is reduced by approximately 20% compared to AODV-HPC.

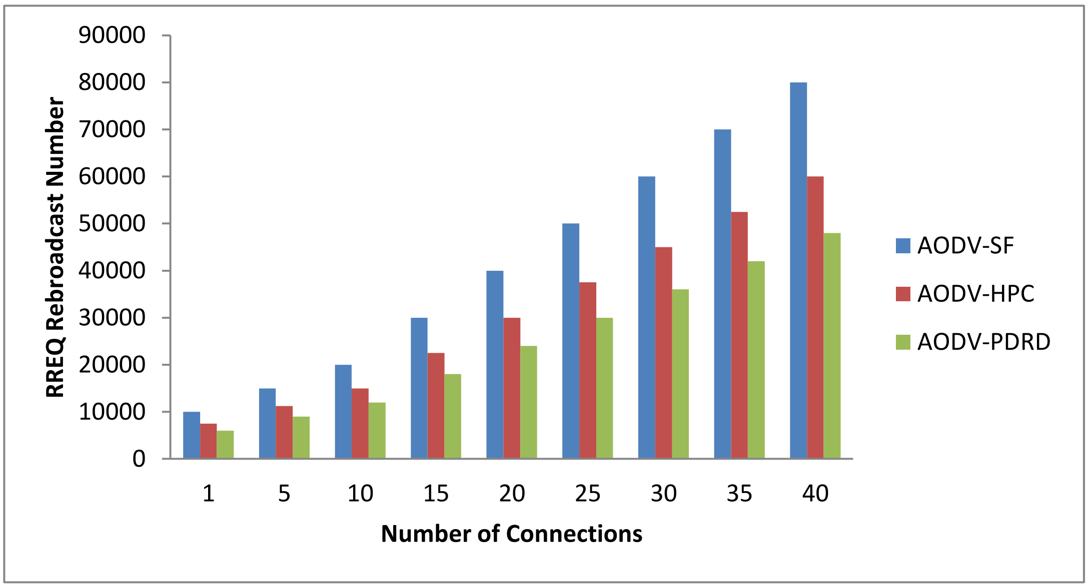

Figure 3-12: RREQ rebroadcast number VS. number of connections for a network of 100 nodes in 1000m x 1000m area.

- **RREQ Collision Rate**

The connections between sources and destinations are selected randomly. The network topology is 1000m x1000m with 150 nodes deployed. Figure 3-13 illustrates the number of RREQ packet collisions that occurred during the simulation time for the three broadcast schemes. Clearly, AODV-PDRD has the best performance compared to its two counterparts. This is due to using an extension timer technique and readjusting rebroadcast probability upon receiving a duplicated RREQ packet at each node. Figure 3-13 also reveals that for a given connection point, AODV-PDRD outperforms AODV-SF and AODV-HPC. In particular, the collision rate of PDRD-AODV is about 19% lower than that of AODV-HPC.

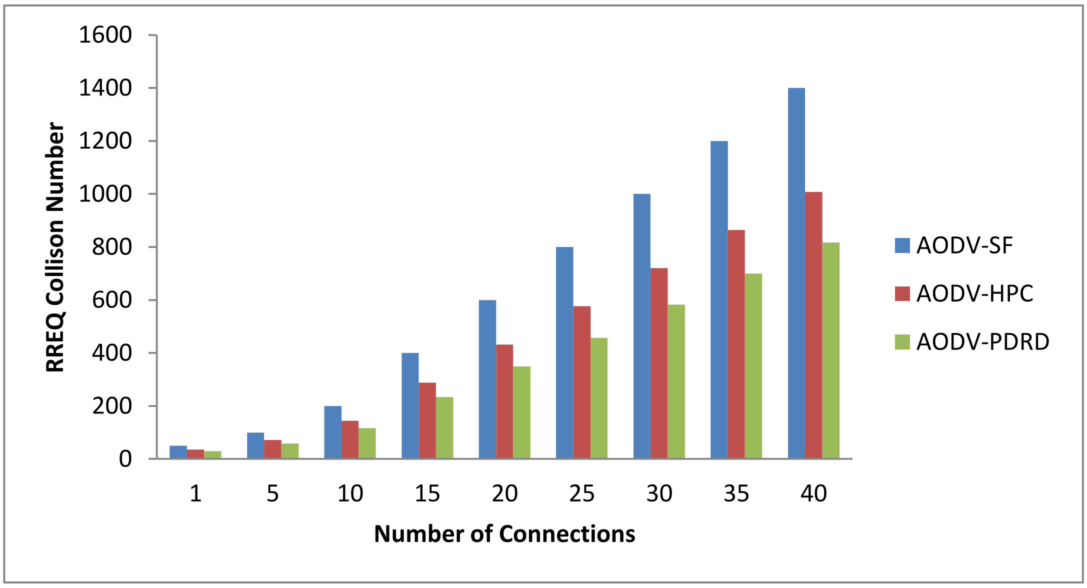

Figure 3-13: RREQ collision number VS. number of connections for a network of 100 nodes in 1000m x 1000m area.

- **Packet Delivery Ratio**

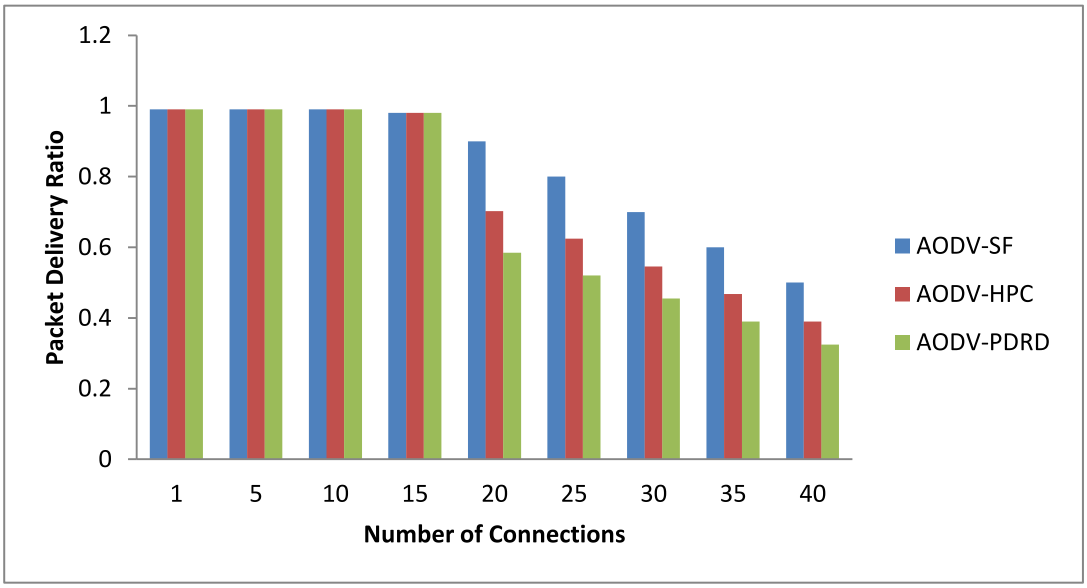

Figure 3-14: Packet delivery ratio VS. number of connections for a network of 100 nodes in 1000m x 1000m area.

Figure 3-14 reports the results of the packet delivery ratio versus the number of connections. It can be noticed from the figure that the packet delivery ratio achieved by the three protocols decreases as the number of connections increases.

This is due to the fact that as more connections are established more routes are needed, and more RREQ packets are generated. Hence, a lot of generated data packets are dropped as a result of collisions and channel contention caused by a high congestion level of generated RREQ packets. However, the AODV-PDRD has the best performance compared to its counterparts. For example, when the number of connection is 30, the packet delivery ratio is 0.7, 0.546 and 0.445 for AODV-PDRD, AODV-HPC, and AODV-SF.

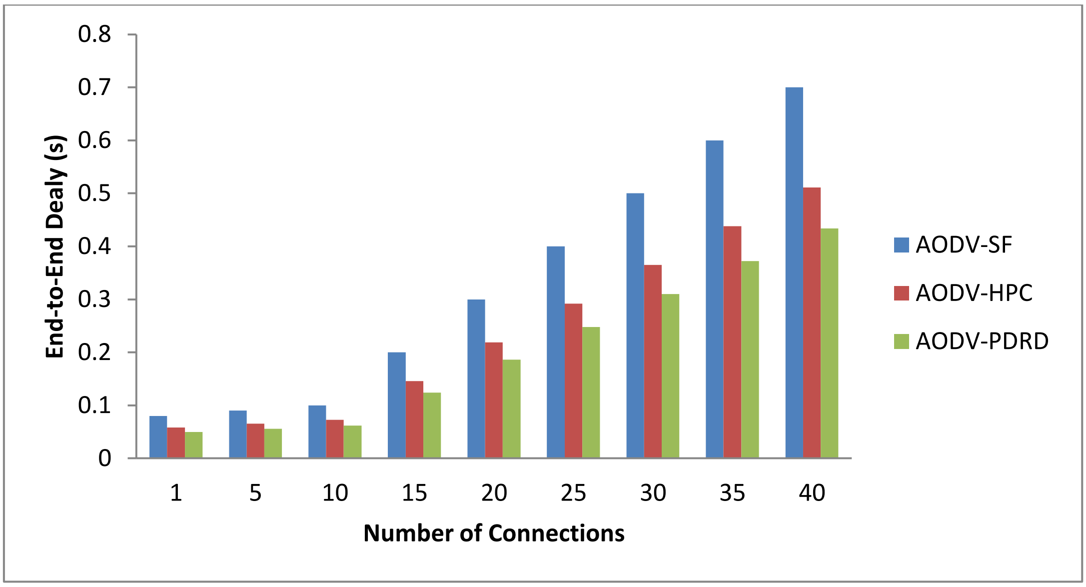

Figure 3-15: end-to-end delay VS. number of connections for a network of 100 nodes in 1000m x 1000m area.

- **End-to-end Delay:**

Figure 3-15 shows the effect of varying number of connections on the average end-to-end delay. The number of total packets transmitted across wireless channels increases, when the number of connections between nodes increases. This forces the data packets to wait additional time in the interface queue and experience high latencies. Clearly, the averag end-to-end delay dramatically increases as the number of connections increases.

Among all the proposed schemes the AODV-PDRD scheme incurs the lowest average end-to-end delay. For instance, when the number of connection is high, i.e. 30, the average end-to-end delay for AODV-PDRD, AODV-HPC, and AODV-SF is 0.5 sec, 0.365 sec and 0.31 sec, respectively.

3.5 Conclusion

In this chapter, we have investigated the broadcast and route discovery problem in MANETs. We have proposed a new AODV-PDRD routing scheme, to mitigate different broadcast storm problems that are usually associated with the route discovery phase. We adopted the random waypoint to evaluate the performance of AODV-PDRD, considering different parameters such as node density and connections. We have conducted several simulation experiments. Results confirm the superiority of the proposed AODV-PDRD scheme in terms of routing overhead, end-to-end delay and collision rates, compared to the AODV based broadcast schemes including the well-known AODV-SF and AODV- HCP. For instance at very dense network points of 100 nodes and 200 nodes, the average end-to-end delay increases from 0.2 sec to 0.3 sec in AODV-SF, and from 0.15 sec to 0.225 sec in AODV-DPRD. The collision rate also of AODV-PDRD is reduced by approximately 65% and 35% compared to AODV-SF and AODV-HPC respectively.

In this chapter the DPRD scheme uses both global and local network density to mitigate the broadcast storm problem during route discovery. In the next chapter a new probabilistic scheme is adopted not only to mitigate the broadcast storm problem, but also to preserve route stability by using node velocity information instead of network density information.

Chapter 4

A Stable Probabilistic Route Discovery Scheme for Mobile Ad-hoc Networks

---

The key objective of this chapter is to present and discuss the new probabilistic routing schemes and, it is organized as follows:

- Explaining in details the new Simple Velocity Aware Probabilistic Route Discovery Scheme (SVAP), its components and steps.
- Explaining in details the new Advance Velocity Aware Probabilistic Route Discovery Scheme (ASVAP), its components and steps.
- Evaluating the performance of the SVAP scheme and the AVAP scheme under different network conditions.
- Concluding the chapter and providing a brief summary.

4.1 Introduction

In the simple Fixed Probabilistic (FP) broadcast scheme, each node floods the network with pure probability *P* and cancels its transmission with *1-P*. To enhance the pure probabilistic scheme, position [12] density [41] and distance [42] thresholds were introduced. For example in [41], a node cancels its retransmission if it has a density level above a predefined density threshold such as maximum network density. Another example is in [42], where the rebroadcast probability is calculated based on the distance between the sender and receiver. The probability of the receiver to cancel its transmission is high if it is located close to the sender. A probabilistic broadcast scheme should be designed in a reliable way in order to facilitate the data packets delivery at minimum overhead.

The decision of selecting the node that should undertake rebroadcasting the received packet plays an important role in the overall network performance. Hence, each node should calculate its rebroadcast probability carefully to avoid any unnecessary retransmission. To the best of our knowledge, existing probabilistic solutions do not include the velocity concept in order to set the most stable routes.

Motivated by the above discussions, we propose two new variation of probabilistic schemes namely, the *Simple Velocity Aware Probabilistic-based* scheme (SVAP) and the *Advance Velocity Aware Probabilistic-based* scheme (AVAP), which can mitigate the broadcast storm problem by improving the overall route discovery phase. These schemes adjust both rebroadcast probability counter threshold, and timer adaptively at each node based on its velocity vector to construct the most stable path between any two nodes. This study is the first that considers the velocity vector probabilistic route discovery in MANETs. The following section describes the proposed scheme.

The remaining part of this chapter is organised as follows. Section 4.2 describes a new Probabilistic Route Discovery Scheme. Sections 4.3 presents performance results to show the effects of node mobility, and network density on the performance of probabilistic flooding. Finally, Section 4.5 concludes the chapter.

4.2 The New Routing Schemes

The node selection is a crucial part in designing the suggested scheme. Thus, in this investigation we classify all of the mobile nodes into *Reliable Nodes* (*RNs*) and *Un-Reliable Nodes* (*U-RNs*) with respect to the velocity of the sender and the receiver node. Notice that *RNs* that have a similar relative velocity compared to the sender velocity are more likely to build the network routes. On the other hand, *U-RNs* are those nodes with very different velocities compared to the sender node's velocity. Therefore, any retransmission by *U-RNs* should be suppressed in order to avoid early link failure and decrease the overhead of routing packets. Before demonstrating the proposed schemes, we first describe the problem via the following example. Figure 4-1 illustrates the example of five nodes (*S*, 1, 2, 3 and *D*). Nodes 1 and 3 move with the same velocity as the Source node (*S*), while Node 2 moves with a different velocity. A connection between node S and node D could be established via two routes: one via node 1 (route *S*-1-3-*D*) and the other via node 2 (route *S*-2-3-*D*). The first route is more likely to be stable compared to the second route as node 2 moves with different velocity compared to node *S* and node 3. Consequently, the selection of the second route is more likely to be invalid after a short time.

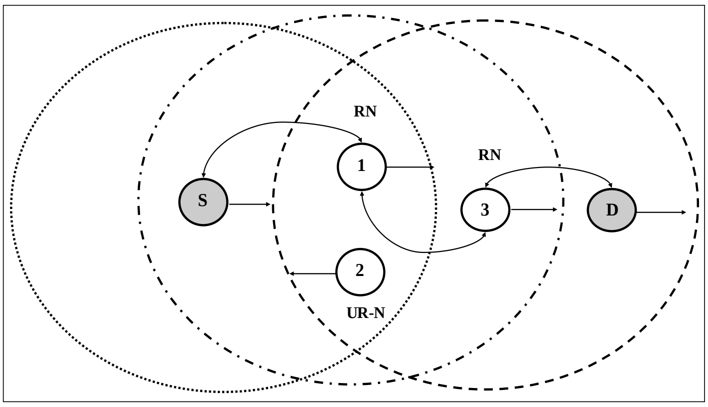

Figure 4-1: Example of RN and UR-N.

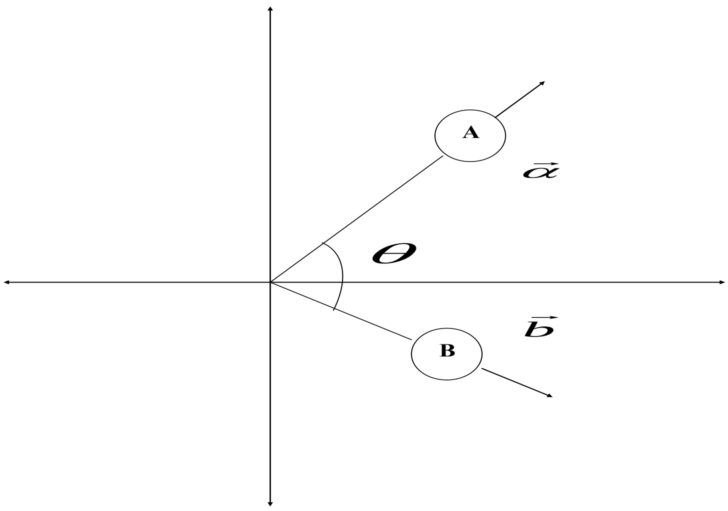

Figure 4-2: The value of the cosine angle between two vectors.

By using the velocity vector information, the cosine angle θ is calculated between the sender and the receiver to determine whether the receiver is *RN* or *U-RN* as in Figure 4-2 If the value of θ is less than the predefined angle threshold θ_{Th}, then the receiver is categorized as *RN* as it moves with the same velocity as the sender. Otherwise, the receiver is categorized as *U-RN*. The angle θ is calculated using the following cosine equation:

$$\theta = \arccos\left[\frac{\vec{a}\,.\,\vec{b}}{\left|\vec{a}\right|.\left|\vec{b}\right|}\right] \tag{6}$$

Where $\vec{a}$ and $\vec{b}$ are the sender and the receiver unit vector information respectively. Selecting the appropriate value of θ_{Th} affects the performance of the proposed scheme. A large value of θ_{Th} privileges all nodes *RN* or *U-RN* to generate RREQ packets and participates in routing process. This decreases route stability, and increases the number of unnecessary RREQ packets. On the other hand, a small value of θ_{Th} *i*ncreases route stability saves unnecessary transmission of RREQ packets, but sacrifices RREQ packet reachability. To maintain a reasonable balance between RREQ packets reachability and saved rebroadcast, several simulation experiments have been carried out to select the best value of θ_{Th}.

Figure 4-3 shows that as the value of θ_{Th} increases, RREQ packet reachability also increases. This relationship can be noticed between 10^o to 90^o, but beyond this interval reachability curve becomes constant.

Figure 4-4 depicts the relationship between saved rebroadcast and value of θ_{Th}. It shows that as the value of θ_{Th} increases, the total number of saved rebroadcast decreases.

This is due to the increasing probability of the nodes to rebroadcast the same received RREQ packets. Thus, motivated by the above observations, the value of θ_{Th} is selected to be 90^0 to guarantee a high level of reachability with minimum retransmission. By assigning this value to the nodes in the network, we limit number of nodes that should take place in routing process, and reduce routing overhead.

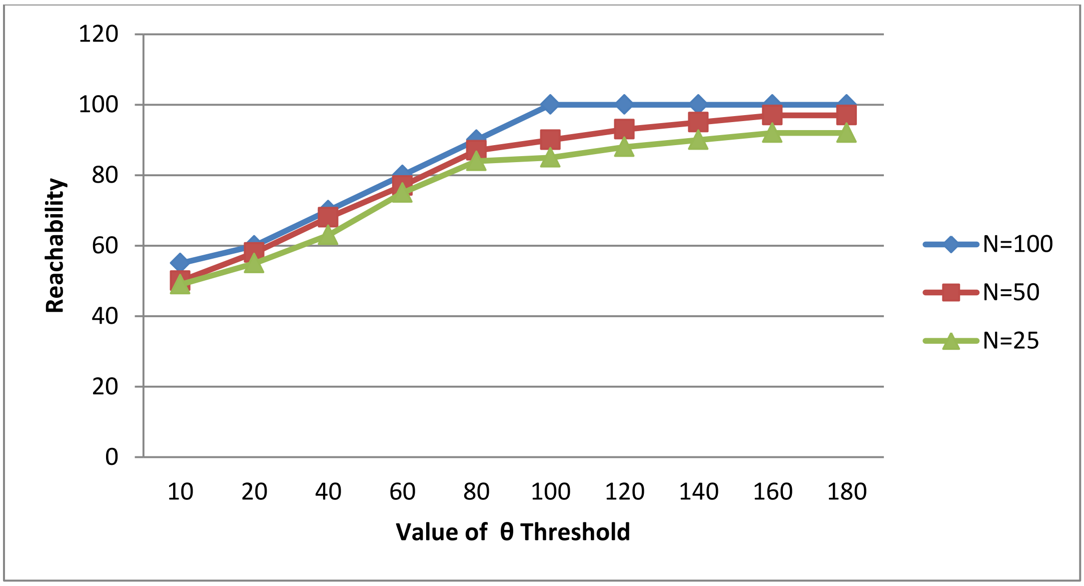

Figure 4-3: RREQ reachability vs. Value of θ Threshold over different network densities.

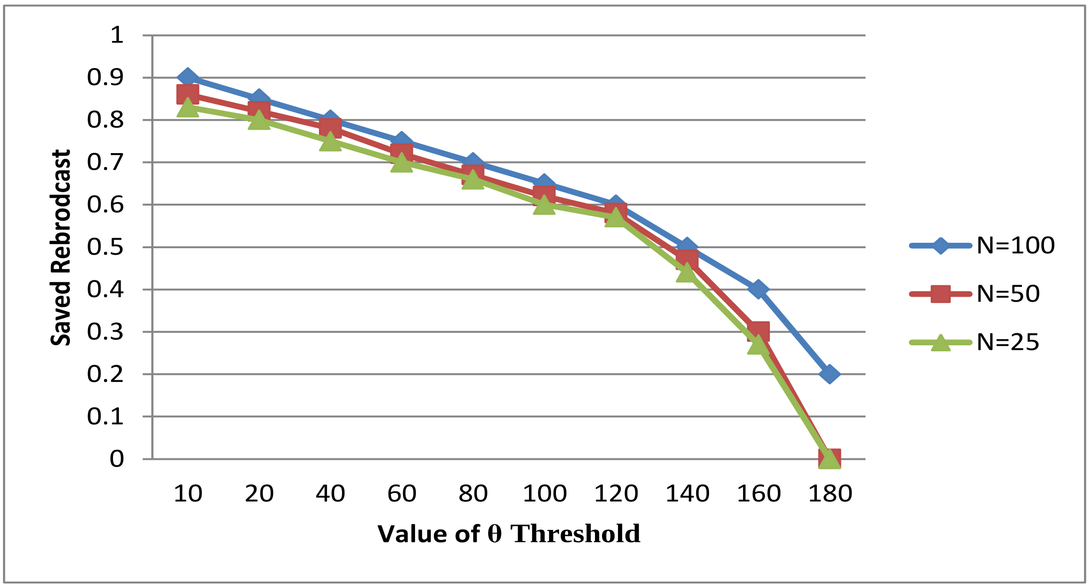

Figure 4-4: RREQ saved rebroadcast vs. Value of θ Threshold over different network densities.

4.2.1 Simple Velocity Aware Probabilistic Route Discovery Scheme (SVAP)

The new proposed scheme helps to distinguish between *RNs* and *U-RNs* by assigning a different value for rebroadcast probability. A high rebroadcast probability is assigned for *RNs*, while a low value is assigned for *U-RNs*. This type of adaptation implicitly helps in establishing the most stable and reliable routes, and thus enhances the overall performance of the route discovery phase. This can be achieved by the *Simple Velocity Aware Probabilistic* route discovery scheme (SVAP) as it can cut off *U-RNs*, which cause frequent link breakage between nodes, and requires the source node to initiate a new route discovery session. The total net effect reduces the number of generated RREQ packets that cause the broadcast storm problem [4]. A brief outline of the SVAP scheme is shown in Figure 4-5, and it operates as follows

- When the Source (*S*) node sends an RREQ packet to find a destination, it adds its own velocity to the RREQ packet header.
- Once any Receiver (*R*) within the source transmission range receives the RREQ packet, it initializes a random timer and a Counter (*C*) to count the number of the received RREQ packet. Then, the cosine angle θ is calculated using equation (6) as given in Steps 1-11.
- After the timer expiration, the receiver is considered an *RN* if the value of θ is less than the θ_{Th}, and is assigned a high Counter Threshold (C_{TH}=C_{HTH}). Otherwise, the receiver is *U-RN* and assigned a low C_{TH} = C_{LTH}. Steps 12-19.
- The receiver is *RN*, and is assigned a high rebroadcast probability, if the number of RREQ packets (i.e. *C*) is less than the pre-assigned counter threshold (i.e. C_{TH}). Otherwise, the receiver is *U-RN* and assigned a low rebroadcast probability. Steps 20-24**.**

- Finally the algorithm generates a Random Number (R_N) between (0, 1); then a node rebroadcasts the RREQ packet if the R_N is less than the pre-assigned p. Otherwise the packet is simply dropped. Steps 25-30.

SVAP: Simple Velocity Aware Probabilistic Scheme

Input: Source Velocity (**S_v**), Receiver Velocity (R_v), Cosine Angle (θ), Cosine Angle Threshold (θ_{Th}), Random Timer (T_{Random}), Low Counter Threshold (C_{LTH}), High Counter Threshold (C_{HTH}).
Output: The Rebroadcast Probability Value (P).

```
1.  IF (RREQ Packet Received for the first time) = TRUE {
2.  S_V ←Get _Source_Velocity();
3.  R_V ←Get _Receiver_Velocity();
4.  θ ←Get_Cosine_Angle ();
5.  θ_Th←Set_Cosine_Angle_Threshold ();
6.  T_Random←Set_Random_Timer();
7.  WHILE (T_RANDOM!= Expired) {
8.  IF (The Same RREQ Packet Receved ) = TRUE {
9.  Get_Number_Copy{C=C+1}
10.    END_IF }
11. END_WHILE }
12. IF (θ > θ_Th) = TRUE {
13. R_S→ Set_Unreliable_Node();
14. C_TH  Set_Low_Counter_Threshold(C_LTH);
15.     END_IF }
16. IF (θ < θ_Th) = TRUE {
17. R_S→ Set_Reliable_Node();
18. C_TH → Set_Highe_Counter_Threshold(C_HTH);
19.     END_IF }
20. IF (C<C_TH) = TRUE {
21. P→  Set_High_Rebroadcast _Probability();
22.    ELSE
23. P→  Set_low_Rebroadcast _Probability();
24.      END_IF }
25. RN ←Random_Number(0,1);
26. IF(RN<P) = TRUE {
27. Rebroadcast_RREQ();
28.   ELSE
29. Drop_RREQ();
30.   END_IF }
31. END_IF }
```

Figure 4-5: Description of SVAP scheme.

4.2.2 An Illustrative Example

The following example illustrates the proposed scheme. In Figure 4-6, nodes 3, 4, 6, 7 and 9 are categorized as *RNs* since they have similar velocity compared to the Source

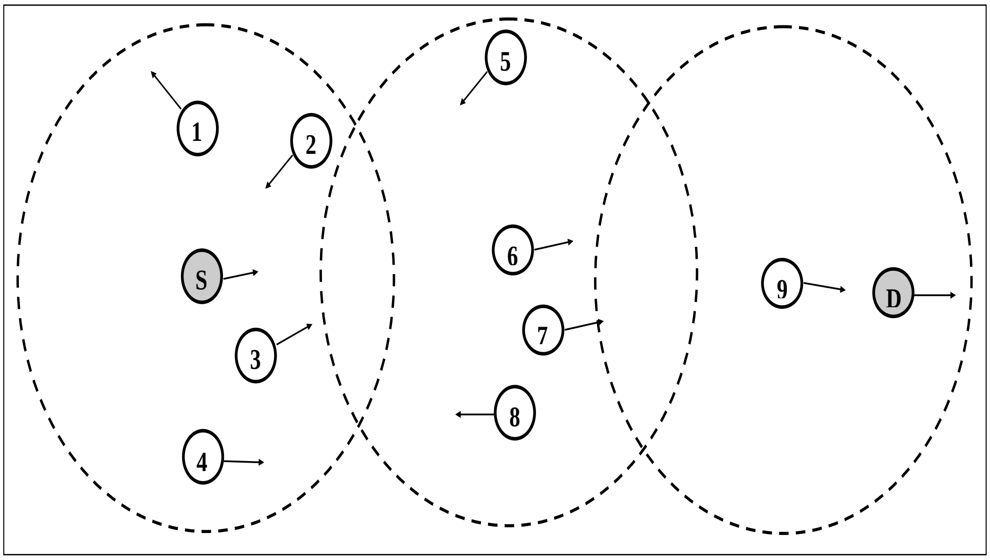

Figure 4-6: Example of both SVAP and AVAP.

(S) velocity. This means that the value of $\theta < \theta_{Th}$, and each node is assigned a high counter threshold ($C_{TH} = C_{HTH}$). Nodes 1, 2, 5 and 8 are classified as *U-RNs* as they have different velocity compared to the source node *S*. This also means that the value of $\theta > \theta_{Th}$, and each node is assigned a low counter threshold (C_{TH}=C_{LTH}). The value of C_{HTH} for the *RNs* and C_{LTH} for the *U-RNs* are adjusted to 2 and 1 respectively to control the rebroadcast decision. When the source node S sends a RREQ packet, nodes 1, 2, 3 and 4 initialize a random $TIMER_{RANDOM}$ (0, 10^{-3}), and count the number of the same received RREQ packets. After the timer expiration, each node compares the value of Counter *C* with the value of C_{TH}, and takes a proper rebroadcast decision. In this scenario, nodes 1, 2, 3, and 4, upon receiving an RREQ packet from node *S*, set the counter *C*=1.

After a random period of time, suppose that node 4 performs its rebroadcast first. Nodes 1, 2 and 3 receive this rebroadcast for the second time (i.e. $C = 2$), while nodes 5, 6, 7 and 8 receive it for the first time (i.e. $C = 1$). Nodes 1 and 2 are assigned a low rebroadcast probability as the value of $C > C_{TH}$ (i.e. 2 > 1), while node 4 assigned a high rebroadcast probability as the value of $C < C_{TH}$ (i.e. 1<=1) .In this way, any rebroadcast by nodes 1 and 2 is likely to be suppressed and is implicitly excluded in constructing any route toward the destination. The same above steps are repeated in the case of nodes 5, 6, 7, 8 and 9. Nodes 6, 7 and 9 are privileged to participate in the route discovery process, which is not the case for nodes 5 and 8.

4.2.3 Advance Velocity Aware Probabilistic Route Discovery Scheme (AVAP)

The efficiency of the SVAP scheme can be improved if a proper timer and probabilistic function are considered to differentiate between the *RNs* and *U-RNs*. It is clearly noticed that SVAP scheme uses a fixed random timer for all different nodes regardless of their reliability. This may cause a *simultaneous broadcast* problem as the timer for some nodes could expire at the same time. Hence, many nodes will rebroadcast simultaneously, thus resulting in increasing the dropped RREQ packets. On the other hand, a comparison of two fixed counters is used to set the rebroadcast probability. This enables *RNs* or *U-RNs* to have the same value of *P*. This increases the contention rate and leads to a huge competition while accessing the same shared wireless medium. Therefore, the need to improve the *SVAP* scheme can approximately eliminate the broadcast storm problem and keep the most reliable routes. For example in Figure 4-1, node number 1 (i.e. *RN*) should have a high possibility to rebroadcast before node number 2 (i.e. *U-RN*) which has a less reliable link connecting it to the source.

Thus, a proper timer and counter threshold should be considered in the SVAP scheme to differentiate between the *RNs* and *U-RNs*.

In the light of the above discussion, we propose here a new version of *SVAP namely Advance Velocity Aware Probabilistic Scheme* (AVAP). A brief outline of the AVAP is given in Figure 4-7 and it operates as follows:

- When the Source (*S*) node sends an RREQ packet to find a destination, it adds its own velocity vector to the RREQ packet header.
- Once any Receiver (*R*) within the source transmission range receives the RREQ packet, it calculates the cosine angle θ, and then takes the rebroadcast decision as follows:
  - The receiver is considered as *U-RN* if the value of $\theta > \theta_{Th}$. Then, a long $TIMER_{LONG}$ (0, 10^{-1}) is initiated with a high counter threshold, C_{HIGH}. Steps 7-17. The value of $TIMER_{LONG}$ is obtained from [92]. This value makes nodes to save more rebroadcast RREQ packets and decreases collision rates.
  - A low rebroadcast Probability P_{LOW} is set to the *U-RN*, as a ratio between the P_i and the value of total C_{HIGH} as follows:
    - $P_{LOW} = (Pi/C_{HIGH})$. Step 16.
  - Otherwise, the receiver is considered as *RN*, and initiates a short timer $TIMER_{SHORT}$ (0, 10^{-3}) and a low Counter threshold C_{LOW}. Steps 18-27.
  - A high rebroadcast probability P_{HIGH} is set to the *RN* as a ratio between the P_i and the value of the total C_{LOW} as follows :
    - $P_{HIGH} = (Pi/C_{LOW})$. Step 26.
- Finally the algorithm generates a Random Number (R_N) between (0, 1), then a node rebroadcasts the RREQ packet if R_N is less than the pre-assigned *P*. Otherwise the packet is simply dropped. Steps 28-33.

AVAP: Advance Velocity Aware Probabilistic Scheme

Input: Source Velocity (**S_v**), Receiver Velocity (R_v), Cosine Angle (θ), Cosine Angle Threshold (θ_{Th}), Long Timer (T_{LONG}), Short Timer (T_{SHORT}), Low Counter Threshold (C_{LTH}), High Counter Threshold (C_{HTH}).
Output: The Rebroadcast Probability Value (P)

```
IF (RREQ Packet Received for the first time) = TRUE {
S_V ←Get _Source_Velocity();
R_V ←Get _Receiver_Velocity();
θ ←Get_Cosine_Angle ();
θ_Th←Set_Cosine_Angle_Threshold ();
P_i ← Set_Initial _Probaibity(0.7, 0.9);
IF ( θ > θ_Th) = TRUE {
R_S→ Set_Unreliable_Node();
C_TH  →Set_High_Counter_Threshold(C_HTH);
T_LONG←Set_Long_Timer();
WHILE (T_long!= Expired) {
IF (The Same RREQ Packet Receved ) = TRUE {
Get_Number_Copy{C_HTH = C_HTH+1}
   END_IF }
    END_WHILE }
P→ Set_Rebroadcast _Probability(){P_LOW = P_i / C_HTH};
  END_IF
IF ( θ < θ_Th) = TRUE {
C_TH  →Set_low_Counter_Threshold(C_LTH);
T_SHORT←Set_Long_Timer();
WHILE (T_SHORT!= Expired) {
IF (The Same RREQ Packet Receved ) = TRUE {
Get_Number_Copy{C_LTH = C_HTH+1}
   END_IF }
    END_WHILE }
P→ Set_Rebroadcast _Probability(){P_HIGH = P_i / C_LTH};
  END_IF
RN ←Random_Number(0,1);
IF(RN<P) = TRUE {
Rebroadcast_RREQ ();
 ELSE
Drop_RREQ ();
  END_IF }
END_IF }
```

Figure 4-7: Description of AVAP scheme

4.2.4 An Illustrative Example

The following example illustrates the AVAP scheme of Figure 4-6:

- When the source node S sends an RREQ packet to find a route to the destination *D*, it adds its velocity vector to the RREQ packet header.

- All of the sources' neighbours calculate the value of cosine angle θ using equation (6). The value of θ between node *S* and nodes 1, 2, 3 and 4 is equal to 110^o, 190^o, 20^o and 30^o respectively.
- Nodes 1 and 2 are *U-RNs* (i.e. $\theta > \theta_{Th}$) so they initialize $TIMER_{LONG}$ with counter C_{HIGH}. Nodes 3 and 4 are *RNs* (i.e. $\theta < \theta_{\mathrm{Th}}$), so they initialize $TIMER_{SHORT}$ with counter *C*.
- *RNs* rebroadcast with high probability *P* and do so early as their timer expired first. This rebroadcast increases the value of Counter at the *U-RNs*, which decreases their opportunity to rebroadcast.
- Nodes 1, 2, 3 and 4 have an initial counter value of $C = 1$ upon receiving the RREQ packet from *S* as it is the first copy received.
- Suppose that node 4 rebroadcasts first with probability $P = (0.7/1) = 0.7$, since it has a short timer (follow line 24 in Figure 4-7).
- After the first transmission of node 4, nodes 1, 2 and 3 increment their counter by the duplicated copy that is received from the node 4. The Counter of nodes 1, 2 and 3 is equal to $C = 2$, hence the rebroadcast probability $P = (0.7/2) = 0.35$, (follow line 14 in Figure 4-7).
- The second rebroadcast is from node 3 with probability $P = 0.35$, since it has the second shortest waiting time. The value of counter *C* for nodes 1 and 2 is equal to 3. So the rebroadcast probability for nodes 1 and 2 is $P = (0.9/3) = 0.23$.

The above steps are repeated for the nodes 5, 6, 7, 8 and 9 until the destination *D* is reached. By showing the above example, it is clearly noticeable that using a proper timer technique can refine the rebroadcast decision by the all *U-RNs*. Table 4-1 shows the timer and value of θ and the value of rebroadcast probability *P*.

Table 4-1 **:** Nodes classification, Timer type, Value of θ and Value of P.

Node ID	θ	**Node Type**	**Timer Type**	**Value of P**
1	190^0	U-RN	$TIMER_{LONG}$	0.23
2	150^0	U-RN	$TIMER_{LONG}$	0.23
3	40	RN	$TIMER_{SHORT}$	0.35
4	30	RN	$TIMER_{SHORT}$	0.7

4.3 Performance Evaluation

The performance and capabilities of the proposed routing discovery schemes are examined and investigated using NS-2.34 as the simulation platform [93]. For each data point in all the figures, at least 30 experiments are used, each one representing different network topology with 95% confidence intervals. The number of nodes in the network was chosen at between 20 to 200 nodes for all scenarios. The nodes are placed in a 1000m X 1000m square area. The random waypoint model [100] is used as the mobility model. In this model, mobile nodes move freely and randomly without boundary restrictions. The application layer at each node generates CBR traffic. Maximum node speed varies between 5m/s to 100m/s.

Due to its high capability in MANETs, AODV routing has been adopted in our experiments. SVAP, AVAP, Blind Flooding (BF), FB [4] and FC [5] have been examined within the underlying AODV routing protocol. In our experiments, we refer to our proposed scheme as SVAP-AODV, AVAP-AODV and we investigate its performance, in comparison with BF-AODV, FB-AODV and FC-AODV.

4.3.1 The Effect of Network Mobility

In this section, we investigate the effect of network mobility on the proposed schemes. In this simulation, we collect the results of the performance comparisons, when the node’s maximum speeds are 5m/s, 20m/s, 40m/s, 80m/s, 100m/s respectively.

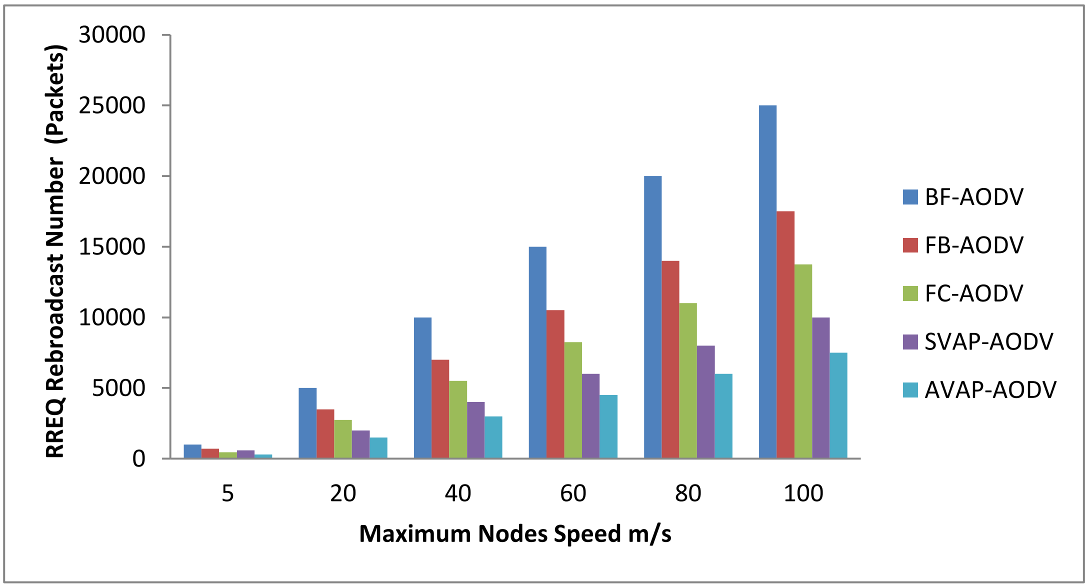

Figure 4-8: Performance of the proposed schemes in terms of RREQ rebroadcast number VS nodes speed m/s.

- **RREQ Rebroadcast Number**

Figure 4-8 shows the routing overhead of AVAP-AODV, SVAP-AODV, FP-AODV, FC-AODV and SVAP-AODV with different node speed, when the number of CBR is set at 10. When the node speed increases, the stability of the existed route between the source and destination is decreased. This can increase the number of invalid routes between nodes. In such circumstances, more RREQ packets are generated and retransmitted in order to re-establish the announced invalid routes. It is clearly noticeable that AVAP-AODV keeps the network stable with less possible number of RREQ packets. For instance, the AVAP-AODV performs better than FP-AODV and FC-AODV as the routing overhead is reduced by approximately 70%, 45% and 30% respectively, compared to BF-AODV.

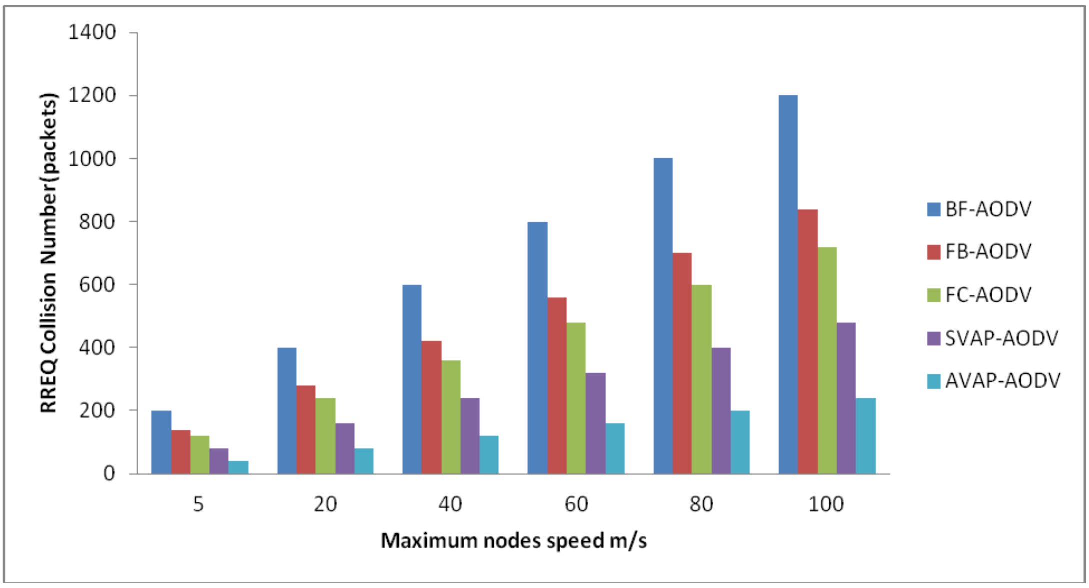

Figure 4-9 : Performance of the proposed schemes in terms of RREQ collision number VS nodes speed m/s.

- **RREQ Collision Number**

The result in Figure 4-9 shows the number of RREQ packet collisions that each scheme incurs. SVAP-AODV incurs less collision compared to FP-AODV, FC-AODV and BF-AODV. The main reason behind this result is that probabilistic awareness of the new proposed schemes can privilege the rebroadcast only to the RN. This will guarantee routing data via the most stable links, which minimises the number of re-initiations of the route discovery phase that require broadcasting a new RREQ packet. As discussed before, as the number of RREQ packets increases, the contention between nodes increases which in turn leads to a higher chance of RREQ packet collisions.

- **Link Stability**

To measure link stability we calculate the number of broken links which occurred during the total simulation time in each scheme. The RERR packet is generated when any node that is part of the route has an invalid link to its neighbours.

In this study, such a node is called *U-RN* and is responsible for sending an RERR packet to inform the source that the current route is broken and a new route discovery session is required. Apparently, the new proposed schemes successfully eliminate the number of *U-RNs*, and thus the number of broken links is reduced as shown in Figure 4-10.

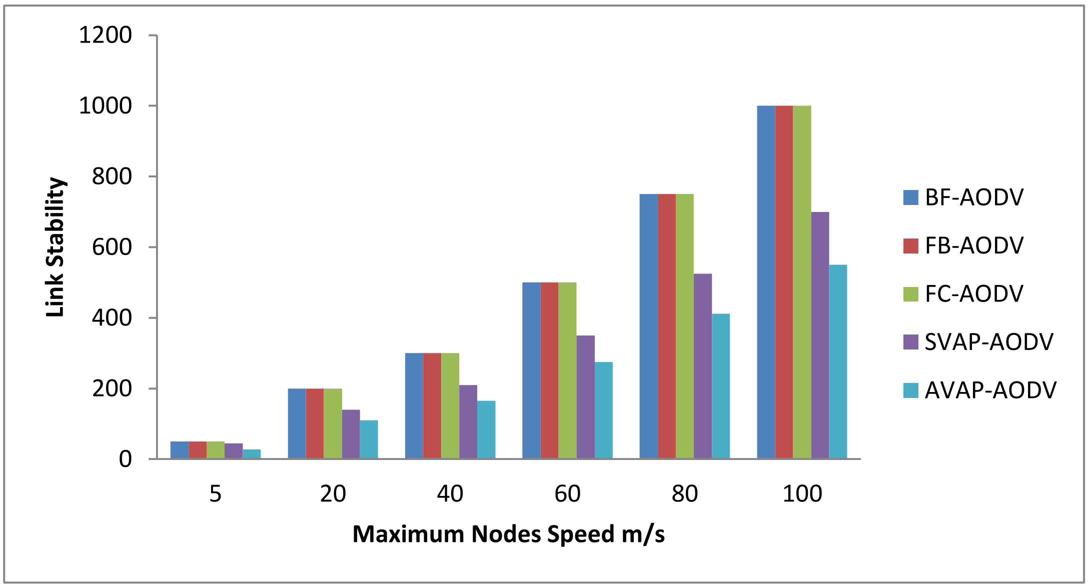

Figure 4-10: Performance of the proposed schemes in terms of Link stability VS node speed.

- **End–to-End Delay**

Figure 4-11 depicts the end-to-end delay of data packets in the five routing protocols for different node speeds. The Figure 4-11 shows as the node speed increases the end-to-end delay of data packets is increased proportionally. This is because the paths between sources and required destinations experience frequent breakages and re-establishment. As a result, the data packets experience a long waiting time in the interface queue until they reach the destination. However, among all maximum node speeds the ASVAP-AODV and SVAP-AODV perform better than FP-AODV, FC-AODV and BF-AODV.

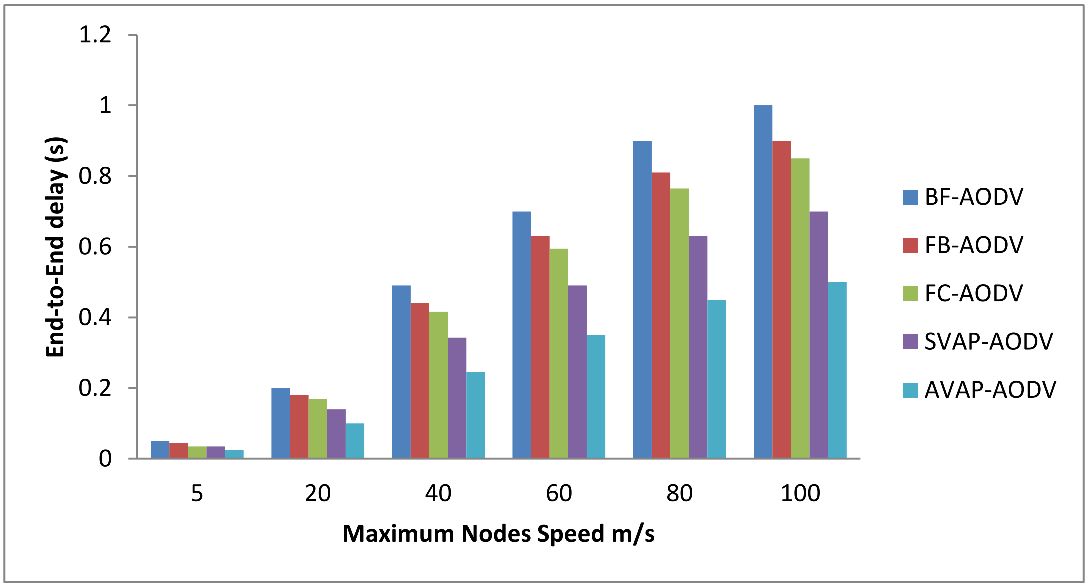

Figure 4-11: Performance of the proposed schemes in terms of end-to-end delay VS nodes speed m/s.

4.3.2 The Effect of Network Density

The network density is a crucial parameter. In these simulation experiments, we evaluate the performance of the proposed schemes under different network density, which can vary from low, medium to high. To adopt the three scenarios of density, we deploy 20 nodes, 40 nodes up to 200 nodes over a 1000m X 1000m square area. Each node has a random maximum speed of 20m/s.

- **RREQ Rebroadcast Number**

Figure 4-12 illustrates the routing overhead incurred by our proposed scheme in comparison with that exhibited by the other schemes. Figure 4-12 shows that as the number of nodes increases the number of RREQ packets increases proportionally. This is a normal behaviour for all of the proposed schemes, since the number of the forwarded nodes increases by including more nodes. However, SVAP-AODV and SVAP-AODV achieves the best performance.

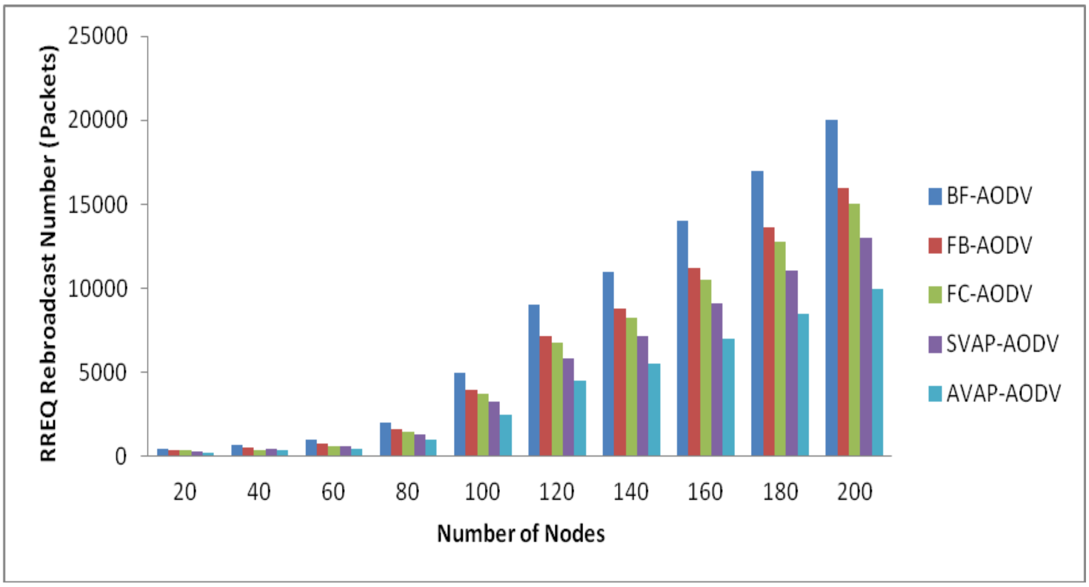

Figure 4-12: Performance of the proposed schemes in terms of RREQ rebroadcast number VS number of nodes.

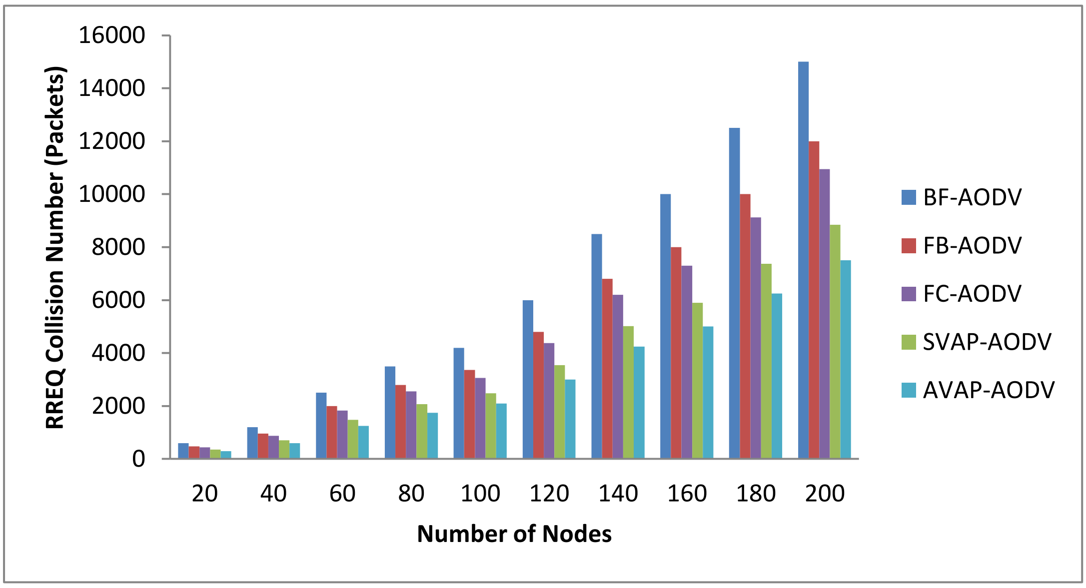

Figure 4-13: Performance of the proposed schemes in terms of RREQ collision number VS number nodes.

- **RREQ Collision Number**

Figure 4-14 depicts the network packet collisions that result from the schemes' performance. The RREQ packet collisions dramatically increase when moving from a low density area to a high density area. This is due to the fact that as the number of nodes increases the number of possible forwarded nodes normally increases. SVAP-AODV and its extension scheme incur less collision in comparison with FP-AODV and FC-AODV; since it is designed with a proper timer, counter broadcast threshold and probabilistic function.

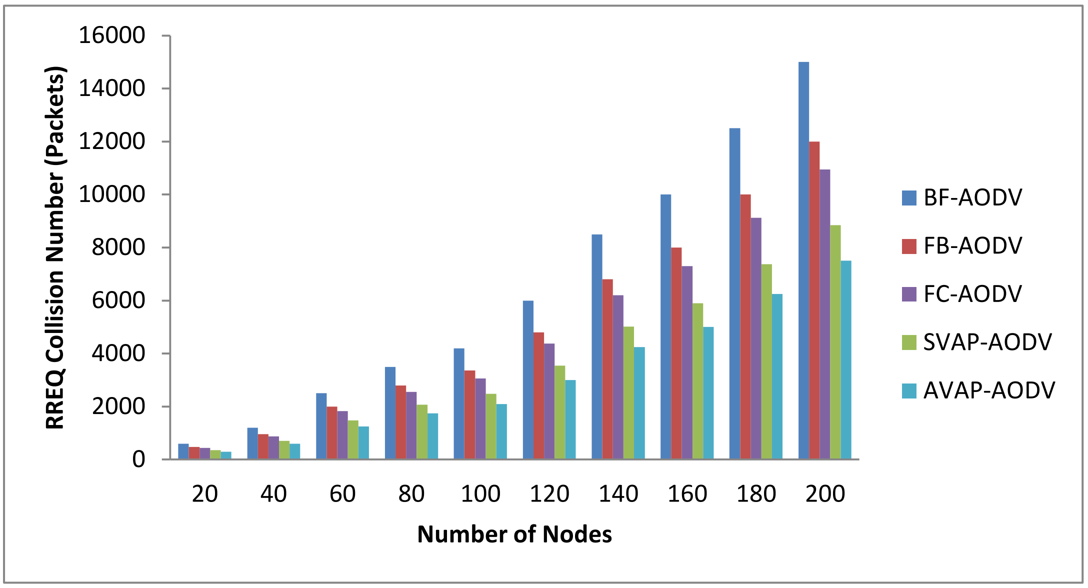

Figure 4-14: Performance of the proposed schemes in terms of RREQ collision number VS number nodes.

- **Link Stability**

Figure 4-15 shows the link stability in terms of the number of broken links within different network densities. According to the results plotted in Figure 4-15, as the number of nodes increases the number of broken links decreases.

This is because the network tends to be stable in a congested area, which forces the nodes to decrease their speed. This is can be noticed in a real life scenario such as vehicles movement on roads. For example during rush hours vehicles move slowly due to traffic congestion. The SVAP-AODV and AVAP-AODV schemes ensure the best performance among all the other traditional schemes.

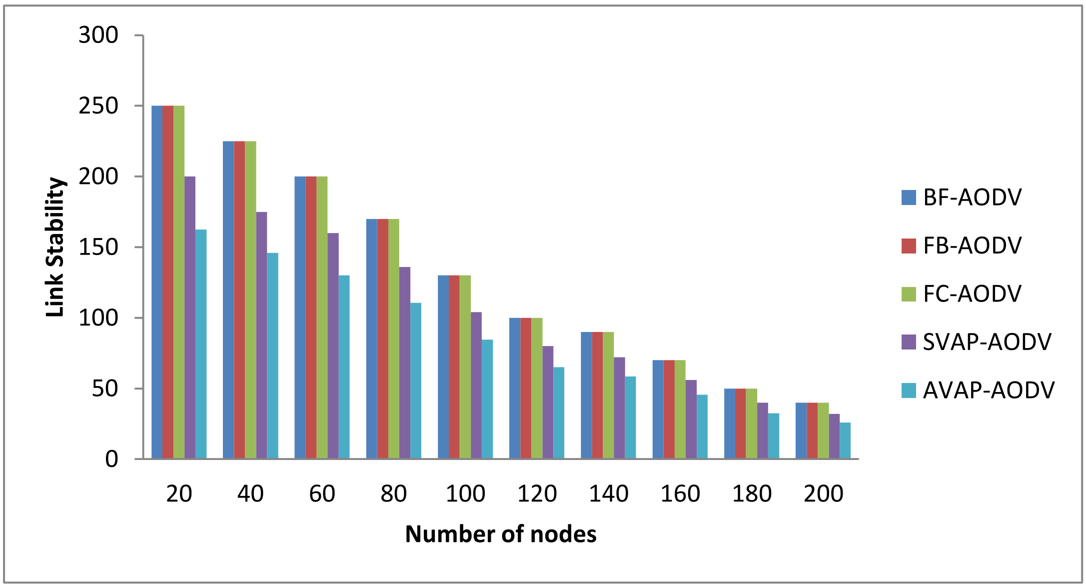

Figure 4-15 : Performance of the proposed schemes in terms of Link stability VS number of nodes.

- **End-to-end Delay**

Figure 4-16 depicts the average end-to-end delay of the proposed schemes. It is obvious from the figure that as the network density increases the propagation delay increases. However, ASVAP-AODV maintains the lowest end-to-end delay compared with FP-AODV, FC-AODV and BF-AODV. For instance, in a dense regime, i.e., 200 nodes the average end-to-end delay is 0.3s, 0.264s, 0.246s and 0.159s for BF-AODV, FP-AODV, FC-AODV and ASVAP-AODV respectively. This is strong evidence of the advantage of both proposed schemes.

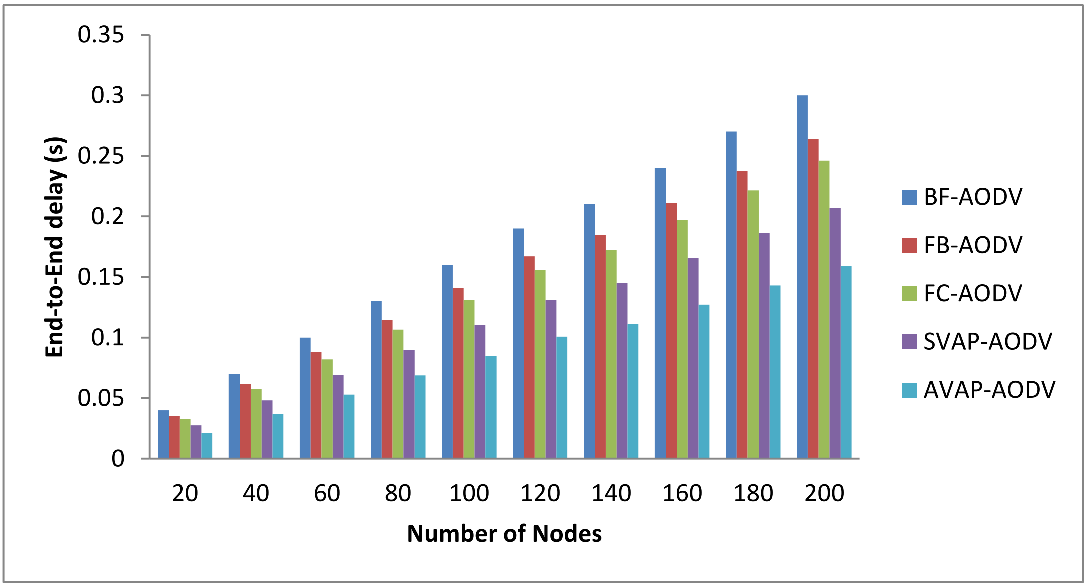

Figure 4-16: Performance of the proposed schemes in terms of end-to-end delay VS number of nodes.

4.4 Conclusion

In this chapter, we proposed new probabilistic routing schemes for MANETs, which overcome the limitations of existing broadcasting schemes. It is shown through extensive simulations that the new proposed schemes outperform BF-AODV, FP-AODV and FC-AODV schemes in different operating conditions and scenarios. Unlike the previous works, our strategy is based on the node velocity vector information to adaptively adjust the rebroadcast probability and categorize the reliability of the nodes accordingly. In this strategy, nodes have been classified into *Reliable Nodes* (*RNs*) and *Un-Reliable Nodes* (*U-RNs*) with respect to the velocity of the sender and the receiver node. Notice that *RNs* that have a similar relative velocity compared to the sender velocity are more stable and more likely to establish network routes. On the other hand, *U-RNs* are those nodes with very different velocities the sender node's velocity. Therefore, any retransmission by *U-RNs* should be suppressed in order to avoid early link failure and decrease the overhead of routing packets.

We applied this velocity vector within AODV protocol and evaluated its performance in terms of different important metrics such as link stability and RREQ packet overhead. The main gain of such schemes is to avoid the route re-discovery phase by the traditional AODV especially at high mobility nodes. The SVAP-AODV scheme can be further enhanced by adding dynamic counter and timer concepts to the mobility aware probabilistic scheme. Therefore, we have extended the SVAP-AODV with AVAP-AODV to overcome the existing shortcomings. Simulation results shows that AVAP-AODV is able to achieve better performance compared to SVAP-AODV in terms of many metrics such route stability.

Research in this chapter and the previous chapter has been dedicated to solving the broadcast storm problem during route discovery in MANETs only. Hence, the focus of the next chapter is dealing with the same problem, but in VANETs.

Chapter 5

A Stable Probabilistic Route Discovery Scheme for Vehicular Ad-hoc Networks

---

The key objective of this chapter is to present a new probabilistic routing scheme for VANETs, and it is organized as follows:

- Explaining in detail the new stable probabilistic route discovery schemes for VANETs, their components and steps.
- Evaluating the performance of the proposed schemes under different network conditions.
- Concluding the chapter and providing a brief summary.

5.1 Introduction

Intelligent Transportation Systems (ITS) are gaining more and more attentions in the recent decade. A common category of applications in these ITS systems is that data about vehicles, drivers and road conditions are reported from vehicles to the ITS system operators for real time traffic control, roads maintenance and new traffic management strategies development. Vehicular networks (VANET) is the main part of ITS, which have attracted significant attention with the vision of vehicular communication being able to provide information regarding traffic condition. Meanwhile, communication and routing concerns from vehicle drives have become a major obstacle that hinders the deployment of such applications.

Recently, many solutions have been suggested to optimize AODV operations in MANETs [10] [38] [70], including the probabilistic solutions that presented in this thesis. Nevertheless, to the best of our knowledge no effort has been made so far to employ probabilistic solutions to optimize AODV operations in a VANET context. Furthermore, probabilistic solutions have been suggested only to reduce the number of unnecessary transmissions by given nodes regardless of their stability.

This chapter attempts to fill the gaps that mentioned above by introducing new stable routing probabilistic schemes, and augmenting them with AODV based VANETs. These schemes are compared with each other in additional to the tradition probabilistic routing schemes, i.e., the Fixed-Counter scheme and Fixed-Probabilistic scheme [5].

The remaining part of this chapter is organised as follows. Section 5.2 describes a new Probabilistic Route Discovery Scheme. Sections 5.3 presents performance results to show the effects of node mobility, and network density on the performance of probabilistic flooding. Finally, Section 5.4 concludes the chapter.

5.2 The New Proposed Schemes

The aim of the proposed scheme is to alleviate the route discovery broadcast problem through finding the most stable routes. Vehicle mobility parameters, such as speed and direction with respect to Source (*S*), are used as a main input for the proposed scheme. Such parameters have a significant impact on the route stability. For instance, a vehicle can only communicate with neighbours that are located within its transmission range. Hence, vehicles that have a low/similar speed can keep a long connection lifetime as they stay close together as long as possible. On the other hand, the link lifetime of vehicles that have a high speed difference could be short and it expires often.

Vehicles moving with the same direction can also build more stable links than those moving in the opposite directions. More details about the new proposed scheme are given below.

5.2.1 Probabilistic Based-Speed Scheme (PBS)

Vehicles that have a low speed difference should assign a high rebroadcast probability, since they move with similar speed and can stay much longer within their transmission range. On the other hand, vehicles that have a high speed difference should assign a low rebroadcast probability, since link brakeage often occurs as they do not stay long within their transmission range. Therefore, the mathematical exponential function is selected to set the probabilistic speed value, as it represents the exact relationship between the value of rebroadcast probability and link stability among vehicles.

Definition 1: *Upon vehicle i receiving an RREQ packet from vehicle j, it checks the packet ID and rebroadcasts with a relative difference speed probability* P_s *between i and j, if the RREQ packet is received for the first time. Otherwise, the packet is dropped.*

Given the relative speed difference S_{ij} between the vehicles *i* and the vehicle *j*, then the probability P_s that each vehicle initializes to forwarding the received RREQ packet is calculated by the following formula:

$$P_s = e^{-\left(\frac{|S_{ij}|}{MAX(S_{ij})}\right)} \tag{7}$$

Assume that the speed of the source vehicle *S* is 100km/h, and it has five neighbouring vehicles: *A, B, C, D* and *E*. Each vehicle moves with speed 20km/h, 40km/h, 60km/h, 80km/h and 100km/h, respectively. The speed difference $|S_{ij}|$ between each vehicle and the source *S* is 80 km/h, 60km/h, 40km/h, 20km/h and 0km/h. Figure 5-1 shows that as the speed difference increases the rebroadcast probability decreases. This means vehicles that have a high speed difference are prevented from constructing routes and vice versa. Beside vehicle speed parameter, vehicle movement direction is also a crucial parameter to determine link stability between vehicles. In general, vehicles moving in the same direction maintain a high level of link stability compared to those moving in the opposite direction. The PSS scheme does not guarantee a high level of stability as vehicles moving in the opposite direction can be part of the route. Therefore the following section discusses a new proposed scheme which overcomes the shortcomings of PSS. Figure 5-1, shows a graph of the rebroadcast speed-probability P_s against speed difference value. Figure 5-2 describes the logical steps of the PPS routing scheme.

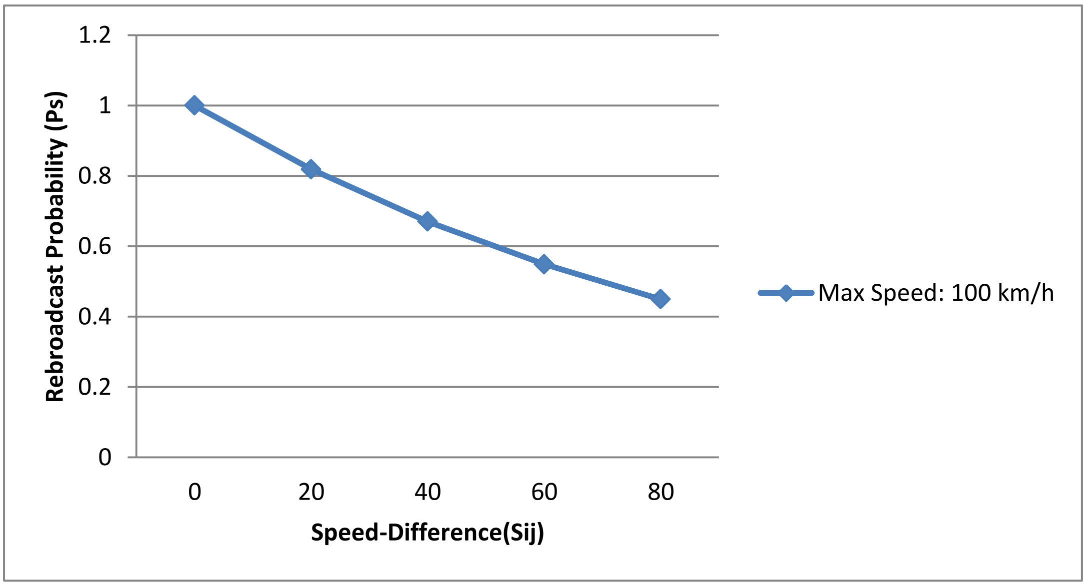

Figure 5-1: Forwarding probability for different speed difference values.

Scheme: Probabilistic BASED SCHEME (PPS)

Input: Speed value for each sender and receiver.
Output: The Rebroadcast Probability Value (Ps)

1:On receiving an RREQ packet at vehicle i from vehicle *j*
2:Calculate a relative difference speed probability *Ps* between vehicle *i* and vehicle *j*
3: IF (the RREQ packet is received for the first time) = **TRUE**
4:Forward the RREQ with a probability *Ps*
5: ELSE
6:DROP_RREQ()
7: END_IF

Figure 5-2: Logical steps of the PPS scheme.

5.2.2 Probabilistic Based-Speed and Direction Scheme (PB-SD)

Assigning vehicles different waiting times according to the vehicle speed and direction is very important in order to maintain the most stable route between source and destination pairs. Furthermore, the simultaneous broadcast problem which is incurred by the simple flooding approach can be avoided.

Definition 2: *Upon vehicle i receiving an RREQ packet from node j, it initializes a relative Timer speed T_s between vehicle i's speed and vehicle j's speed, it initializes Probability P_i, Sets a Counter C_n, and it counts all the same RREQ packets within the period T_s. Then after T_s expiries, vehicle i rebroadcasts with a relative counter probability P_c, if it is moving in the same direction as the source vehicle. Otherwise, T_s is extended according to the number of packets received C_n.*

Given the relative speed difference between $|S_{ij}|$ vehicle *j* and vehicle i, the average maximum speed S_{MAX}, and the number of RREQ copies C_n, then the time T_{si} that each vehicle has to wait before rebroadcasting is calculated by the following formula:

$$T_s = \begin{cases} 1 - e^{-\left(\frac{|S_{ij}|}{MAX(Sij)}\right)} \times t,\ d_i = d_j \\ C_n \times (1 - (e^{-\left(\frac{|S_{ij}|}{MAX(Sij)}\right)} \times t)),\ d_i \neq d_j \end{cases} \quad (8)$$

The waiting time is designed for each vehicle in this scheme, in such a manner that the receiver is assigned a longer time if it moves in the opposite direction to the source vehicle and at a different speed compared to its neighbours. Then, the Counter *C* of the vehicles that have a high speed difference stores more duplicated packets than those that have a similar speed. The link between vehicles that move in the opposite direction does not last long and is likely to break early. Therefore, all the vehicles moving in the opposite direction extend the timer *Ts* for each duplicated RREQ packet received, to maximise the probability for each vehicle to receive more duplicated RREQ packets, thus decreasing their probability of participating in the routing discovery process. The rebroadcast probability decision P_c at each vehicle is taken, based on the ratio of the Initial rebroadcast probability *Pi*, and the total number RREQ packets C_n. *Pc* is calculated as the following:

$$P_c = P_i/C_n \quad (9)$$

Where P_i is the initial rebroadcast probability and is selected between the interval value of [0.7, 0.9]. The value of 0.7 is used in [4] [5], and the value of 0.9 is selected to prevent all nodes to flood the received packet. Figure 5-3 shows the logical steps of the proposed scheme, and Figure 5-4 shows a graph of the timer speed value against the speed difference value.

PB-SD : Probabilistic Based-Speed and Direction Scheme

```
1:IF (RREQ Packet Received for the First Time) = TRUE {
2:     Initialize A relative Timer Speed T_S
3:     Initialize A Probability P_i
4:    END_IF
5:WHILE (T_S != Expired) {
6:Get_Number _Copy () {C_n=C_n+1}
9:     END_WHILE
7: IF (The Same RREQ Packet Received From Different Direction) = TRUE{
8:   Timer_Extension  (){T_S = T_S x (C_N)}}
9:   END_IF
10:  END_WHILE
11: P_C ← p_i/C_n
12: RN←Random_Number (0,1)
13: IF RN< P_C = TRUE
14: Rebroadcast_RREQ()
15:  ELSE
16:   DROP_RREQ()
17: END_IF
```

Figure 5-3: Logical steps of the PB-SD scheme.

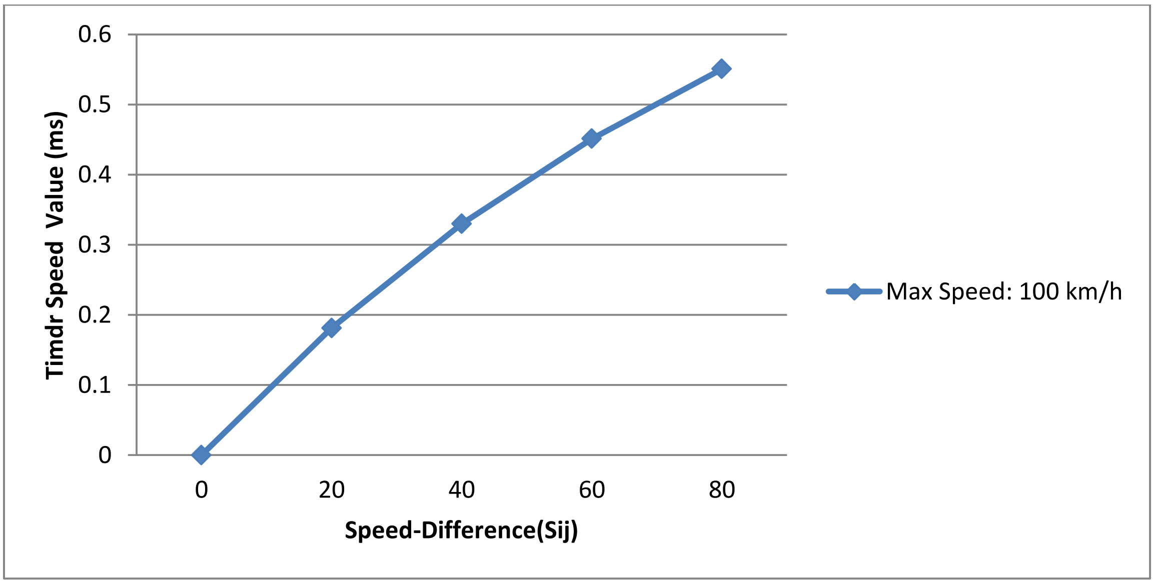

Figure 5-4: Timer speed value for different speed difference values.

5.2.3 Illustrative Example

The following simple example illustrates the PB-SD scheme.

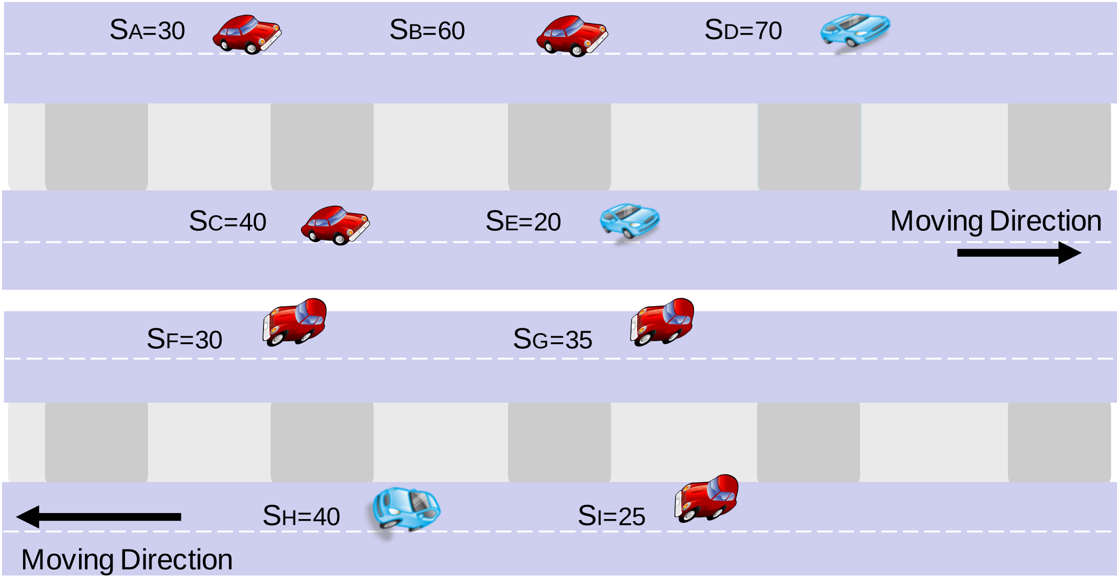

Figure 5-5: Illustrative example of the proposed schemes.

In the source vehicle *A* needs to send a data packet to the vehicle *D*. vehicle *A* sends an RREQ packet and moves with speed S_A = 30km/h. Each vehicle *B* and *C* upon receiving the first RREQ copy from vehicle *A*, calculates the speed difference, determines its direction with regard to the source vehicle (i.e. vehicle *A*), and initialise a Counter C_n with a value equal to one. The receiver vehicles *B* and *C* initialise a proper timer T_s according to the speed difference, i.e., a small-timer or a long-timer, if the receiver is moving in the same direction as the source vehicle *A*. Hence, vehicle *B* initialises a long-timer compared to vehicle *C* that initialises small-timer. The second retransmission is from vehicle *C* since its timer expires first. The value of the rebroadcast probability for vehicle *C* is equal to 1.0 by using equation (3). Vehicle *B* increments its counter to be equal to two (i.e. C_n= 2), while the vehicles *E*, *F* and *G*, receive an RREQ packet for the first time.

Each vehicle initializes C_n with value equal to one, determines its speed difference and direction with regard to vehicle *C*. The third retransmission is from vehicle *E*, with probability $P_c = 1.0$. The value of each counter after *E's* transmission at the vehicles *B*, *F* and *G* is equal to *C*=3, *C*=2 and *C*=2, respectively. Vehicles *F* and *G* extend their timer as they move in the opposite direction to vehicle *A*. By applying, the same methodology on the reset of the other vehicles, vehicles *B, F* and *G* are prevented from rebroadcasting with a probability equal to 0.3, 0.5 and 0.5 respectively. Vehicles *H* and *I* could be not involved in the route discovery process as the RREQ packet could be suppressed at vehicles *F* and *G*. Therefore, it is clear that applying the probabilistic concept with the assistance of the speed parameter for each vehicle, helps to build the most stable end-to-end route. In Figure 5-5, the best possible route from the source vehicle *A* to the destination vehicle *E* is through vehicles *C* and *D*.

5.3 Performance Evaluation

In this study, we examined the proposed schemes under two different scenarios. In the first scenario, we measured the performance of AODV-PB-SD, AODV-PSS and AODV-BF for different network densities varying from low density to high density. However, in the second scenario, we fixed the network density at a certain density and varied the vehicle speed parameter from low speed to high speed. In this study, we used Network Simulator NS-2.34 [93], and network City Mobility (CM) generator [103], to evaluate the performance of the proposed schemes. CM is used to create the Manhattan Grid Model layout similar to a city environment Vehicles are placed on an area of 1000 m x 1000 m, and for 15 minutes simulation time.

The simulation area contains 40 blocks of uniform size, which represents the distance between streets (meter). The number of vehicles for each simulation varied from 20-200 vehicles.

Each street has four lanes and vehicles move in both directions with turning possibility at the intersection. Four lanes were selected to test the proposed schemes under a large road width. Semaphores are distributed randomly on the streets with 20/s the maximum time delay that a vehicle can be stopped. Vehicle density and speed vary from high density and low speed as in the downtown area, to low density and high speed as in the outskirts.

Table 5-1 : Summary of the parameters used in the simulation experiments.

Parameters	Value
Number of vehicles	20-200 vehicles
Number of lanes	4 lanes
Area	1000 m x 1000 m
Downtown speed	25km/h-60km/h
Outskirts speed	70km/h-100km/h
Pause time	20/s
Transmission range	250m
Number of blocks	40 blocks
Mobility model	City Mobility
Routing protocol	AODV
Transmission Range	250 m
Simulation Time	900s
Number of trials	30 trials
Confidence interval	95%

In this simulation, we created one downtown; vehicles crossing it move with a random speed between 25km/h and 60km/h while vehicles moving in the outskirts move with a random speed between 70km/h to 100km/h. Vehicles engage in communication transmitting within a standard reliable transmission range of 250 m radius. We evaluate the performance of the proposed schemes within the context of AODV routing protocol, and we refer to each scheme as AODV-PSS and AODV-PB-SD.

We compared the impact of both schemes with to the traditional Flooding AODV protocol AODV-BF. A summary of the simulation parameters is given in Table 5-1.

5.3.1 The First Scenario: Effect of Vehicle Mobility

Figures from number 6 to number 9 display the experiment results of running AODV-PB-SD and AODV-PSS against AODV-BF. The network density is set at 70 vehicles randomly distributed on the network area of 1000 m x 1000 m. Vehicles in the downtown area move with random speed between 25km/h and 60km/h, while vehicles in the outskirts move with random speed between 70km/h to 100km/h.

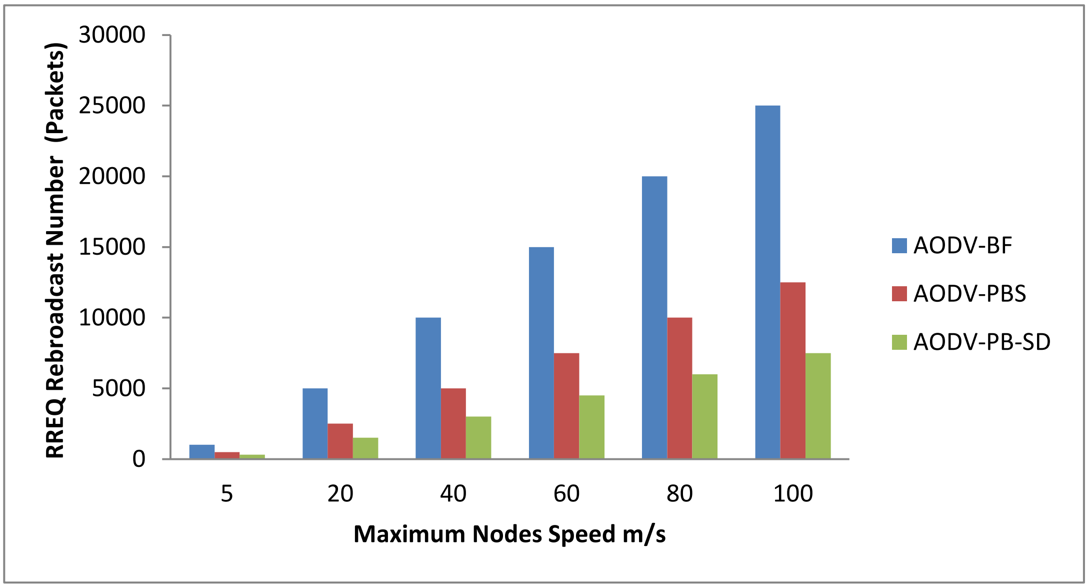

Figure 5-6: Performance of the proposed schemes in terms of RREQ Rebroadcast Number vs. number of nodes.

- **RREQ Rebroadcast Number**

Figure 5-6 shows the routing overhead of AODV-PB-SD, AODV-PSS, and AODV-BF with different node speeds. In general, RREQ packets increase when the speed of vehicles increases, due to increase the number of broken links. In such circumstances, more RREQ packets are generated and retransmitted in order to re-establish the announced broken link.

It is clearly noticeable in the Figure 5-6 how the proposed schemes keep the network stable with a lower possible number of RREQ packets. For instance, the AODV-PB-SD performs better than AODV-PSS, and AODV-BF. For example, at max speed 80 m/s, the routing overhead generated by AODV-PB-SD, AODV-PSS, and AODV-BF is 6000, 10000, and 20000 respectively. It is clear that the saving in RREQ packets in AODV-PB-SD compared to AODV-BF is beyond 50%.

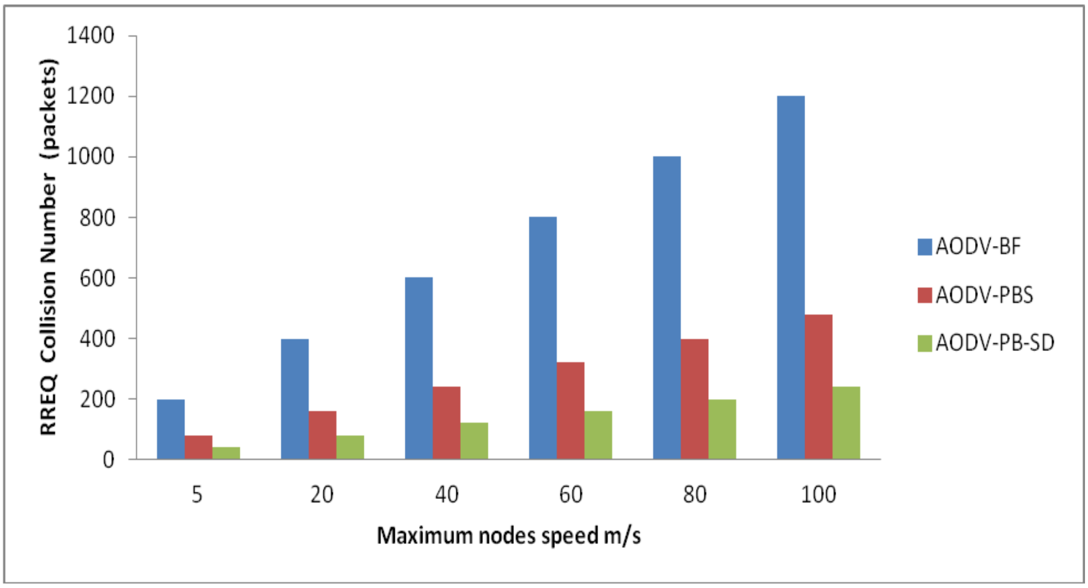

Figure 5-7: Performance of the proposed schemes in terms of RREQ collision number vs. maximum nodes speed.

- **RREQ Collision Number**

Figure 5-7 depicts the average RREQ collision number for each of the proposed schemes against the maximum node speed. The results in the show that as the node speed increases the average RREQ collision number increases.

This is due to the increasing number and frequency of broken routes, which requires the vehicles to generate new RREQ packets and disseminate them throughout the network.

For example, when the maximum node speed is increased from 5m/sec to 100m/sec, the average RREQ collision number of AODV-BF, AODV-PBS, and FPAODV-PB-SD is increased from 200 to 1200 packets, 80 to 480 packets, and 40 to 240 packets respectively.

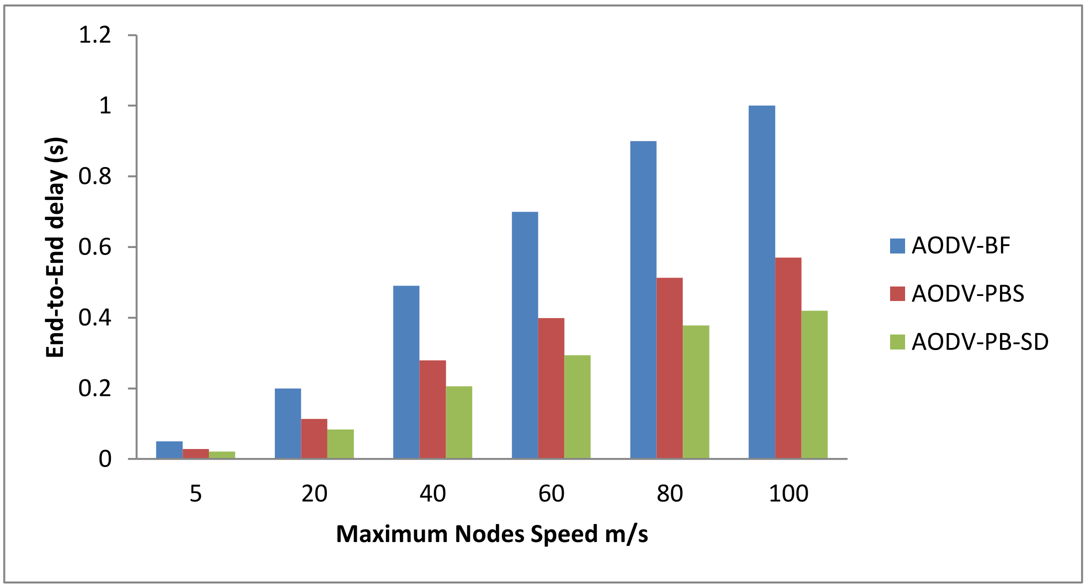

Figure 5-8: Performance of the proposed schemes in terms of end-to-end delay vs. maximum nodes speed m/s.

- **End-to-end Delay**

Figure 5-8 shows the end-to-end delays of data packets when vehicle speed is varied. It is clear that as the vehicle speed increases, the end-to-end delay of data packets increases. This is due to the frequent breakage of the path between sources and required destinations. As a result, the data packets experience long waiting times in the interface queue until they have reached the destination. It can be seen from Figure 5-8 that the use of AODV-PB-SD and AODV-PSS results in less end-to-end delay compared to AODV-BF.

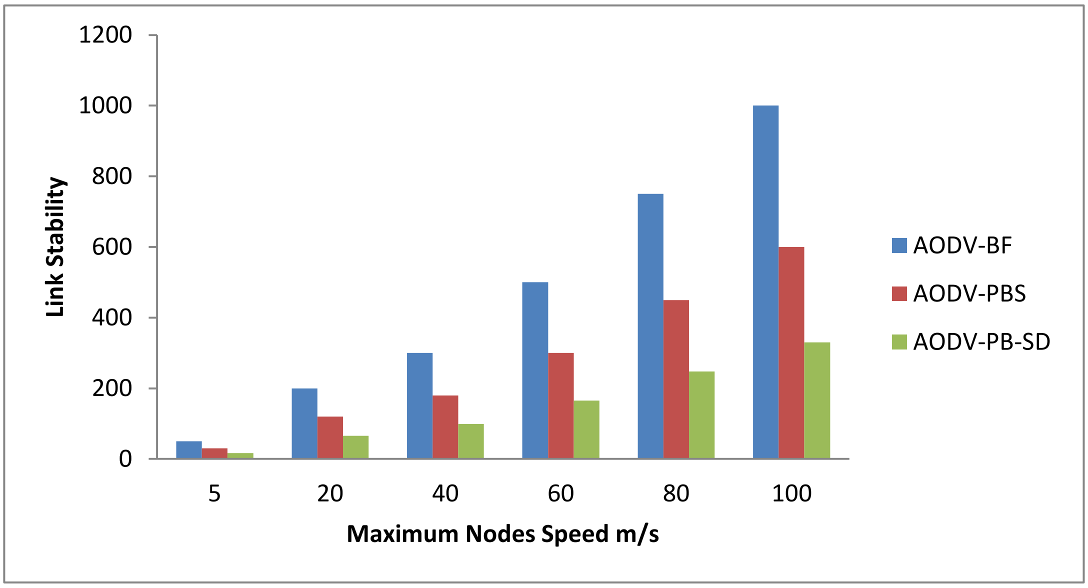

Figure 5-9: Performance of the proposed schemes in terms of Link stability vs. maximum nodes speed m/s.

- **Link Stability**

Figure 5-9 shows how the average number of broken links increases when the vehicle speed increases. We notice that BF-AODV incurs the highest number of broken links compared to the other schemes. This is due to the blind selection of routing nodes regardless of their stability. On the other hand, the AODV-PB-SD incurs the lowest number of broken links and privileges routing to the most stable nodes only. For example the number of broken links that BF-AODV produces at max speed 100km/h is 1000 broken links, while at the same max speed this amount is reduced to 330 broken links when AODV-PB-SD is deployed.

5.3.2 The Second Scenario: Effect of Vehicle Density

Figures from number 10 to number 13 display the performance results of comparing AODV-PSS and AODV-PB-SD protocols against AODV-BF protocols using networks with different vehicle density. The number of vehicles is varied from 25 to 150 with a minimum speed of 25km/h and a maximum speed of 60km/h.

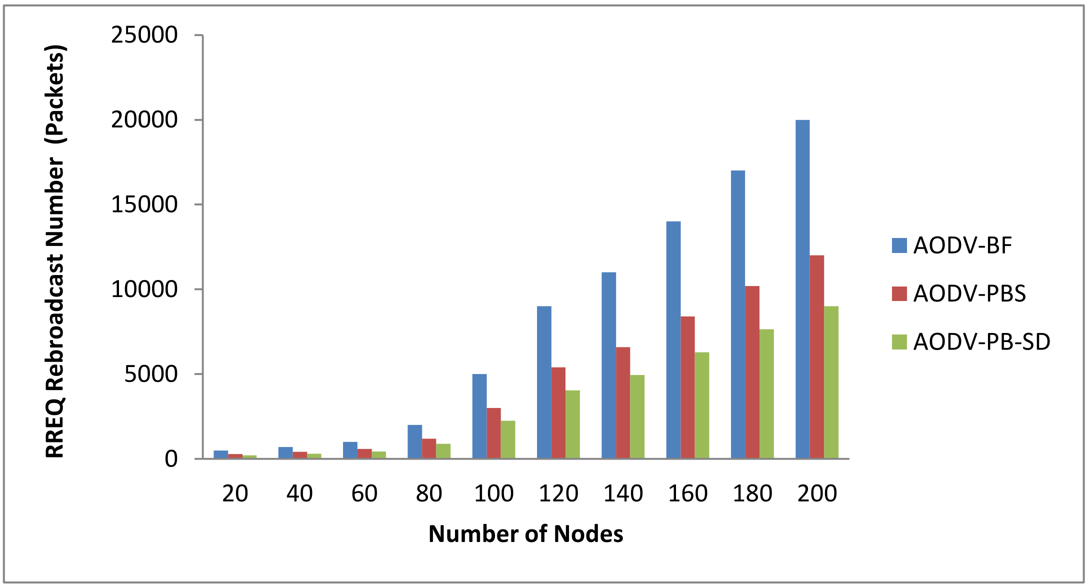

Figure 5-10: Performance of the proposed schemes in terms of RREQ rebroadcast number vs. number of nodes.

- **RREQ Rebroadcast Number**

The routing overhead measures the total number of RREQ packets broadcasted at each vehicle during the simulation time. Figure 5-10 shows the routing overhead generated by each scheme at different network densities. Obviously, as the number of vehicles increases the number of RREQ packets also increases proportionally. The performance of both AODV-PSS and AODV-PB-SD protocols outperforms the performance of AODV-BF protocol. This is due to the ability of the proposed schemes to suppress the unnecessary retransmissions from the unstable vehicles such as those moving in the opposite direction or those which have high speed deference.

- **RREQ Collision Number**

Figure 5-11 shows the relationship between the number of vehicles and number of packet collisions. It is obvious that the collision rate for each scheme increases as the number of vehicles increases. For instance, when the network density is low (e.g. 40 vehicles), the number of RREQ collisions is 1200, 756 and 600 for AODF-BF, AODV-PBS and AODV-PB-SD respectively.

In a relatively dense network (e.g. 200 vehicles), the number of RREQ collisions is 15000, 9450 and 7500 for AODF-BF, AODV-PBS and AODV-PB-SD respectively.

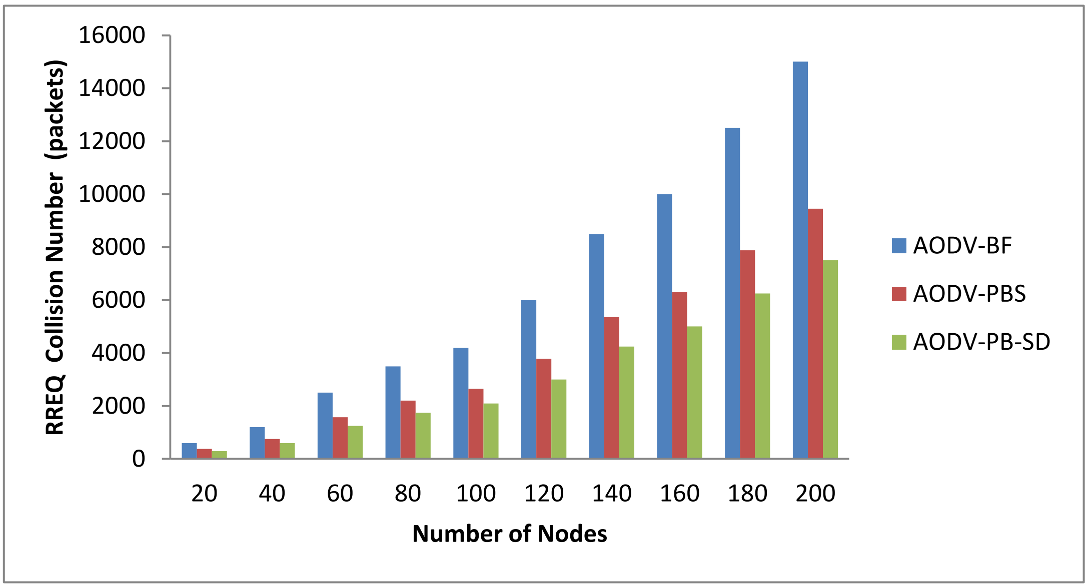

Figure 5-11: Performance of the proposed schemes in terms of RREQ collision number vs. maximum nodes speed m/s.

- **Link Stability**

Link stability measures the result of the number of broken links between routing vehicles by running each protocol under different vehicle densities. According to the results of Figure 5-12, as the number of vehicles increases the number of broken links decreases. This is because the network tends to be stable in a congested area, which forces the vehicles to decrease their speed. This can be noticed in the downtown area where vehicles move slowly due to high traffic congestion. AODV-PB-SD protocol ensures the best performance in terms of minimum number of broken links compared to AODV-PSS and AODV-BF protocols. For example, the number of broken links is reduced by about 37% and 65% in AODV-PB-SD and AODV-PSS respectively compared to AODV-BF.

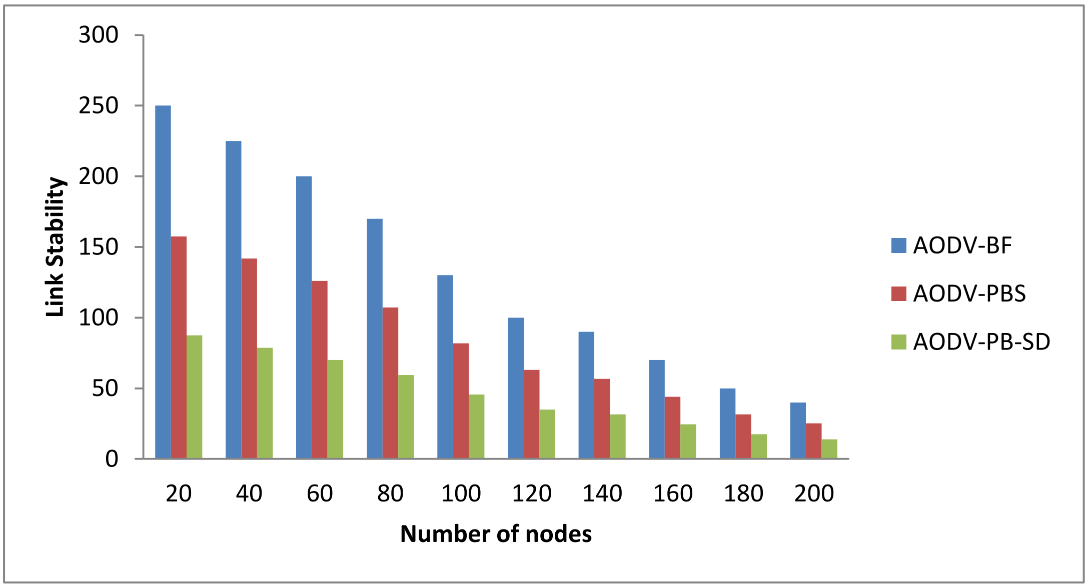

Figure 5-12: Performance of the proposed schemes in terms of Link stability vs. number of nodes.

- **End-to-end delay**

Figure 5-13 shows the performance of the three protocols with regard to the end-to-end delay metric under different network densities. In sparse networks, communication between vehicles is very difficult as the RREQ packets fail to reach surrounding neighbours, where the vehicles connectivity is very poor. On the other hand, the RREQ packets in dense networks also fail to reach surrounding neighbours due to the increased probability of channel contention and packet collisions. For both cases, the travelling time of the data packets between source and destination increases. It is shown in Figure 5-13, the AODV-BF protocol has the poorest delay performance compared to the AODV-PSS and AODV-PB-SD protocols in dense networks. This is partly due to the fact that the data packets in the AODV-BF could be routed through unstable routes, which experience frequent link breakage. Therefore, vehicles buffer the data packets for extra time in the interface queue until repairing the broken link.

Furthermore, extra routing overhead is required for the routing maintenance phase; which increases the number of RREQ packet contentions and collisions, preventing them from reaching the required destination. As a result, the time taken to send the data packet between the source and destination increases. On the other hand, data packets in AODV-PB-SD are routed through the most stable routes, which enable them to reach the destination in one routing session without needing to undergo repairing or buffering process.

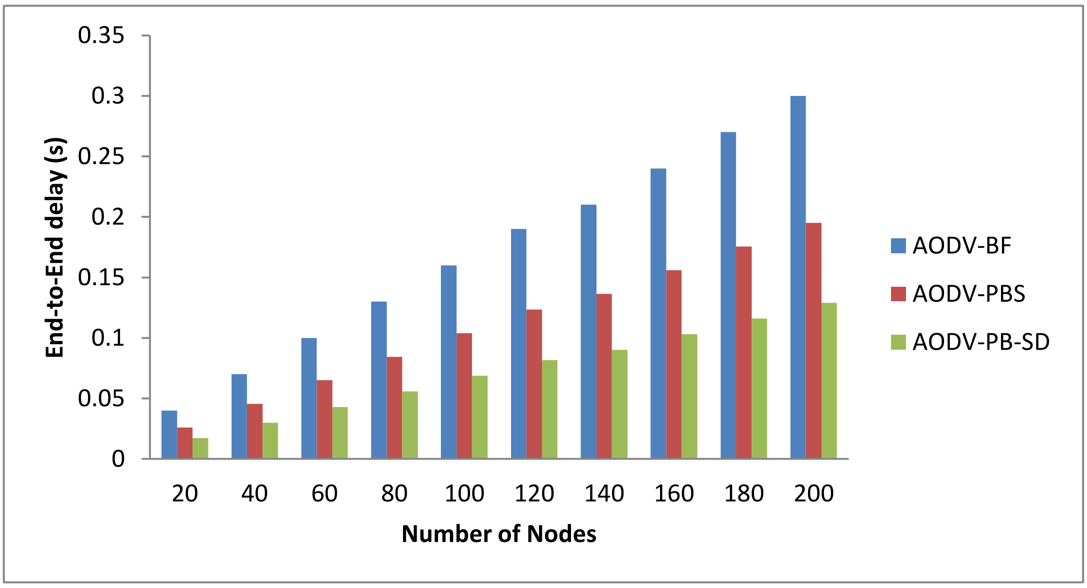

Figure 5-13: Performance of the proposed schemes in terms of end-to-end delay vs. number of nodes.

5.4 Conclusion

In this chapter, we have investigated the broadcast problem and routing task in VANETs. We have proposed new AODV-PB-SD and AODV-PSS routing schemes, to mitigate the broadcast storm problem during the routing discovery process and provide stable link connectivity between vehicles in VANETs.

City Mobility generator was adopted to evaluate the performance of the proposed schemes, considering a wide range of parameters such as vehicle velocity, pause time and density. We have conducted intensive simulation experiments and our results confirm the superiority of the AODV-PB-SD and AODV-PSS schemes over the well-known existing works. Simulation results show the scheme’s effectiveness in terms of high link stability, minimum end-to-end delay, and minimum routing overhead. For instance, when the effect of vehicle mobility on the performance of the schemes has been tested, the number of broken links that BF-AODV produces at max speed 100km/h is 1000 broken links, while at the same max speed this amount is reduced to 330 broken links when AODV-PB-SD is deployed. On the other hand , when the performance of the schemes are tested under different network densities, the number of broken links is reduced by about 37% and 65% in AODV-PB-SD and AODV-PSS respectively compared to AODV-BF.

The lessons learned in this study will open a new door towards optimizing the routing and broadcasting communication in next generation VENETs. We believe that the obtained results have practical significance for VANETs designers to develop broadcast based applications with prescribed degrees of coverage and connectivity.

Chapter 6

Conclusions and Future Work

6.1 Introduction

Mobile Ad-hoc networks (MANETs) have been gaining tremendous attention owing to the advances in wireless technologies which have accompanied many applications. However, there are still a number of issues in MANETs which require further investigations and efficient solutions. Out of these issues, broadcasting in MANETs has been a major problem for both industry and the research community. The

Broadcast communication (or one-to-all communication) is one of the most primitive collective capabilities of any network. However, it is also central to many important group-based applications, and fundamental to the implementation of other group communication-based operations. Furthermore, broadcasting is widely used to send information messages between nodes in many applications such as real-time applications including online TV, distance learning and gaming and so forth. For instance, broadcasting warning messages between cars on the roads about road accidents or weather information. Broadcast communication is also usually required to disseminate a message to all the nodes of a network. This operation is essential in MANETs to distribute necessary information and ensure efficient control and coordination over the network nodes. Evidently, broadcasting reduces the cost of communication compared to sending unicast packets multiple times. Route discovery is a cornerstone operation in many Ad-hoc routing protocols that use [3] [4] broadcasting to set up a route between the source and its destination(s).

One of the primitive yet widely deployed methods of implementing the broadcast is Simple Flooding (SF) [5]. In this approach, each node 'floods' the network with the message that has been received, in order to guarantee that other nodes in the network have been successfully reached. Although flooding is simple and reliable, it consumes network resources, as it floods the network with a large number of redundant packets, that forces nodes to compete on the same shared wireless medium. This phenomenon is well-known in MANETs and VANETs as the so-called *Broadcast Storm Problem* (BSP) [5].

VANETs can play key roles in public service such as police or emergency recovery units. Examples of this category are the support of emergency vehicles by virtual sirens or signal pre-emption capabilities. By using these applications, emergency vehicles can reach their destination much faster than today. The applications that can benefit from our research outcomes of this thesis can be divided into two main categories, namely, Safety applications and non-safety applications. Safety applications are considered as the typical and most desirable group of applications for VANETs with direct impact on road safety. This usually requires efficient communication algorithms to facilitate these applications. Non-safety applications, here the focus is on delivering services to customers, automation of vehicle-related tasks or payment applications, such as download of music, fleet management, simpler vehicle maintenance, or payment for parking or road usage.

6.2 Summary of the Results

This thesis has proposed new probabilistic route discovery schemes for routing protocol in MANETs and VANETs, to suppress the broadcast storm problem that is associated with the primitive routing process-based simple flooding scheme in AODV protocol.

The main contributions made by this thesis are organized as follows:

- Firstly, a new Probabilistic Distributed Route Discovery Scheme (PDRD) is proposed for MANETs to overcome the shortcomings of the existing traditional probabilistic routing schemes. In the PDRD scheme, when a node receives an RREQ packet it initializes a density timer and a probabilistic density value according to the global and the local node density information. The mathematical exponential function is used in this scheme to determine the value of the timer and the probability for each node dynamically. These values are also adjusted every time the node receives a duplicated RREG packet. The timer value is extended and the next rebroadcast probability is reduced. This methodology can help to eliminate the number of unnecessary retransmissions.
- Extensive simulation experiments have been run to evaluate the performance of the PDRD under different network conditions. Ns-2.34 is used to carry out the results and the random way point model is adopted to represent the network topology. The PDRD scheme is compared with a recent counterpart scheme namely the Hybrid Probabilistic Counter scheme (HPC), and Simple Flooding (SF) is used as the baseline to compare both schemes. All of the schemes are augmented with a well-known MANETs protocol, namely AODV. Network density and network mobility scenarios are considered in the experiments to test the performance of the schemes with different metrics. Simulation results show the superiority of the PDRD scheme compared to the HPC and SF schemes.
- For example, in a dense network the collision rate of AODV-PDRD is reduced by approximately 45% compared to AODV-SF and 25% compared to AODV-HPC.

  The RREQ rebroadcast number of AODV-PDRD is reduced by approximately 65% and 35% compared to AODV-SF and AODV-HPC respectively.

- Secondly, a new Simple and Advance Velocity Aware Probabilistic (SVAP) and (AVAP) route discovery schemes are proposed for MANETs to utilize probabilistic ideas in the routing stability concept. This scheme categorizes the nodes according to their stability into reliable nodes and unreliable nodes. A reliable node is considered to be a stable node as it moves approximately with the same direction and speed as the sender node. Such nodes can keep a connection for longer and with less frequent link breakages. On the contrary, an unreliable node is considered to be unstable node as it moves in a different/opposite direction and with a different speed compared to the sender node. The connection life time of this node is very short and it disconnects early. The probabilistic idea helps to privilege transmission to the reliable node and to restrict transmission to the unreliable node. To achieve this, a high rebroadcast probability value is assigned to the reliable node and a low rebroadcast probability is assigned to the unreliable node.
- To evaluate and compare the performance of the SVAP and AVAP schemes, numerous simulation experiments have been conducted under different network conditions. Existing implementation of the AODV has been modified in order to incorporate SVAP and AVAP schemes. Link stability is the most important metric that has been considered in the analysis along with other metrics such as end-to-end delay and routing overhead. Simulation results show that SVAP-AODV and AVAP-AODV achieve a high level of stability with minimum end-to-end delay and routing overhead compared to BF-AODV, FB-AODV and FC-AODV.

For instance, link stability, i.e., number of broken links for each scheme BF-AODV, FB-AODV, FC-AODV, SVAP-AODV and AVAP-AODV at maximum node speed 100km/h is 100, 1000, 1000, 1000, 700, 550, respectively.

- Additionally, while most routing probabilistic solutions, including our proposed solutions have been suggested for MANETs, the final contribution of this thesis is to handle the routing issue in a VANETs environment. Toward this end, stable probabilistic route discovery schemes are proposed for VANETs. Because the traditional version of AODV is not suitable for VANETs, AODV incorporates the new proposed schemes to make it workable under VANETs conditions. The first scheme is called Probabilistic Based-Speed Scheme (PBS), which privileges the routing option to the vehicles that move with relatively similar speed regardless to their directions. The second scheme is called Timer Speed-Direction Scheme (PB-SD), which considers both vehicles' direction and speed parameters to select the most stable routing vehicles.
- To evaluate the performance of the PBS-AODV and PB-SD-AODV within a similar VANETs environment, the City Mobility (CityMob) model [103] generator is used in this study. The performances of PBS and PB-SD are compared to each other and blind flooding is used as a baseline to compare both schemes. The performance impacts on several system parameters such network mobility and network density have been examined. The simulation results have shown that PB-SD-AODV scheme has the best performance, compared to PBS-AODV and BF-AODV schemes respectively. For instance, the AODV-PB-SD performs better than AODV-PSS, and AODV-BF. For example, at max speed 80 m/s, the routing overhead generated by AODV-PB-SD, AODV-PSS, and AODV-BF is 6000, 10000, and 20000 respectively.

It is clear that the saving in RREQ packets in AODV-PB-SD compared to AODV-BF is beyond 50%.

6.3 Directions for Future Work

During the course of this research, many interesting issues and problems have appeared which require further research and investigation. They are briefly summarized below:

- In this work, the performance of all the proposed schemes has been evaluated with the assistance of existing AODV protocol under ns-2.34 directory. It would be desirable if other reactive protocols such as DSR [52] and Ad-hoc On-demand Multipath Distance Vector (AOMDV) [87] are considered in the performance evaluation of the proposed schemes.
- In chapters three and four, the Random Way Mobility model is considered to test and evaluate the performance of the PDRD scheme and VAP schemes. Recently, several different mobility models have been designed for different purposes [98, 99, 100]. For instance, the Group mobility model which simulates a battle field environment [98], and the community mobility model which represents human movements within communities and between different communities [99]. A further investigation would be to evaluate the performance of the PDRD scheme and VAP schemes for such mobility models.
- In chapter five, the performance of PBS-AODV and PB-SD-AODV schemes has been evaluated within a city environment by using the City Mobility (CityMob) model [103] generator only. It becomes more interesting if a highway environment is considered in the simulation experiment to discover behaviour of the proposed schemes.

- Furthermore, the performance of the proposed schemes can be examined by using other VANETs mobility generators such SUMO [101] and VanetMobiSim [102].
- In this thesis, CBR traffic that relies on UDP connections is used to evaluate the performance of the all the proposed schemes. It would be interesting to investigate the schemes' behaviour under different patterns such as VBR traffic that relies on TCP connection.

References

[1] Imrich Chlamtac A , Marco Conti B , Jennifer J. -n. Liu C,” Abstract Mobile Ad-hoc Networking: Imperatives and Challenges,” *Ad-hoc Networks Journal*, vol.1, no.1, pp.13-46, July, 2003.

[2] C.-K. Toh, *Ad-hoc Mobile Wireless Networks, Protocols and System*. Prentice-Hall, New York, 2002.

[3] C. Toh, “Future Application Scenarios for MANET-Based Intelligent Transportation Systems,” *Proceeding of the Future Generation Communication and Networking (FGCN)*, vol. 2, pp. 414–417, December, 2007.

[4] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, “The Broadcast Storm Problem in a Mobile Ad-hoc Network,” *Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking (MobiCom)*, pp. 151–162, 1999.

[5] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, “The Broadcast Storm Problem in a Mobile Ad-hoc Network,” *Wireless Networks Journal*, vol. 8, pp. 153–167, 2002.

[6] Y. L. Morgan, “Managing DSRC and WAVE Standards Operations in a V2V Scenario,” *International Journal of Vehicular Technology*, vol. 2010, pp. 1–19, April, 2010.

[7] S. Grafling, P. Mahonen, and J. Riihijarvi, “Performance Evaluation of IEEE 1609 WAVE and IEEE 802.11p for Vehicular Communications,” *Proceeding of 2nd International Conference on Ubiquitous and Future Networks (ICUFN)*, pp. 344 –348, June, 2010.

[8] L. J. Miller, “The ISO Reference Model of Open Systems Interconnection” *Proceedings of the ACM conference*, pp. 283–288, 1981.

[9] C. S. R. Murphy and B. S. Manoj, *Ad-hoc Wireless Networks: Architectures and Protocols,* New Jersey: Prentice Hall PTR, May 24, 2004.

[10] J. S. Ahn, P. B. Danzig, Z. Liu, and L. Yan, “Evaluation of TCP Vegas: Emulation and Experiment,” *Proceedings of the conference on Applications, Technologies, Architectures, and Protocols for Computer communication (SIGCOMM),* pp. 185–195, 1995.

[11] P.P.-K, Lam, and S. C. Liew, "UDP-Liter: An improved UDP Protocol for Real-Time Multimedia Applications over Wireless Links," *Proceedings of 1st International Symposium on Wireless Communication Systems*, pp. 314-318, September, 2004.

[12] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva, “A Performance Comparison of Multi-hop Wireless Ad-hoc Network Routing Protocols,” *Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking (MobiCom*), pp. 85–97, 1998.

[13] I. C. S. L. M. S. Committee, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," IEEE Standard 802.11-1997. Retrieved on January 2, 2008, from IEEE 802.11 Wireless Local Area Networks Website:http://www.ieee802.org/11, 1997.

[14] G. Anastasi, E. Borgia, M. Conti, and E. Gregori, "IEEE 802.11 Ad-hoc Networks: Performance Measurements," *Proceedings of the 23rd International Conference on Distributed Computing Systems Workshops*, pp. 758 –763, May 2003.

[15] R. Sollacher, M. Greiner, and I. Glauche, "Impact of Interference on the Wireless Ad-hoc Networks Capacity and Topology," *Wireless Network Journal*, vol. 12, no. 1, pp. 53–61, February, 2006.

[16] I. Stojmenovic, *Handbook of Wireless Networks and Mobile Computing*, John Wiley & Sons, Inc, 2002.

[17] C. S. R. Murphy and B. S. Manoj, *Ad-hoc Wireless Networks: Architectures and Protocols*, New Jersey: Prentice Hall PTR, May, 2004.

[18] P. Mohapatra and S. Krishnamurthy, *Ad-hoc Networks: Technologies and Protocols*, 1 Ed: Springer, September, 2004.

[19] K. Wong, T. Kwon, and V. Varma, "Towards Commercialization of Ad-hoc Networks," *IEEE International Conference on Networking Sensing and Control*, vol. 2, pp. 1207 – 1211, 2004.

[20] M.Raya, P.Papadimitratos and J-P.Hubaux, "Secure Vehicle Communication," *IEEE Wireless Communication Journal*, vol.13, no.5, pp.8-15, September, 2006.

[21] Y. Qian and N. Moayeri, "Design of Secure and Application-Oriented VANETs." *Proceedings of the Vehicular Technology Conference (VTC)*, pp. 2794–2799, October, 2008.

[22] X. Liu, Z. Fang, and L. Shi, "Securing Vehicular Ad-hoc Networks," *Proceedings of the 2nd International Conference on Pervasive Computing and Applications (ICPCA)*, pp. 424 –429, July, 2007.

[23] J. Guo and N. Balon, "Vehicular Ad-hoc Networks and Dedicated Short-Range Communication," *University of Michigan - Dearborn*, Technical Report, June, 2006.

[24] R. Baldessari, B. Boedekker, "Car-2-Car Communication Consortium-Manifesto," *CAR 2 CAR Communication Consortium*, Technical Report, August, 2007. [Online]. Available: http://www.car-to-car.org/index.php?id=31.

[25] C. A. M. P. V. S. C. Consortium, "Vehicle Safety Communications Project: Identify Intelligent Vehicle Safety Applications Enabled by DSRC," *Department of Computer and Information Science, University of Michigan-Dearborn*, Technical Report, 2004.

[26] J. Luo and J.-P. Hubaux, "A Survey of Inter-Vehicle Communication," *School of Computer and Communication Sciences, EPFL*, Technical Report, 2004.

[27] Y. Do, S. Buchegger, T. Alpcan, and J.-P. Hubaux, Centrality Analysis in Vehicular Ad-hoc Networks. Technical Report, EPFL/T-Labs, 2008.

[28] Y.-C. Tseng, S. yao Ni, and E. yu Shih, "Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad-hoc network," *IEEE Transactions on Computers,* vol. 52, no. 5, pp. 545–557, May, 2003.

[29] F. Tobagi and L. Kleinrock, "Packet Switching in Radio Channels: Part ii–the Hidden Terminal Problem in Carrier Sense Multiple-Access and the Busy-Tone Solution," *IEEE Transactions on Communications,* Vol. 23, no. 12, pp. 1417 – 1433, December, 1975.

[30] X. Wu, Y. Yang, J. Liu, Y. Wu, and F. Yi, "Position-Aware Counter-Based Broadcast for Mobile Ad-hoc Networks," *Proceedings of the 5th International Conference on Frontier of Computer Science and Technology (FCST),* pp. 366–369, August, 2010.

[31] P. Y. Taifei Zhao, Xizheng Ke, "Position and Velocity Aided Routing Protocol in Mobile Ad-hoc Networks," *International Journal of Digital Content Technology and its application,* vol. 4, pp. 101–109, 2010.

[32] A. Qayyum, L. Viennot, and A. Laouiti, "Multipoint Relaying for Flooding Broadcast Messages in Mobile Wireless Networks," *Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS),* pp. 3866 – 3875, January, 2002.

[33] Y.-B. Ko and N. H. Vaidya, "Location-Aided Routing (LAR) in Mobile Ad-hoc Networks," *Wireless Networks Journal,* vol. 6, no. 4, pp. 307–321, July, 2000.

[34] M. Yassein, M. Khaoua, L. Mackenzie, and S. Papanastasiou, "Performance Evaluation of Adjusted Probabilistic Broadcasting in MANETs," *Proceeding of the 2nd IEEE International Symposium on Dependable, Autonomic and Secure Computing,* pp. 245 –249, October, 2006.

[35] A. Mohammed, M. Ould-Khaoua, L. Mackenzie, and J. Abdulai, "Improving the Performance of Counter-Based Broadcast Scheme for Mobile Ad-hoc Networks," *Proceeding of the IEEE International Conference on Signal Processing and Communications (ICSPC),* pp. 1403 –1406, November, 2007.

[36] A. Mohammed, "Hybrid Probabilistic Broadcast Schemes for Mobile Ad-hoc Networks," *Ph.D. dissertation, Department of Computing Science, University of Glasgow,* July, 2009.

[37] Q. Zhang and D. P. Agrawal, "Dynamic Probabilistic Broadcasting in MANETs," *Journal of Parallel and Distributed Computing,* vol. 65, no.2, pp. 220–233, February, 2005.

[38] S. O. Al-Humoud, L. M. Mackenzie, and W. Vanderbauwhede, "Dynamic Counter-Based Broadcast in MANETs," *Proceedings of the 4th ACM Workshop on*

Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks, pp. 84–88, 2009.

[39] P.-J. Chuang, P.-H. Yen, and T.-Y. Chu, "Efficient Route Discovery and Repair in Mobile Ad-hoc Networks," *Proceedings of the IEEE 26th International Conference on Advanced Information Networking and Applications (AINA),* pp.391 –398, March, 2012.

[40] X. Zhang, E. Wang, J. Xia, and D. Sung, "A neighbour Coverage Based Probabilistic Rebroadcast for Reducing Routing Overhead in Mobile Ad-hoc Networks," *IEEE Transactions on Mobile Computing,* , vol. 12, no.3, pp. 424-433, March, 2013.

[41] M. Bani Yassein, M. Bani Khalaf, and A. Al-Dubai, "A New Probabilistic Broadcasting Scheme for Mobile Ad-hoc On-Demand Distance Vector (AODV) Routed Networks," *The Journal of Supercomputing*, vol.53, pp. 196–211, July, 2010.

[42] O. Tonguz, N. Wisitpongphan, J. Parikh, F. Bai, P. Mudalige, and V. Sadekar, "On the Broadcast Storm Problem in Ad-hoc Wireless Networks," *Proceeding of 3rd International Conference on Broadband Communications Networks and Systems(BROADNETS),* pp. 1 –11, October, 2006.

[43] M. L. J. Aminu, M.;Ould-Khaoua, "Performance Evaluation of an Efficient Counter-Based Scheme for Mobile Ad-hoc Networks Based on Realistic Mobility Model," *Proceeding of the International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS)*, pp.181-188, June, 2008.

[44] J.-d. Abdulai, A. Mohammed, K. S. Nokoe, and E. Oyetunji, "Route Discovery in Wireless Mobile Ad-hoc Networks with Adjusted Probabilistic Flooding," *Proceeding of the 2nd International Conference on Adaptive Science Technology (ICAST)* , pp. 99 –109, January, 2009.

[45] J.-D. Abdulai, M. Ould-Khaoua, L. Mackenzie, and A. Mohammed, "Neighbour Coverage: A Dynamic Probabilistic Route Discovery for Mobile Ad-hoc Networks," *Proceeding of the International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS)* , pp. 165 –172, June, 2008.

[46] H. Guo, F. Thani, W. C. Wong, and Y. Wu, "An Optimized Routing Protocol for Vehicular Ad-hoc Networks," *Proceeding of the IEEE TENCON Conference*, pp. 245 – 250, November, 2010.

[47] X. Yu, H. Guo, and W.-C. Wong, "A Reliable Routing Protocol for VANET Communications," *Proceeding of the 7th International Wireless Communications and Mobile Computing Conference (IWCMC),* pp. 1748 –1753, July, 2011.

[48] B. Ding, Z. Chen, Y. Wang, and H. Yu, "An Improved AODV Routing Protocol for VANETs," *Proceedings of the International Conference on Wireless Communications and Signal Processing (WCSP),* pp. 1 –5, November, 2011.

[49] B. Williams and T. Camp, "Comparison of Broadcasting Techniques for Mobile Ad-hoc Networks," *Proceedings of the 3rd ACM international symposium on Mobile Ad-hoc networking & computing (MobiHoc)*, pp. 194–205, 2002.

[50] A. Nasipuri, J. Mandava, H. Manchala, and R. Hiromoto, "On-Demand Routing using Directional Antennas in Mobile Ad-hoc Networks," *Proceedings of the 9th International Conference on Computer Communications and Networks*, pp. 535 –541, 2000.

[51] C. Perkins and E. Royer, "Ad-hoc On-Demand Distance Vector Routing," *Second IEEE Workshop on Mobile Computing Systems and Applications (WMCSA)*, pp. 90 –100, February, 1999.

[52] Y. H. D. Johnson and D. Maltz, "Dynamic Source Routing (DSR) for Mobile Ad-hoc Network," *IETF MANET Working Group, Internet Draft*, July, 2004.

[53] V. Park and S. Corson, "Temporally Ordered Routing Algorithm (TORA), Internet Draft, March, 2004. Online: http://www.ietf.org/proceedings/53/I-D/draft-ietf-manet-tora-spec-04.txt.

[54] C. Barba, M. Mateos, P. Soto, A. Mezher, and M. Igartua, "Smart City for VANETs Using Warning Messages, Traffic Statistics and Intelligent Traffic Lights," *Proceeding of the IEEE in Intelligent Vehicles Symposium (IV)*, pp. 902 –907, June, 2012.

[55] Z. J. Haas, J. Y. Halpern, and L. Li, "Gossip-Based Ad-hoc Routing," *IEEE/ACM Transactions on Networking (TON)*, vol. 14, no. 3, pp. 479–491, June, 2006.

[56] J. Wu and W. Lou, "Forward-Node-Set-Based Broadcast in Clustered Mobile Ad-hoc Networks," *Wireless Communication and Mobile Computing Journal*, vol. 3, pp. 155–173, 2003.

[57] M. Khabbazian and V. Bhargava, "Efficient Broadcasting in Mobile Ad-hoc Networks," *IEEE Transactions on Mobile Computing*, , vol. 8, no. 2, pp. 231 –245, February, 2009.

[58] J. Wu and F. Dai, "Efficient Broadcasting with Guaranteed Coverage in Mobile Ad-hoc Networks," *IEEE Transactions on Mobile Computing*, vol. 4, pp. 259–270, 2005.

[59] C. Fragouli, J. Widmer, and J.-Y. Le Boudec, "Efficient Broadcasting Using Network Coding," , *IEEE/ACM Transactions on Networking*, vol.16, no. 2, pp. 450 –463, April, 2008.

[60] M. B. Yassein, M. Ould-Khaoua, and S. Papanastasiou, "On the Performance of Probabilistic Flooding in Mobile Ad-hoc Networks," *Proceedings of the 11th International Conference on Parallel and Distributed Systems*, vol.2, pp. 125–129, July, 2005.

[61] J. Cartigny and D. Simplot, "Border Node Retransmission Based Probabilistic Broadcast Protocols in Ad-hoc Networks," *Telecommunication Systems Journal*, vol.22, no.1-4, pp. 189-204 (16), January, 2003.

[62] Muneer Bani Yassein, B. Abed Al-Hameed, and Constandinos Mavromoustakis," Adaptive Counter-Based Broadcasting Scheme in Mobile Ad-hoc Networks," *Proceedings of the 1st ACM Workshop on High Performance Mobile Opportunistic Systems* (HP-MOSys), 2012.

[63] P. Ruiz and P. Bouvry, "Enhanced Distance Based Broadcasting Protocol with Reduced Energy Consumption," *Proceeding of the International Conference on High Performance Computing and Simulation (HPCS),* pp. 249 –258, July, 2010.

[64] H. Lim and C. Kim, "Flooding in Wireless Ad-hoc Networks," *Computer Communications Journal*, vol.24, no. 3-4, pp. 353 – 363, February, 2001.

[65] W. Peng and X.-C. Lu, "On the Reduction of Broadcast Redundancy in Mobile Ad-hoc Networks," *Proceeding of 1st Annual Workshop Mobile and Ad-hoc Networking and Computing (MobiHOC),* pp. 129 –130, 2000.

[66] F. Dai and J. Wu, "Distributed Dominant Pruning in Ad-hoc Networks," *Proceeding of the IEEE International Conference on Communications (ICC),* vol.1, pp. 353 – 357, May, 2003.

[67] I. Khan, A. Javaid, and H. L. Qian, "Distance-based Dynamically Adjusted Probabilistic Forwarding for Wireless Mobile Ad-hoc Networks," *Proceeding of 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN),* pp. 1 –6, May, 2008.

[68] W. A. Imran Ali Khan, Sajjad Ahmad Madani and K. Hayat, "Location Based Dynamic Probabilistic Broadcasting for MANETs," *World Applied Sciences Journal,* vol.13, no.11, pp. 2296–2305, 2011.

[69] C. Chen, C.-K. Hsu, and H.-K. Wang, "A Distance-Aware Counter-Based Broadcast Scheme for Wireless Ad-hoc Networks," *Proceeding of IEEE Military Communications Conference (MILCOM),* vol.2, pp. 1052 –1058, October, 2005.

[70] A. Mohammed, M. Ould-Khaoua, L. Mackenzie, and J.-D. Abdulai, "Dynamic Probabilistic Counter-Based Broadcasting in Mobile Ad-hoc networks," *Proceeding of 2nd International Conference on Adaptive Science Technology (ICAST),* pp. 120 –127, January, 2009.

[71] N. Wisitpongphan, O. Tonguz, J. Parikh, P. Mudalige, F. Bai, and V. Sadekar, "Broadcast Storm Mitigation Techniques in Vehicular Ad-hoc Networks," *IEEE Wireless Communications Journal,* vol.14, no.6, pp. 84 –94, December, 2007.

[72] R. S. Schwartz, R. R. R. Barbosa, N. Meratnia, G. J. Heijenk, and J. Scholten, "A Simple and Robust Dissemination Protocol for VANETs," *Proceeding of the 16th European Wireless Conference,* pp. 214–222, June, 2010.

[73] K. Hafeez, L. Zhao, Z. Liao, and B. Ma, "A New Broadcast Protocol for Vehicular Ad-hoc Networks Safety Applications," *Proceeding of 2010 IEEE Global Telecommunications Conference (GLOBECOM 2010)*, pp. 1 –5, December, 2010.

[74] A. Bachir and A. Benslimane, "A Multicast Protocol in Ad-hoc Networks Inter-Vehicle Geocast," *Proceeding of the 57th IEEE Semi-annual Vehicular Technology Conference (VTC)*, vol. 4, pp. 2456 – 2460, April, 2003.

[75] K. Ibrahim, M. Weigle, and M. Abuelela, "P-IVG: Probabilistic Inter-Vehicle Geocast for Dense Vehicular Networks," *Proceeding of IEEE 69th Vehicular Technology Conference (VTC)*, pp. 1 –5, April, 2009.

[76] K. Suriyapaibonwattana and C. Pomavalai, "An Effective Safety Alert Broadcast Algorithm for VANET," *Proceeding of International Symposium on Communications and Information Technologies (ISCIT)*, pp. 247 –250, October, 2008.

[77] S. Yu and G. Cho, "A Selective Flooding Method For Propagating Emergency Messages in Vehicle Safety Communications," *Proceeding of International Conference on Hybrid Information Technology (ICHIT)*, vol.2, pp. 556 –561, November, 2006.

[78] F. J. Martinez, C.-K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "A Street Broadcast Reduction Scheme (SBR) to Mitigate the Broadcast Storm Problem in VANETs," *Wireless Personal Communications*, vol.56, no.3, pp. 559–572, February, 2011.

[79] S. Oh, J. Kang, and M. Gruteser, "Location-Based Flooding Techniques for Vehicular Emergency Messaging," *Proceeding of 3rd Annual International Conference on Mobile and Ubiquitous Systems-Workshops*, pp. 1 –9, July, 2006.

[80] Y.-T. Yang and L.-D. Chou, "Position-Based Adaptive Broadcast for Inter-Vehicle Communications," *Proceeding of International Conference on Communication Workshops (ICC)*, pp. 410 –414, May, 2008.

[81] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," *Proceedings of the Conference on Communications Architectures Protocols and Applications*, pp. 234–244, 1994.

[82] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)," *Network Working Group. RFC 3626*, October, 2003.

[83] Toh and Chai-Keong, "Associatively-Based Routing for Ad-hoc Mobile Networks," *Wireless Personal Communications: An International Journa*l, vol.4, no. 2, pp.103-139, March, 1997.

[84] M. R. P. Z. J. Haas and P. Samar, "The Zone Routing Protocol (ZRP) for Mobile Ad-hoc Networks," *IETF MANET Working Group, Internet Draft*, July, 2002.

[85] I. D. Chakeres and C. E. Perkins, "Dynamic MANET On demand (DYMO) Routing," *draft-ietf-manet-dymo-05, Internet Draft*, June, 2006.

[86] R. Boppana and S. Konduru, "An Adaptive Distance Vector Routing Algorithm for Mobile, Ad-hoc Networks," *Proceeding of 20th IEEE Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)*, vol.3, pp. 1753 – 1762, 2001.

[87] W.-I. Lee, S. Chowdhury, G.-Y. Kee, W.-S. Baek, and J.-Y. Pyun, "Velocity Aware Multipath Distance Vector Routing Protocol for High Mobility over Vehicular Ad-hoc Networks," *Proceeding of 5th International Conference on Multimedia and Ubiquitous Engineering (MUE)*, pp. 189 –194, June, 2011.

[88] M. K. Marina and S. R. Das, "Ad-hoc On-demand Multipath Distance Vector Routing," *Wireless Communications and Mobile Computing*, vol.6, no.7, pp. 969–988, 2006.

[89] J. Wu, M. Cardei, F. Dai, and S. Yang, "Extended Dominating Set and its Applications in Ad-hoc Networks Using Cooperative Communication," *IEEE Transactions on Parallel and Distributed Systems*, vol.17, no.8, pp. 851 –864, August, 2006.

[90] F. Dai and J. Wu, "An Extended Localized Algorithm for Connected Dominating Set Formation in Ad-hoc Wireless Networks," *, IEEE Transactions on Parallel and Distributed Systems*, vol.15, no.10, pp. 908 – 920, October, 2004.

[91] W. Peng and X. Lu, "AHBP: An Efficient Broadcast Protocol for Mobile Ad-hoc Networks," *Journal of Computer Science and Technology*, vol. 16, pp. 114–125.

[92] S. O. Al-Humoud, "The Dynamic Counter-Based Broadcast for Mobile Ad-hoc Networks," *Department of Computing Science, University of Glasgow*, 2011.

[93] NS, "The Network Simulator NS-2," Retrieved from: <http://www.isi.edu/nsnam/ns>.

[94 X. Zeng, R. Bagrodia, and M. Gerla, "Glomosim: A Library for Parallel Simulation of Large-Scale Wireless Networks," *Proceeding of 12th Workshop on Parallel and Distributed Simulation (PADS)*, pp. 154 –161, May, 1998.

[95] OPNET, "Opnet Network Simulator," Retrieved from : <http://www.opnet.com/>.

[96] QualNet, ""QualNet: Scalable Network Technologies," Retrieved from: <http://www.scalablenetworks. com/>.

[97] A. Varga and R. Hornig, "An Overview of the OMNET++ Simulation Environment," *Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops*, no.60, pp. 60:1–66, 2008.

[98] T. Camp, J. Boleng, and V. Davies, "A survey of Mobility Models for Ad-hoc Network Research," *Wireless Communication & Mobile Computing (WCMC): Special*

issue on Mobile Ad-hoc Networking: Research, Trends and Applications, vol.2, pp. 483-502, 2002.

[99] M. Musolesi and C. Mascolo, "A Community Based Mobility Model for Ad-hoc Network Research," *Proceedings of the 2nd ACM/SIGMOBILE International Workshop on Multi-hop Ad-hoc Networks (MobiHoc'06)*, pp. 31-38, May, 2006.

[100] W. Navidi and T. Camp, “Stationary Distributions for the Random Waypoint Mobility Model,” *IEEE Transactions on Mobile Computing*, vol.3, no.1, pp. 99 – 108, January, 2004.

[101]R. C. Krajzewicz D, “Simulation of Urban Mobility (SUMO),” *German Aerospace Centre*, 2007.

[102]J. Härri, F. Filali, C. Bonnet, and M. Fiore, “VANETMOBISIM: Generating Realistic Mobility Patterns for VANETs,” *Proceedings of the 3rd International Workshop on Vehicular Ad-hoc Networks*, pp. 96–97, 2006.

[103] F. Martinez, J.-C. Cano, C. Calafate, and P. Manzoni, “CityMob: A Mobility Model Pattern Generator for VANETs,” *Proceeding of IEEE International Conference* on *Communications Workshops (ICC)*, pp. 370 –374, May, 2008.

[104] F. J. Martinez, C. K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, “A survey and Comparative Study of Simulators for Vehicular Ad-hoc Networks (VANETs),” *Wireless Communications & Mobile Computing*, vol. 11, no. 7, pp. 813–828, July, 2011.

[105] Q. Zhang and D. Agrawal, “Analysis of Levelled Probabilistic Routing in Mobile Ad-hoc Networks,” *Proceeding of IEEE International Conference on Communications*, vol. 7, pp. 3896 – 3900, June, 2004.