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DSDV Extension to Enhance the Performance of Ad Hoc Networks in High Diverse-Velocity Environments.

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Dedication:

To my parents who is still caring for me as I were a child, to my wife who stands by me and supports me, to my daughter the source of my smile, to my brothers and sisters, to all of them I dedicate this thesis.

Mada' Abdel Latif Yousef Abdel Jawad.

Declaration:

I certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed: ----------------------

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Date:12/12/ 2018.

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Abstract

A Mobile Ad-Hoc Networks (MANET) is a type of Wireless Sensor Networks (WSNs) without fixed infrastructure. In this type of networks, the mobile nodes route and forward data based on their routing information without the need for routing devices (i.e., routers); each node acts as a router to forward traffic for other nodes. Nodes are moving in an unstructured environment where some nodes are temporarily fixed at some positions, others are moving in a constant velocity, and others are having diverse velocities ratios. Therefore, they need special routing protocols that keep tracking the network topology changes and efficiently dealing with high diverse-velocity application scenarios.

Destination Sequenced Distance Vector routing protocol (DSDV) is considered as one of the main well-known routing protocols cited by the research community that was mainly proposed to handle the routing problem in MANETs. It is a table-driven routing protocol which was developed many years ago. Since then, a large number of proposals have been suggested to enhance its performance, and many variants appeared, and others are still on the horizon. The protocol was mainly proposed to solve the routing loop problem. It showed good performance measurements when deployed in sparse and low mobility environments. However, it suffers from several performance issues when it is implemented on high diverse-velocity and dense MANET applications. Very recent studies presented several DSDV performance enhancements. In some cases, these enhancements have side effects, while in others they did not achieve the desired results. Therefore, in this master thesis, we present a new approach to promote the performance of the DSDV when applied into high-diverse velocity Ad hoc networked applications. Unlike the other approaches, this method will meet the required objectives without causing high side effects. To achieve the main objective of this study, several changes are applied on the generic DSDV

protocol. The proposed changes include adding two new fields on the update messages without increasing the size of the original one by decreasing the size of the hops count field from four bytes to two bytes. We have carried a number of simulation scenarios using the Network Simulator tool (NS-3) and analyzed the efficiency of the proposed method by studying its effect on four performance metrics that are mainly used by the research community to evaluate routing protocols efficiency. These matrices are: routing overhead, end to end delay, throughput and Packet Delivery Ratio (PDR). In addition to simulations we have built a mathematical model to study the effect of the modifications we have made on the path duration which is an indicator of how well productivity has improved.

We compared the obtained results with the original DSDV and some of its new variants, namely Efficient DSDV Routing Protocol (E-DSDV), Improved DSDV (I-DSDV) and Optimized VANET DSDV (O-DSDV). The new approach showed noticeable improvements in all scenarios. The measured performance metrics outperformed the others except the average end-to-end delay where the performance of the new protocol was modest. The packet delivery ratio and throughput of the modified version of the DSDV were 20% higher in some scenarios, and at worst the improvement rate was 2%. As for the routing overhead, also the modified protocol showed improvement up to 4% in scenarios with a speed of less than 25 m/s. However, at higher speeds, the routing overhead fell to the rest of the protocols.

بروتوكول التوجيه (DSDV) المحسن لتعزيز الأداء في الشبكات اللاسلكية المخصصة (Ad Hoc) في البيئات ذات السرعات المتباينة

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الملخص

شبكات الادهوك اللاسلكية المخصصة (MANETs) هي شبكات لاسلكية لا تحتاج الى بنية تحتية. يمكن لنقاط الاتصال في هذا النوع من الشبكات التحرك بحريه وتبادل وتوجيه البيانات فيما بينها اثناء تحركها دون الاعتماد على اجهزة ربط متخصصة كالموجهات او نقاط الاتصال. هذا يعني ان نقاط الاتصال تعتمد على بعضها البعض في توجيه البيانات بدلا" من اجهزة التوجيه. ففي حال كانت نقطة الاتصال تشكل حلقة وصل بين نقتطي اتصال اخريين، فانها تقوم بدور الموجه في هذه الحالة. من هنا ظهرت فكرة استخدام بروتوكولات توجيه تتلاءم مع هذا النوع من الشبكات.

البروتوكول (DSDV) هو احد اشهر بروتوكولات التوجيه في الشبكات اللاسلكية المخصصة، قام بتطويره تشارلز بيركينز وزملاؤه لحل مشكلة الحلقات المفرغة. ان استخدام هذا البروتوكول لتوجيه البيانات في الشبكات اللاسلكية المخصصة اظهر اداءا" متميزا" و خصوصا في الشبكات القليلة الكثافة وفي الشبكات ذات نقاط الاتصال بطيئة الحركة. بالرغم من ادائه الجيد في بعض التطبيقات، الا انه لم يكن بالمستوى المطلوب في بعض النماذجوخصوصا في الشبكات العالية الكثافة او الشبكات ذات الاجهزة السريعة الحركة. مؤخرا، ظهرت العديد من البروتوكولات التي تطرح تعديلات على

البروتوكول DSDV لتحسين ادائه، لكن هذه التحسينات كانت على حساب عوامل ومعايير اخرى.

في هذه الاطروحة قمنا باجراء عدد من التعديلات على البروتوكول DSDV لتحسين اداءه مع تجنب ان تؤثر هذه التعديلات على معايير اخرى كما هو الحال في البروتوكولات اللاحقة للبروتوكول DSDV. لتقييم اداء البرتوكول المقترح ومقارنة ادائه مع البروتوكولات السابقة اعتمدنا عددا من المعايير التي تستخدم عادة لتقييم اداء الشبكات اللاسلكية، المعايير هي: الانتاجية، نسبة توصيل البيانات، زمن التاخير وعبء التوجيه.
احد اهم التعديلات التي قمنا باجرائها هو اضافة حقلين جديدين على رسائل التوجيه في البروتوكول DSDV، حيث يستخدم احد هذه الحقول لتحدد نوع الرسالة (بيانات توجيه و طلب توجيه) والحقل الثاني يستخدم لارسال سرعة حركة نقاط الاتصال، حيث ستستخدم هذه البيانات للحكم على عمر الرابط بين الاجهزة و مدة الاحتفاظ بالبيانات.

لقد قمنا باختبار عدد من السيناريوهات باستخدام برنامج المحاكاة NS3 لتقييم المنهجية الجديدة ومقارنتها مع البروتوكول DSDV والبروتوكولات اللاحقة له اعتماداً على المعايير الانفة الذكر. حيث اظهر البروتوكول المعدل تحسننا ملحوظا في كل السيناريوهات ووفقا لكل المعايير باستثناء معاير (زمن التاخير) الذي لم يظهر تحسنا في جميع السيناريوهات. حيث كانت نسبة تسليم البيانات و الانتاجية للبروتوكول المعدل اعلى بمقدار 20% في بعض السيناروهات، وفي اسوا الاحوال كانت نسبة التحسين 2%. اما بالنسبة لعبء التوجيه فان البروتوكول المعدل اظهر تحسننا يصل الى 4% في السيناريوهات التي تقل فيها السرعة عن 25 متر/ثانية اما في السرعات الاكبر فان عبء التوجيه تراجع ليكون في مستوى باقي البروتوكولات.

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List of Abbreviations

ARM-DSDV	Adapting to Route-demand and Mobility DSDV
IARP	IntrA-zone Routing Protocol
AODV	Ad Hoc On-demand Distance Vector
CBR	Constant Bit Rate
CDF	Cumulative Density Function
CGSR	Cluster-Head Gateway Switch Routing Protocol
C_{Tpath}	Cumulative Density Function Complementary
DSDV	Destination Sequenced Distance Vector
DSDV-MC	A Proactive Routing Protocol for Multi-Channel Wireless Ad-hoc Networks
DSR	Dynamic Source Routing
E-DSDV	Efficient DSDV Routing Protocol
EFF-DSDV	An Efficient DSDV Routing Protocol
E_h	Expected Number of Hops
E_{Tpath}	Expected Path Duration
FSR	Fisheye Routing Protocol
F_{vr}	Cumulative Density Function of the Relative Velocity
f_{vr}	Probability Density Function of the Relative Velocity
I-DSDV	Improved DSDV
IERP	IntEr-zone Routing Protocol
LRD	Least Remaining Destination
MAC	Media Access Control layer
MANET	Mobile Ad Hoc NETwork
MPR	Multi-Point Relay
NDP	Neighbor Discovery Protocol
O-DSDV	Optimized VANET DSDV
OLSR	Optimized Link State Routing Protocol
PAN	Personal Area Network
PDF	Probability Density Function
RREP	Route Reply
RREQ	Route Request
RWP	Random Way Point Model
TC	Topology Control
T_d	Default Update Interval

T_{min}	Minimum Update Interval
TORA	Temporally Ordered Routing Algorithm
T_s	Settling Time Default Interval
V_{max}	Maximum Expected Velocity
V_n	Node Velocity
Vr	Relative Velocity
V_s	Sender Node Velocity
WRP	Wireless Routing Protocol
WSN	Wireless Sensor Networks
z	Distance
ZRP	Zone Routing Protocol

Chapter 1

Introduction

1. Chapter 1: Introduction

1.1. Introduction

Mobile Ad Hoc network (MANET) is a type of is a decentralized type of wireless network where the nodes (computers, laptops, mobile phones, etc) are connected without a fixed infrastructure. This means that there is no need to use routers or access points to connect any two nodes. Instead of acting like a normal node that can send and receive connections request, nodes in MANETs can also work as routers or gateways to other nodes, The nodes in this type of networks have the ability to forward the connection requests from one node to another. All operations are distributed among all nodes. Therefore, there is no centralized management for security and routing. Most nodes have a small size of memory and low power resources. Links between nodes are wireless making them subjected to path disconnections and packet losses. As a result of this, the mobility nature of the nodes makes it difficult to build routing information.

MANETs face several challenges. (i) the transmission range is confined; (ii) security is another important challenge due to the wireless environments; (iii) the power resources are limited. And finally, (iv) the mobility nature of MANETs makes its topology highly dynamic which leads to an increase in the number of lost packets and routes' changes.

To deal with these challenges, several protocols were proposed by both the research community and the industrial sector. Routing protocols are part of them, which are sets of algorithms used by wireless devices to find the best path onto which data should be transmitted. Many routing protocols were proposed and a large number of their variants were extended, and others are still appearing. These protocols were supposed to take into consideration minimizing the overhead, utilizing the available bandwidth efficiently, maintaining a high level of security, managing network failures, and preserving resources. A large number of routing protocols is now available in the literature, each one has its own design philosophy and focuses on some of these characteristics and ignores the others. This is mainly depending on the field where it is designed to work for. Also, many contributions tried to classify existing routing protocols, one of these studies classified them into three categories: proactive routing protocols (or table-driven in other contexts), reactive protocols (or on-demand in other contexts) and hybrid protocols which combine the proactive and the reactive methods.

In summary, in this thesis, we focus on the DSDV protocol and try to enhance its performance. Despite the fact that . many research contributions have been presented to enhance functioning of the protocol, it still has several drawbacks when being deployed in specific environments. The existing DSDV contributions can be classified into three areas. First, some studies focused on improving nodes power consumption; Second, other studies focused on enhancing the fault tolerance metric; And third, some studies handled network overhead and bandwidth performance issues. In this research study, a new approach is presented to enhance the DSDV end to end delay, network throughput, and packet delivery ratio, especially when its being applied in high-density and high-mobility MANET applications. The obtained results are examined and compared with the most relevant and updated contributions of this protocol, and the original DSDV as well.

1.2. Problem Statement

The DSDV protocol is considered as one of the most utilized MANETs protocols worldwide. Many contributions were proposed to enhance this protocol. It operates well in some network application scenarios and has some performance degradation when applied to others. Several research efforts argued that the DSDV protocol does not operate very well in high-density and high-diversity velocity scenarios. Therefore, the main question that this research study is trying to answer is:

Can we propose new mechanisms to improve the performance of the DSDV protocol when being deployed in high-diverse velocity environments?

1.3. Hypothesis

The main hypothesis that will be assumed to achieve the main objective of this research study is that there is a relationship between some of the main DSDV protocol features and the network environments and applications' characteristics. For instance, settling, update, and hold down times are highly flexible values. These variables must be dynamically tuned so that we can minimize the end to end delay, maximize the network throughput and maximize packet delivery ratio. For example, by considering nodes' velocity, and making the nodes inform other nodes about their velocity, this will help the other nodes to adjust their timing parameters to foster the performance of the protocol.

The stale routing information usually occurs in high mobility environments because the topology of the network is changed rapidly. Thus, if a node moves at high speed and lost the connection with another node, it can reconstruct the connection by sending a route request to its neighbors only. In this way, we can minimize the delay that is needed to reconstruct connection using normal update message.

1.4. Our Contributions

Our reliance on wireless networks and their applications are increasing every day. In some seenarios there is no predefined infrastructure to connect wireless devices. Hence, the need for MANETs have emerged. MANETs are characterized by the fact that they do not need intermediate devices such as routers to route packets. In this regard, the nodes are co-operating in order to create multi-hop connections. They need special routing protocols to suit their conditions. The development and updating of existing routing protocols are still effective, because of their importance and role they play in the wireless communication context.

In DSDV protocol, every node sends a routing information about its status periodically and forwards the routing information which are received from neighbors. Every node collects the routing information about the neighbors' devices and the paths to each device. In this thesis, we proposed a DSDV extended mechanism to enhance the way that devices collect and send information. We have developed a number of procedures that significantly improved the DSDV performance when being deployed in some applications that need high diverse-velocity Scenarios. Examples of such scenarios are urban traffic, emergency situations, natural disasters, etc. This enhancement increases the speed of information exchange between mobile devices. To do this, the DSDV generic message has be modified by adding two new fields; `SPEED` and `TYPE`. The `SPEED` field is used to inform the neighbor nodes about the source node's speed. This will help the destination node to manage several performance parameters. The TYPE field is used to recover expired routing information. For example, when a node that uses the DSDV protocol discovers an invalid routing information, the node waits until it receives a valid routing information. In case of our approach, this node will attempt to find a valid routing information by sending a routing request to the adjacent nodes. This modification will increase the routing overhead, on the other hand, it will increase throuput. Chapter 4 contains further clarification and details.

The main contributions obtained from this research are:

1. We have proposed a mathematical model to study the effect of the procedures and parameters being applied by the DSDV protocol on the path duration estimation process. The mathematical model was also used to study the effect of velocity and increasing number of hops on the path duration calculations. We used the tested the mathematical model by comparing it with the path duration of the DSDV protocol with the modified version we have proposed.
2. Based on the results of the DSDV protocol analysis, we have implemented a number of modifications to the protocol's parameters For example, we have added two new fields to the DSDV header and have made a number of modifications on DSDV working mechanism to improve its performance, especially in high diverse-velocity environments.

1.5. Thesis Structure

In addition to the introduction chapter, This thesis includes five other chapters, Chapter 2 (Background) contains an introduction to the Ad Hoc Networks (MANETs) and lists their main characteristics and challenges. It concludes examples of some existing routing protocols with their classifications. Chapter 3 (Related Work) It discusses and analyzes the previous research on the DSDV protocol. This chapter mainly reviews the generic protocol and its variants and explains the main differences among them and their relevancy to work presented in this thesis document. Chapter 4 (Methodology). The chapter includes our methodology, an explanation of our approach, and the relevant parameters that have been changed in the DSDV protocol and the main justifications. It also includes a mathematical model to estimate the path duration in MANETs and thecalculations necessary to find the effect of both the extended DSDV version and the original one on the effective utilization rate for the path duration.Chapter 5 (Simulation Results and Analysis) It includes a list of the performance metrics that will be used for comparing the performance of our approach with the performance of the DSDV and some of its variants all the scenarios that will be used for testing. Finally, this chapter concludes with a comprehensive comparison of the simulation results and their discussions. Chapter 6 (Conclusions and Future Work) Based on the results of the comparative study, this chapter concludes the main findings derived from this research. It concludes with a list of some future work research lines.

Chapter 2

Background

2. Chapter 2: Background

2.1. Introduction

Devices that rely on wireless networks have increased significantly in recent years. Many applications are now relying on wireless topology to offer their services. MANETS is one type of these networks. They are defined as collections of independent mobile nodes (computers, laptops, mobile phones etc) that can communicate with each other wirelessly without the need for a fixed infrastructure, such as routers or access points. In MANET topology changes dynamically. Therefore, Nodes have to do all network activity by themselves, including discovering the topology and delivering messages. As well as the ability to send and receive data of other nodes, i.e., they act like a router to other nodes and have the ability to forward the connection requests from one node to another. All the operations are distributed on the nodes. Therefore, there is no centralized management for security or routing. Most nodes have a small size of memory and low power making them subjected to path disconnections and packet losses. Mobile nodes that are in radio range of each other can directly communicate while the other nodes should cooperate with the nodes between them to deliver the data to the destination node.

MANETs have many applications in our lives as they are used in the military field, taxis, disaster areas etc. In these fields, it is not possible to rely on fixed infrastructure because of its absence or its high cost. Figure 2.1 shows an example that represents a simple MANET network where nodes A, B, and C represent communication nodes and the circle drawn using section line represents the signal range of each node. As it is observed from the Figure 2.1 that node A and B, or node A and C can communicate directly without the need for an intermediate node. In case of nodes B and C, the connectivity depends on node A, i.e., it can be used to forward data between them without the need for a router or an access-point.

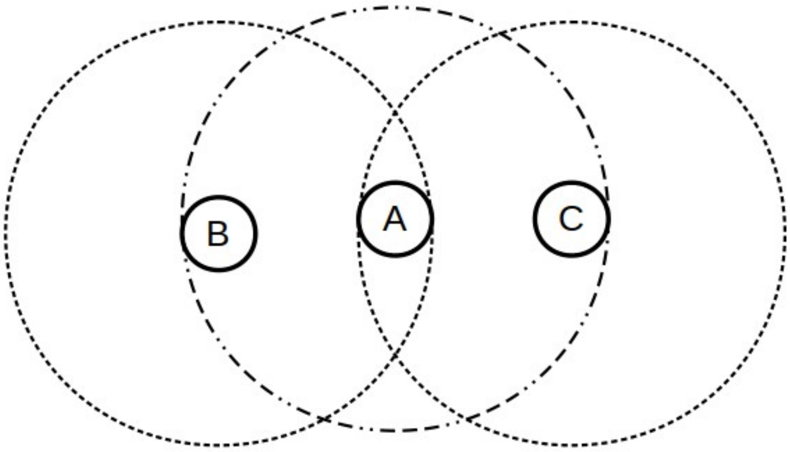

Figure 2.1: Node A acts as a router for the nodes B and C.

One of the main challenges of MANETs is routing. By considering the fact that nodes are mobile, the network topology may vary rapidly and indeterminable over time. The process of managing the network, routing data and finding communication links between nodes in fixed infrastructure networks is router's responsibility. In MANETs, all nodes have to perform these functions and because of the network's topology is constantly changing, this is one of the most important challenges for nodes. Unlike wired networks, wireless networks have many factors that cause data loss such as interference and overlay of communication channels.

2.2. Characteristics of MANETs

Due to the mobility nature of mobile nodes, and their tiny resources, MANETs in general share the following main characteristics [1][4][22]:

- Autonomous Terminal: All nodes are independent. This means that besides its rule of generating user data, each node independently collects routing information about the network topology without the use of routers.

- Lightweight Terminals: MANETs depend on mobile devices that have limited resources. These devices have low speed processors for data processing and have also limited sources of energy such as batteries and low volumes of memory.
- Dynamic Network Topology: In MANETs, network topology is constantly changing because all nodes in the network are mobile. The speed of the topological changes mainly depends on the movement of the nodes. The continuous motion of the node also results in frequent broken communication links, loss of data and minimize data transfer rate.
- Bandwidth constrained: Wireless communication channels are inherently having low bandwidth links, subject to noise, signal interference and fading. Adjacent nodes usually use the same channels, and this leads to low data transfer rate. The channel cannot be used from two nodes at the same time.
- Multi-hop Routing: Nodes that do not exist within the signal range of another node, it needs to pass data through the intermediate nodes in order to be able to deliver data to the final destination.
- Distributed Operation: Networks are usually managed through central devices such as servers and routers. These devices are also responsible for security and data routing. The case differs in MANETs, where all nodes collaboratively work to perform these functions.
- Security: In this type of networks, security is a big challenge due to the distributed nature of management, coordination, synchronization, and traffic controlling.

- Network Scalability: Increasing number of nodes in ad hoc applications effect on the performance and put burden on the limited resources that are available in each node such as frequency, routing, etc.

2.3. MANET Applications

There are many mantle applications that rely on MANET infrastructure for their operations. The following list summarizes the most important MANET applications[1][4][22]:

- Military battlefield: Ad hoc networks can provide communication between soldiers, vehicles and headquarters within military units on the battlefield without the need for additional infrastructures.
- Rescue mission and emergency: When disasters such as earthquakes and floods occur in an area, communication networks and power grids are disrupted. Ad hoc networks can operate under these conditions since they are decentralized networks and rely on independent power sources such as batteries.
- Personal Area Network (PAN): Applications that use Bluetooth for their nodes' communication allow communication within a specific distance and allow the use of each other's resources such as hot-spot networks.
- Wireless Sensor Networks (WSNs): Many weather monitoring systems use this type of network. It is also used by many research centers that study animals and their migrations.
- Home and enterprise networking: Wireless networks have many home applications such as multi-user games, phones and smart TVs, among others.

- Educational Applications: This type of network can be used to hold virtual classrooms and conferences, it can also be used for extracurricular activities.

2.4. MANET Challenges

MANETs have the following main challenges [1][4][22]:

- Limited bandwidth: Wireless networks in general rely on limited bandwidth links. The nodes are used in wireless networks at limited frequencies for data exchange. Because they are all adopted at the same frequency, this reduces the effectiveness of the channel allocation problem. Besides other factors that affect the communication efficiency such as interference and signals noises which in turn reduce the effectiveness of the used channel.
- Dynamic topology: The nodes in Ad hoc networks move freely, their signals, transmission range, and power resources vary from node to node. The dynamics of Ad hoc networks make network management a difficult task. This is one of the main reasons for the design of routing protocols for asphalt networks.
- Routing overhead: Due to the constantly changing network topology, nodes need to exchange routing information more rapidly, which increases the overhead of data routing, and this in turn restricts the use of the available bandwidth.
- Hidden terminal problem: The hidden peripheral terminal problem occurs when data from different sources interfered and collided at the receiving nodes. This form of poor coordination occurs when the destination node is in the range of two source nodes, but these nodes are out of range of each other. Many solutions have been made to solve this type of interference. A hand shaking mechanism can be applied

that can partially solve the problem. We can also increase the transmission power and use omni directional antennas.

- Packet losses: There are many factors that affect the performance of wireless networks which negatively affect data delivery. Examples of these factors are noise, interference, unidirectional link, and frequent links disconnect.
- Mobility-induced route changes: Nodes in wireless networks are constantly moving, resulting in frequent communication links' breaks. Repeated breaks dictate the need to change routing information frequently so that the connection is resumed.
- Battery constraints: The devices used in this type of network often rely on limited power sources such as batteries. These devices are often designed to be portable and lightweight, forcing designers to reduce battery sizes and capacity.
- Security threats: In wired networks, network management is often centralized, making it easier to apply security to central machines. In wireless networks, the nodes cooperate with each other to manage the network, making it difficult to protect the network as security procedures must be applied to all nodes. The nature of wireless networks facilitates penetration because data exchange is on open bandwidth, which requires additional protection and encryption procedures.

2.5. Routing Protocols

Routing protocols are sets of mechanisms and procedures used by devices to route data from a source to a destination[7][1]. Their main responsibility is to choose the best path to forward data within the network which highly depends on a number of alternatives.

Routing protocols exchange routing information in such way that they have a full impression of the network topology. Some of these protocols send routing information periodically and others send routing information when needed.

Since the advent of Ad hoc networks, many routing protocols have emerged. Each protocol has its advantages and disadvantages, and each protocol is compatible with specific environments. In this section, we review a number of these protocols, their working mechanisms, and their classifications.

2.6. Routing Challenges in MANET

The most important routing challenges in wireless networks can be summarized as follows[7]:

- **Asymmetric links:** Unlike the wired networks that have a symmetric nature of quantity and speed of data transmission, *i.e.,* a fixed infrastructure with specific capabilities, in wireless networks the nodes within the network depend on each other for data transmission. These nodes vary in their capabilities, each node has a transmission speed, signal range and direction of motion that might be different from the other one, which makes the data transfer process not as efficient as the directional one.
- **Routing Overhead:** The overhead of routing data in wired networks is relatively small, since routers are installed in specific places and the network structure does not change significantly. In MANETs, the nodes are constantly moving, which leads to changing the network topology constantly. The rapid change of network

topology makes the nodes increasing the exchange of routing data so that the routing information remains almost updated.

- **Interference:** The connections between nodes in Ad hoc networks is constantly subject to interruption, because the communication between the nodes depends on the strength of the signal and the distance between the nodes. Nodes' signals are also subjected to interference. These factors affect the data transfer and increase routing difficulties whereas nodes send data more than once to compensate for lost or corrupted data.

- **Dynamic Topology:** The routing information should always reflect the status of the network. Since the ad hoc network's architecture changes rapidly, it requires routing protocols that have the ability to constantly monitor network changes and update their routing table accordingly.

2.7. Classification of Ad Hoc Routing Protocols

MANET routing protocols can be categorized according to different criteria, routing mechanism, the use of temporary routing information, routing topology, and the use of specific resources. There are many other classifications, but these are the most classifications cited by the research community. The following is a brief description of each one of them [5][7].

2.7.1. Classification of routing protocols Based on the use of temporal information for routing

Due to the dynamic change in the network topology and frequent disconnection of nodes links, this type of protocol uses temporal information to cover new changes. According to this classification there are two categories of routing protocols:

- Using past temporal information: The protocols of this category use routing information that is available at the moment when needed to route data. When an unexpected break occurs in the connections, the connection needs to be reconfigured, putting pressure on resources. DSDV is an example of this class.
- Using future temporal information: The protocols in this category predict the state of connections between nodes and the age of each node based on a number of factors such as battery status and signal strength. The protocols evaluate routing decisions based on these expectations. One of the most famous protocols on this category is Flow Oriented Routing Protocol (FORP)[13]. Figure 2.2 presents examples of both categories.

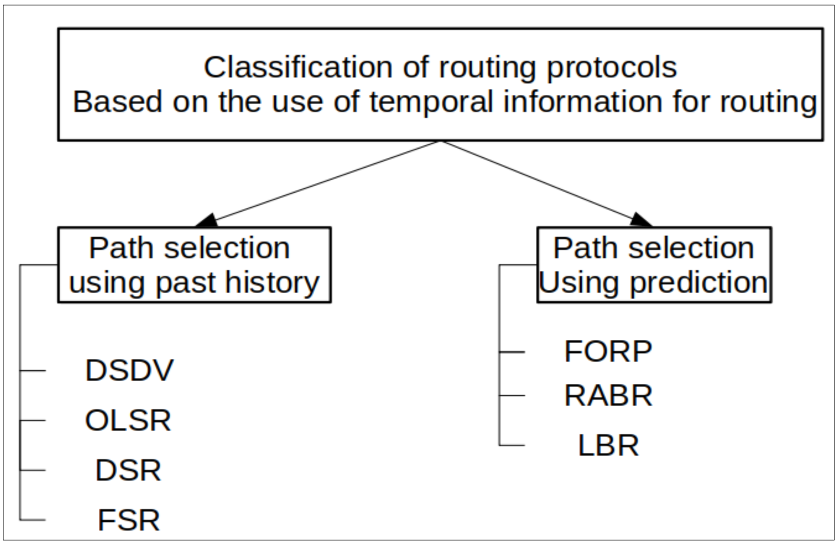

Figure 2.2: Classification of routing protocols based on the use of temporal information for routing[26].

2.7.2. Classification of routing protocols Based on the routing topology

Since Ad hoc networks are decentralized networks, routing protocols in this type of network are designed to fit the dynamic nature of the network and the nodes are connected in a peer-to-peer manner. However, when the network is expanded, the hierarchical control mechanism is required. Protocols can therefore be classified by this criterion into:

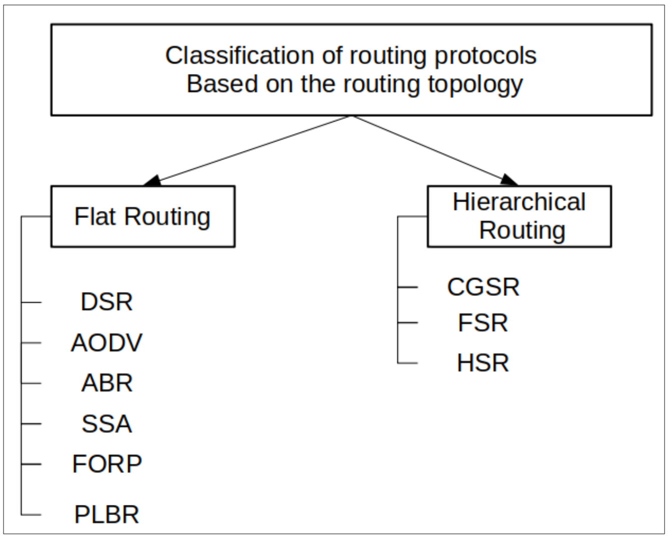

Figure 2.3: Classification of routing protocols based on the routing topology[26].

- Flat topology routing: In this category all the nodes is peers. That is, all elements of the network have a single address that can be accessed using it whereas there are no local and global nodes. This type of protocol can be used in small and medium networks where the routing overhead is relatively low. DSR[9] and AODV [39] are examples on this category.
- Hierarchical topology routing: The grid is divided into a number of clusters. Each node belongs to a particular cluster. The nodes belonging to the same cluster elect a head node that coordinate the communication between the nodes within the cluster

and organizes the communication of the nodes of the sector with the other sectors. The clustering process can expand to include a multi-level hierarchy. Cluster-Head Gateway Switch Routing Protocol (CGSR) is an example of Hierarchical protocol. Figure 2.3 illustrates the classification of some routing protocols based on routing topology.

2.7.3. Classification of Routing Protocols based on the Utilization of Specific Resources

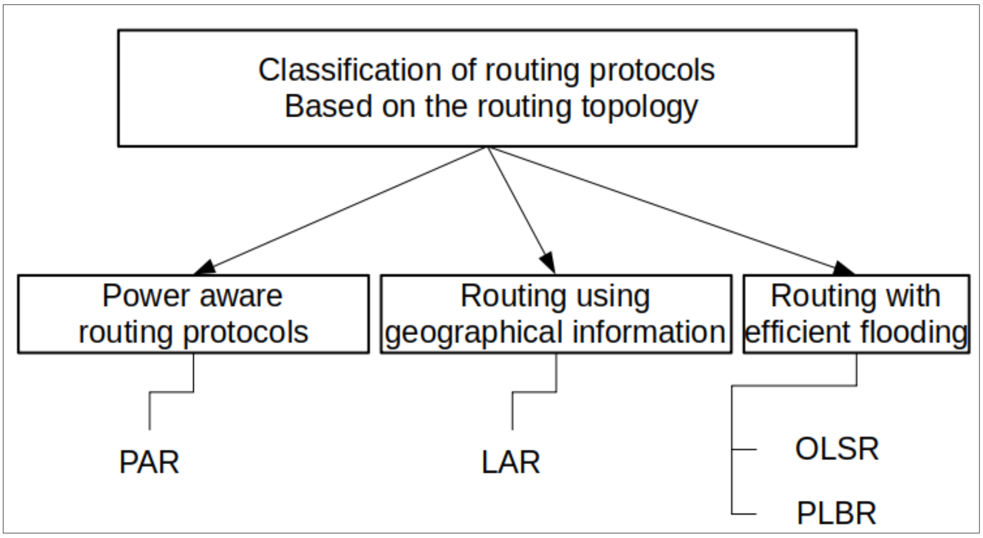

Figure 2.4: Classification of routing protocols based on the utilization of specific Resources[26].

The classes in this category are not precisely defined. Protocols according to this classification are classified according to very specific characteristics. For example, some protocols are very concerned with energy consumption, and others use special devices such as GPS to route data. Figure 2.4 illustrates the classification of some routing protocols based on the utilization of some resources.

2.7.4. Classification of Routing Protocols based on the Routing Information Update Routing Mechanism

This criterion is one of the most widely used classifications. The process of routes updating is a fundamental part of the functions of the routing protocols. Protocols based on this standard can be classified into three categories:

- Table-driven routing protocols (Proactive): The protocols of this class periodically exchange routing information. Each protocol maintains one or more routing tables containing routing information for the nodes within the network. The data is routed using the information in the table. Examples of this type of protocols are optimized link state routing protocol (OLSR) and wireless routing protocol (WRP)
- On-demand routing protocols (Reactive): Protocols in this category do not exchange data periodically, instead they send a routing request when they need tosend data to the destination. One of the most famous protocols of this type of protocols is Dynamic Source Routing protocol (DSR), Ad Hoc On-Demand Distance-Vector Routing protocol (AODV).
- Hybrid routing protocols: Nodes in this category are divided into zones or clusters. Data are routed within the same zone using the table-driven mechanism. For routing data outside the zone or cluster, the on-demand routing mechanism is used. Examples of this type is the zone routing protocol (ZRP).

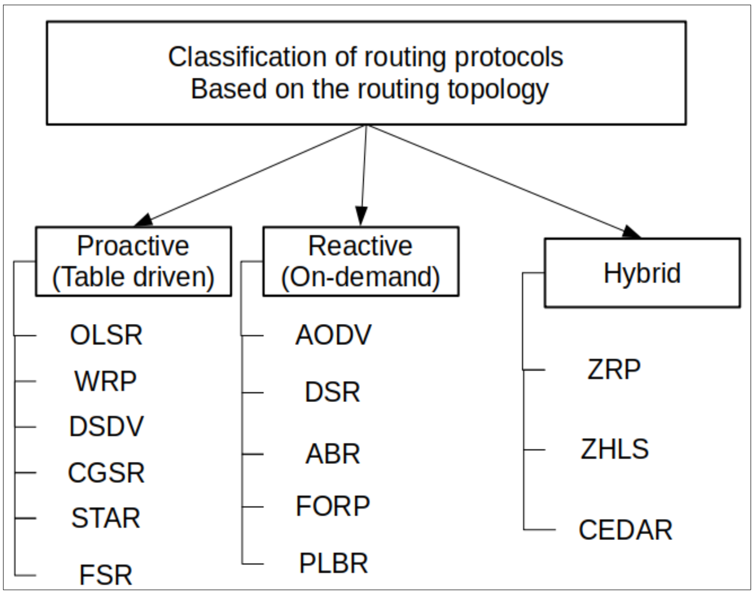

Figure 2.5: Classification of routing protocols based on the routing information update routing mechanism[26].

2.8. Common Routing Protocols

As previously mentioned, there are dozens of routing protocols designed for MANETs. It is also noted that routing protocols can be classified into many different classifications according to some characteristics. In this section, we overview a set of common routing protocols, list their characteristics, used mechanisms and their classifications.

2.8.1. Distance Sequence Distance Vector (DSDV)

Destination-Sequenced Distance Vector (DSDV) [6] is a proactive routing protocol having Bellman-Ford routing mchanism in its design. It was developed by C. Perkins *et al.* [6] to solve the routing loop problem. Since this protocol is the main subject of this thesis, we give more details in the related work chapter.

2.8.2. Fisheye State Routing Protocol (FSR)

Fisheye Routing Protocol (FSR) [12] is a proactive link state routing protocol. It maintains a table of link states for all nodes within the network, *i.e.,* it builds a complete topological view about the network. Mobile nodes use the flooding mechanism to broadcast their link states advertisements to all nodes periodically or when the link states are changed. A node that receives routing data from neighboring nodes takes a copy and rebroadcasts it to its neighbors. To distinguish between new and old routing information, a time stamp is added to the routing information. Every time the routing data is rebroadcast, the forwarding node selects the shortest path. The nodes also calculate the shortest path when there is a change on the network topology.

The protocol is designed in a similar way to the vision system found in the fish, where the vision is clearer and more concentrated in the center and its quality decreases in the sides. The protocol works like link state protocols, except that each node sends routing updates to the neighbors' nodes more frequently than remoter ones. Each node maintains several tables such as neighbors table, network topology table, next hop table, and distance table. To determine the frequency of sending routing information to the nodes in the network, the nodes are divided around each node into scopes so that the routing information is sent to the nearby scopes more frequently than the remote scopes. Figure 2.6 illustrates the scopes of node A according to the FSR protocol. It is clear this protocol is designed to reduce overhead costs, especially in large networks.

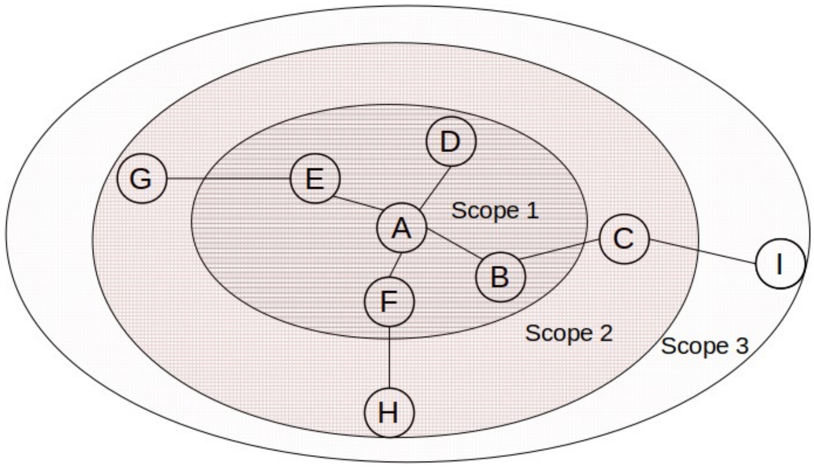

Figure 2.6: Fisheye routing protocol scoping example.

2.8.3. Optimized Link State Routing Protocol (OLSR)

Optimized Link State Routing protocol (OLSR) [31] is also classified as a proactive routing protocol. It was introduced as an optimization of the link state protocol. OLSR has the same features of the link state routing protocol. Furthermore, it minimizes routing overhead costs by reducing number of re-transmissions. The protocol uses a multi-point idea to minimize network flooding. Each node selects a set of node neighbors to rebroadcast routing information updates. This set of nodes is called Multi-Point Relays (MPR). All neighbors' nodes can receive and process updates of routing information, the nodes within a MPR set are the only ones who are able to rebroadcast these updates. Each node within the network has its own set of MPRs, members of these sets are constantly changing according to the network topology changes. Each node reports its own MPR to its neighbors. Network nodes maintain a table called MPR selectors that includes nodes that chose it as a MPR.

Each node selects its own MPR set from its neighbors having direct connection or one hop distance. The node selects a set of nodes that contain as few one hops neighbors as possible that has a bidirectional link with all two hop neighbors. Each node detects the one hop neighbors periodically. To do this, each node sends a HELLO message periodically. The HELLO message also contains a list of the one hop neighbors of the sender nodes who have an active bidirectional link and another list of one-hop neighbors who have not been confirmed to have a bidirectional link. The recipient nodes can determine their second hop neighbors using the HELLO message contents.

In addition to the previous uses of the HELLO message, the nodes use it to report its own new MPR set. The node needs to change its MPR set when a change is detected in its neighbors or a change is made in the bidirectional links. The nodes being selected as MPR maintain a table called MPR selectors. This table maintains a list of nodes that chose the corresponding node as their MPR, considering that the node can be a MPR for more than one node. The node that owns a non-empty list periodically broadcasts the contents of that table. A special message called Topology Control (TC) message can be used to achieve this purpose. In addition to MPR list, the message contains a unique identifier to distinguish between old and new updates. A TC message is broadcast using the usual broadcast technique to the entire network. The period between the transmission of the TC message and the other is affected by the change in the MPR selectors table. In case the table changes, the period is shortened to a certain extent. The nodes can build topology table depending on the content of the TC messages.

In the following example (Figure 2.7), node A can have a connection to node K through nodes D and E as it can contact the G and H nodes via the nodes B and C. Node A selects as few one hop neighbors as possible to connect to the two hop neighbors. Therefore, it selects both nodes B and D as its MPR set. All nodes in this scenario periodically exchange

HELLO messages which include node A one hop neighbors addresses and the addresses of the nodes that are chosen as MPRs. The nodes being selected as MPRs are the only ones who can broadcast TC messages which can be used to report the link state between node A and its MPR (nodes B and D in this example). When these messages reach the two hops neighbors, they update their network topology table. In summary, we can conclude that the nodes (F, G and H) can reach node A via the node B only. That is, the nodes (G and H) cannot use the path across the C node.

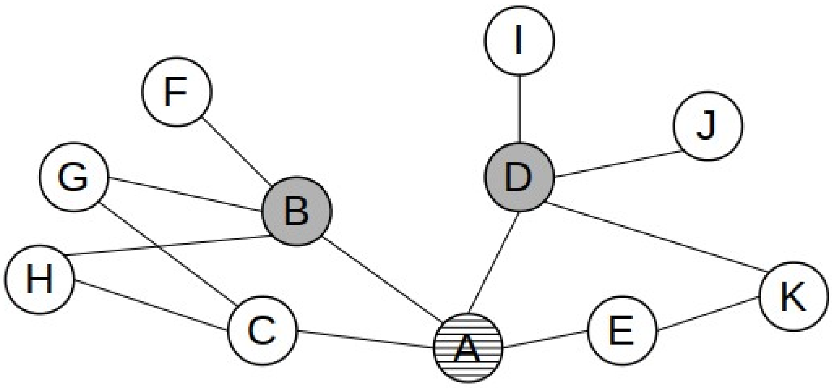

Figure 2.7: OLSR selects the lowest number of one hop neighbor to reach the greatest number of two hops neighbors.

2.8.4. Dynamic Source Routing Protocol (DSR)

The Dynamic Source Routing protocol (DSR) [9] is one of the most popular reactive routing protocols implemented for Ad hoc networks. Like other protocols, DSR allows the network to be decentralized and self-management without the need for an infrastructure. DSR is characterized by a simple design where the routing mechanism allows the discovery and maintenance of source routes in the Ad hoc networks. The use of source routing has made the routing packets simply loop free which avoids the need to use of up to date routing information.

Routing discovery is the mechanism that the protocol applies to find routing information between the source and the destination. The source node begins this process when it needs to send data to the target node and it does not have the routing information at that moment. When a node needs to send data to another node within the network, it initially searches within the cache for previously learned routes. If it did not find any route for that destination, it starts the process of route discovery over the network. To start the routing discovery process, the source node broadcasts a ROUTE REQUEST received by all nodes within its signal range. The ROUTE REQUEST message includes the source address, the target address, the message ID and a list of node addresses that received the message and rebroadcast it.

When a node receives a ROUTE REQUEST and it was the target node, it sends a ROUTE REPLY that includes a copy of the cumulative list of all intermediate nodes which are included in the ROUTE REQUEST message. On the other hand, when a node receives a ROUTE REQUEST message and that message has been seen before (the message has the same source address and has the same message ID), it is ignored by the node. The intermediate nodes which have received the message will rebroadcast it after appending its address to the list of intermediate nodes' addresses found in the message. In the case that intermediate nodes received a ROUTE REQUEST which already rebroadcast (node addresses in the intermediate nodes list of the message) will not rebroadcast it again. Upon receiving the ROUTE REPLY message, the node places it in the routing cache to be used to route subsequent packages to the same destination. The nodes that foreword the ROUTE REPLY use the same path as the ROUTE REQUEST message in case all nodes were bidirectional. In case of unidirectional paths, the nodes send a ROUTE REQUEST to the initiator node (the node that started the basic route discovery process).

The initiator node retains a copy of the data packets in the send buffer in case there is no valid routing in the routing cache. The time will be added to the packets in the send buffer and when the packages exceed the maximum time limit without being sent they will be dropped.

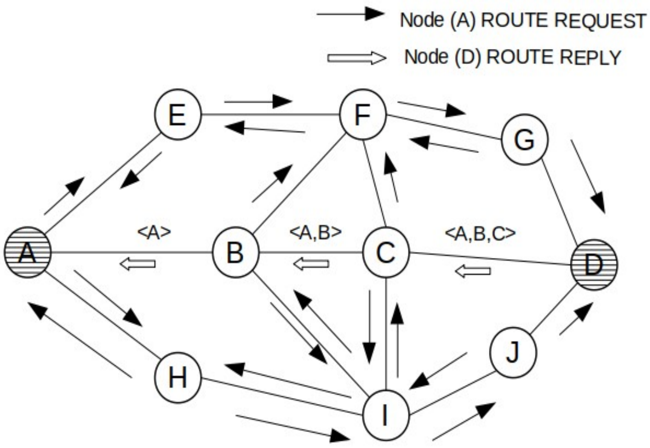

Figure 2.8: An illustrative example of the DSR route's discovery process.

Figure 2.8 illustrates an example of the DSR route discovery process. Node A established the routing discovery process to reach node D. The intermediate nodes added their addresses to the ROUTE REQUEST message and then rebroadcast it. When a node receives the request, it will send a ROUTE REPLY to node A using the same path that is included in the ROUTE REQUEST message which was received.

When the initiator node or the forwarding nodes send a packet to the next hop in the routing source, it is responsible for confirming the package arrival to the next hop. There are many methods that the protocol uses to make sure that the package is received by the next hop. However, in case the sender node does not receive confirmation of packet arrival, it will re-transmit it again, the transmission will be repeated until confirmation of packet arrival is received or maximum re-transmission is achieved. When the node reaches the maximum limit, it will send a ROUTE ERROR message to the initiator node. The initiator node will then delete the broken route and search for alternative routes from the cache. If there is an active route to the same destination, the packets are resent using the new route, otherwise, the initiator node initiates the new routing discovery process again.

As another example, In Figure 2.9, node (A) is trying to send data to node (E). Therefore, it pass the data through the path A,B,C,D,E. When node (D) start passing the data to node (E) it will discover that the link is broken. Therefore, It will inform the source node (A) that there is a broken connection by sending a ROUTE ERROR message.

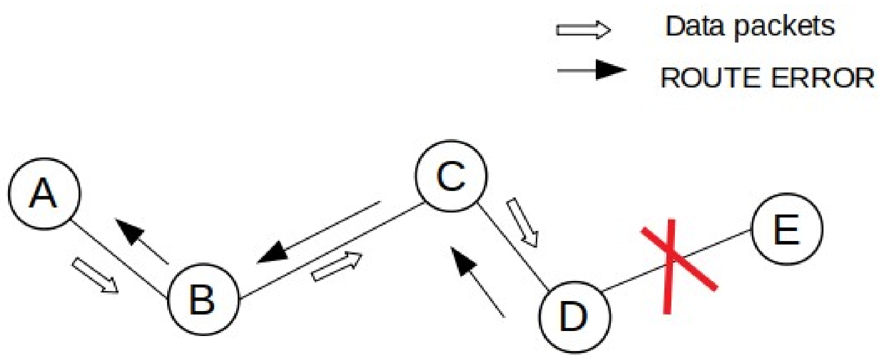

Figure 2.9: An illustrative example of the DSR route maintenance process.

2.8.5. Ad-Hoc On-Demand Distance Vector Protocol (AODV)

Ad hoc On-Demand Distance Vector [39] is one of the most popular reactive routing protocols. It is designed by Nokia to be used in MANETs. The protocol is a modified version of the Bellman-Ford algorithm. One of the most important features of this protocol is that it does not set up routing paths unless it is needed. The protocol relies on four types of routing messages to construct or maintain routing paths. The collected routing data is kept within the routing table that maintains only the active paths.

In the AODV-dependent networks, when one node within a wireless network needs to send data to a destination node that does not have a routing record in its table, it broadcasts a control packet called the Routing REQuest message (RREQ). This packet is sent to inquire about appropriate routing information from the adjacent nodes. The route request messages (RREQ) include the following fields: source address which includes the IP address of the sender, request ID which is used to distinguish between different requests, source sequence number that is used for ensuring that there is no redundancy, destination Address which includes the IP address of the destination, destination sequence number is used for ensuring that there is no redundancy, and hops count which is the count of hops to reach the sender.

When a node receives a message, it verifies its fields. If the message has been replied before, it is ignored. If it is not answered, it will be replied if the node has the appropriate routing entry. In case the node does not have the appropriate routing entry, the sender's address is retained to be used to reply to the sender request when appropriate routing record is available and rebroadcast the rout request RREQ after increasing the hops count.

If the node receives the request message and the node is the destination or has routing record for the destination, it unicasts a Route REPly message (RREP) that contains the following fields: source address, destination address, destination sequence number, hops count and lifetime. In Figure 2.10), node A broadcasted a routing request to get node I path. When the request reaches node I, that node unicasts a route reply message (RREP) using a specific path.

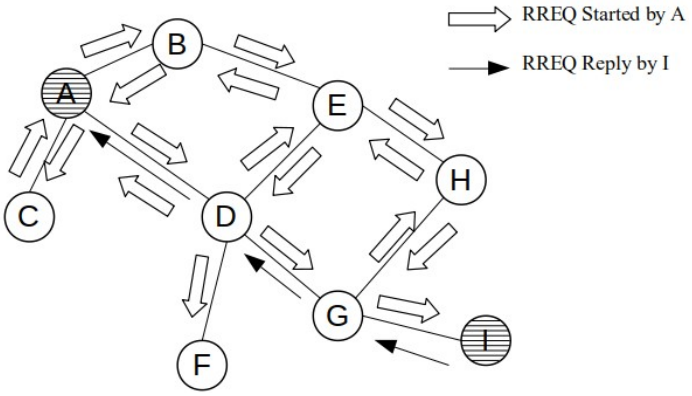

Figure 2.10: An illustrative example of the AODV route request process.

The nodes using this protocol send HELLO messages on specific time period to inform neighboring nodes that the links are still alive. This type of messages is not rebroadcast. If the node does not receive this message from an adjacent node, it sends an error message RERR to report the loss of connection to the node.

One of the main advantages of the AODV protocol is the ability to reduce control messages where it uses the unicasts messages to respond to route requests RREQ. AODV responds very quickly to changes in network topology, it refreshes the routing records at each connection attempt. The protocol saves memory and energy as the nodes do not respond to the route request more than once and also nodes' routing table does not retain more than one record for each destination.

On the other hand, it is difficult to determine an appropriate period to consider when the route is expired. In some cases, the link is considered expired, and in fact it is still active. AODV routing tables contain routing data for a limited number of nodes because the routing information is routed through specific paths to the sender to minimize routing overhead. The performance of this protocol is greatly reduced in large networks due to the decrease in the path duration.

2.8.6. Zone Routing Protocol (ZRP)

Zone Routing Protocol [46] is a hybrid protocol. It is designed to combine features of both reactive and proactive protocols. As it is clear from its name, the protocol is based on the concept of zones. These zones are overlapping in adjacent nodes. The routing zone has a specific radius measured by the number of hops. That is, all nodes within a node's zone should not exceed a specified number of hops.

The nodes belonging to the same zone are divided into two types, the peripheral nodes located on the periphery of the region, *i.e,* the distance from the central node equals to the maximum number of hops allowed, the second type is the interior nodes whereas the number of hops to reach them from the central node is less than the upper limit.

Figure 2.11 shows the zone of node A where the radius of node A zone is two hops. The nodes B, C, D, E and F are located within the node zone, while the node G and H are located outside the zone. The node B and G represent peripheral nodes.

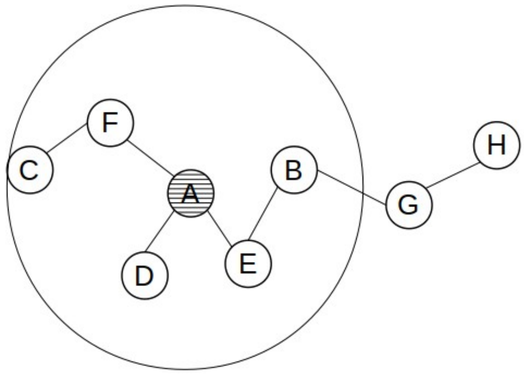

Figure 2.11: Node (A) zone includes all nodes within two hops from the node.

ZRP includes a number of components that help to route data. One of these components is the IntrA-zone Routing Protocol (IARP) and IntEr-zone Routing Protocol (IERP). IARP is a proactive link-state protocol with limited depth. This protocol maintains routing information for the nodes within the zone of the central node. IERP is an interactive routing protocol that routes data to nodes outside the zone of the central node.

Broadcasting that is mainly used in reactive protocols has been replaced with so-called Bordercast, where routing requests are sent to peripheral nodes only to reduce network congestion. Bordercast Resolution Protocol (BRP) uses the zone routing table which is maintained by IARP protocol.

To discover the neighbor's nodes and detect failed links, the ZPR relies on another protocol called Neighbor Discovery Protocol (NDP) that is provided by the Media Access Control (MAC) layer. NDP sends a HELLO message periodically, and the neighbor's nodes that received the message updates its routing table. The nodes that did not receive this message considers that the sender nodes no longer exist, therefore it will be deleted from the routing table.

When a node needs to send data to another node within the network, it checks the routing table maintained by IARP protocol to verify that the destination node is within the zone. If the destination node is within the zone, the data is routed using the routing information in the routing table. In case the routing data is not available for the destination node, the IERP protocol is used to send a routing request to the external nodes. Upon the receipt of the routing request, the peripheral nodes repeat the process as they check their own routing tables and if no routing data is available for the destination node, they send a rout request to their peripheral nodes. When there is appropriate routing data in the table, a routing response is sent to the sender node.

Chapter 3

Related Work

3. Chapter 3: Related Work

3.1. Introduction

Over the past years, many research papers have been presented that offer new ways to improve the performance of the DSDV protocol, and our research provides a new contribution to these researches. In this chapter, we review the structure and methodology of the DSDV, review the extended versions of the DSDV protocol and discuss some of their performance improvements and weaknesses points.

3.2. Highly Dynamic Destination Sequenced Distance Vector Routing Protocol (DSDV)

The DSDV protocol [6] was presented as an Ad Hoc network proactive loop free distance protocol. This protocol adds sequence number attribute for each route table. Nodes using DSDV periodically broadcast packets regarding routing information about themselves. Routing messages contain three fields: destination, hops count, and sequence number. Neighbors that received these messages update their routing tables accordingly. Updates will be applied on the routing table in certain situations, when there is no routing information about the destination in the routing table, the update message has a higher sequence number, or the update message has the same sequence number but with shorter path (fewer hops count). Any new update in the routing table will be immediately broadcast after increasing the metric parameter in the records by one. The protocol implements two types of periodic updates: full updates where all routing information from own table will be sent, and incremental updates routing information that has been modified since the last update will be broadcast. Figure 3.1 Illustrates an example of the DSDV routing exchange process.

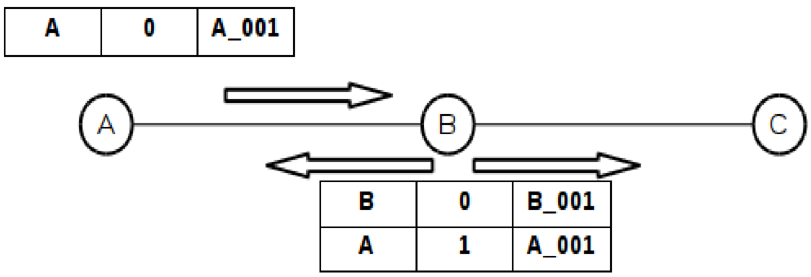

Figure 3.1: The routing information exchange in the DSDV protocol.

Beside destination, hops count and sequence number which form the routing message contents, the routing table has three more fields they are next hop, settling time and hold down time. Table (3.1) shows the content of node's (A) routing table.

Table 3.1: Routing table contents of node A.

Destination	Next hop	Metric	Sequence number	Settling time	Hold down time
A	A	0	A_0012	0	∞
B	B	1	B_0017	3	30
C	B	2	C_004	3	30

The routing table mainly contains the following fields:

Next hop: It represents the first node to be visited to reach the destination.

Metric: It is the number of nodes which the data packet will visit before reaching the destination.

Sequence number: It is the number used for distinguishing between old and new updates.

Settling time: It represents the time that the node will wait before broadcasting the incoming updates.

Hold down time: It represents the time that the node will wait before considering the record as expired (broken connection).

Each node maintains two tables having the same structure, the first table is called the advertisement routing table, this table is used to keep routing information that has been recently received and has not been re-sent. This type of routing information is retained for a period called (*settling time*). Routes that finish their waiting period are sent after a copy of them is kept in the second routing table. Routing data is used in the second table for routing data, and the contents of this table are periodically sent.

The protocol applies the concept of damping fluctuation. In some scenarios, the same updates may be sent through different paths at the same time. For various reasons the message may be delayed through the shortest path and the updates may reach nodes using the longest path. For example, in Figure 3.2 node (A) sends the update information through two paths, in case there is a network congestion on node (B). Node (F) receives node's (A) routing information through node (E) which in turn broadcasts it immediately. After a while the same update will reach node (F) with a better hop count through node (B). As a result, node (F) will broadcast the same update with different paths twice. To avoid unneeded updates and broadcasting, the authors in [6] presented the idea of settling time to damp the fluctuation.

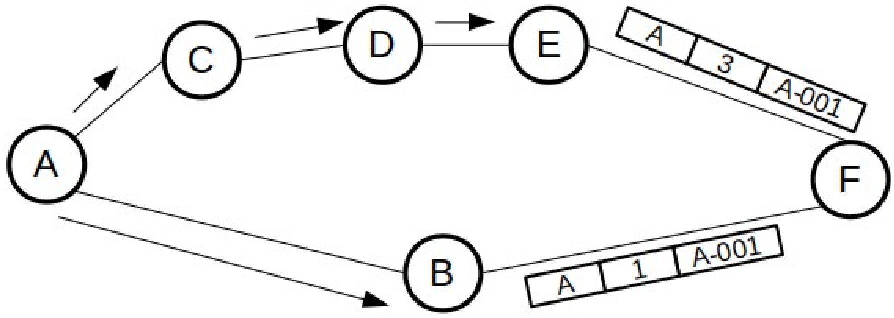

Figure 3.2: Network congestion in node B leads to the arrival of routing information over the longer path.

Many comparative studies showed that the protocol has a good performance in low mobility environments, but its performance recedes at high speeds and high-density ad hoc networked applications.

3.3. A Proactive Routing Protocol for Multi-Channel Wireless Ad-hoc Networks (DSDV-MC)

Unghee Lee *et al.* [41] enhanced the performance of DSDV protocol by utilizing multiple channels. The basic idea of the protocol is to use multiple channels so that many simultaneous data transfers can be made, thus increasing network capacity. The proposed scheme assumed that every node in the MANET equipping nodes with multiple network interface cards (NICs). The protocol was design to select one channel to exchange control messages and another one or more channels to transfer data messages. Routing table fields are similar to those in the DSDV routing table excepts a new field was used as an indicator for the channel number. DSDV-MC requires every node to advertise its routing information including the selected channel for data transmission. All nodes try to avoid overlapping channels by selecting a channel that has not been used by neighboring nodes. Simulation results have shown that the DSDV-MC increases network goodput and decreases in the dropped packets when number of channels increased.

3.4. An Efficient DSDV Routing Protocol (EFF-DSDV)

EFF-DSDV [18] overcomes the problem of stale routes, and thereby improves the performance of regular DSDV. In DSDV, the absence of an effective route in a node does not necessarily mean that there is no such route for neighbors. The protocol proposed two types of control messages ROUTE-REQUEST and ROUTE-ACK messages. In case a node lost the connection with another node it will try creating a temporary connection through its neighbors by sending a route request message ROUTE-REQUEST. In turn, the neighbors return the ROUTE-ACK if it has a valid route to the destination. When the node receives more than one reply, it will choose the most recent route, since each message contains the route plus the update time. In terms of dropped packets and end to end delay, the results of the simulation indicate that the performance of the Eff-DSDV protocol is superior to the generic DSDV.

3.5. Randomized DSDV(R-DSDV)

In this protocol [3], the authors considered an extension to the DSDV routing protocol for congestion control. R-DSDV consists of propagating routing messages according to a routing probability distribution, instead of a regular basis. An overloaded node can tune its own routing probabilities to the purpose of probabilistically diverting traffic to other paths, without overhad traffic. The protocol advertises the routing table according to probabilities, which determine independent advertisement rates for different nodes in the network. By reducing advertisement rates, a congested node is able to probabilistically reduce the amount of message traffic routed through the node itself.

3.6. Efficient DSDV Routing Protocol (E-DSDV)

The E-DSDV protocol [25] was proposed to reduce the end to end delay and congestion level in MANET networks. Delay efficiency is achieved by advertising the route advertisement message for a particular node immediately and discarding the packet with same sequence number which was arrived later despite the fact that it offers better route to that destination. The simulation results have shown that the end to end delay for packet transmission in the E-DSDV is less than the generic DSDV. Also, congestion level is reduced by choosing the different path which is not congested.

This protocol does not give importance to the length of the path and concentrates on paths that do not contain network congestion. The use of this protocol increases the end to end delay; *i.e.,* passing data over longer paths increases the time required to move from source to destination.

3.7. Adapting to Route-demand and Mobility DSDV (ARM-DSDV)

ARM-DSDV [33] is a proactive routing protocol based on DSDV. It was design to dynamically adapt in a totally distributed manner to changes in node mobility and workload route-demands. This protocol includes an algorithm to calculate node speed depending on the change in neighbors. The algorithm deals with two tables. The first table contains the neighbors since the last update. The second table contains the neighbors in the current update. The node speed is calculated by finding the number of nodes in the first table, which remained in the second table divided by the number of nodes in the second table. The speed of the node is used for controlling the time interval required for updates. The higher the speed, the less the update time. Another algorithm was proposed in this protocol to keep track of which destinations the node has forwarded packets to recently. In this way, a node does not have to send all routing information in every routing update if that part of information is not being used by other nodes. The simulation results show that for various mobility and workload scenarios, ARM-DSDV typically achieves better delivery ratio than DSDV. ARM-DSDV also achieves higher data delivery ratio than non-optimized DSDV.

3.8. Improved DSDV (I-DSDV)

I-DSDV [38] was presented to improve the packet delivery ratio in DSDV routing protocol. The authors suggest a novel message exchange scheme for invalid route reconstruction. The protocol suggests that If a node detects a broken link, it sends a message to find another valid link through the neighbors. On the other hand, the nodes that received this message will respond in case it has a valid route at that moment and this link does not pass through the node that sent the message. If the node that received the route request message itself needs this route, it also sends a route request message. When a node receives more than one reply, it chooses a path that contains fewer hops count that it carries the highest sequence number. Compared with DSDV, I-DSDV shows that it can adapt more quickly to frequent topology changes in MANETs, reducing the number of dropped data packets with little increased overhead at higher mobility rates.

The repairng process of broken links in this protocol requires an effective link with the same length as the broken link or less. The existence of this condition reduced the possibility of using the available paths only because it is longer. In our point of view the protocol should use any available path even if it is longer because this solution is temporary until the arrival of the next updates.

3.9. Optimized VANET DSDV

This protocol [31] was designed to suit high-speed environments like VANETs. It contains an algorithm to monitor the speed of the node. In case the node speed exceeds 25 m/s, the algorithm gradually reduces node's periodic update settling times. If the speed exceeds 40 m/s, the value of both factors remains at the lowest level. The performance of this protocol is the same of the DSDV at low speed. At high speeds, the protocol showed a significant improvement in throughput, packets delivery ratio and routing overhead.

This approach enhanced the DSDV performance, but it is not behaving very well in high diverse velocity environments. The neighbors of the high-speed node will not be informed about this node's speed, and consequently they will deal with the updates from these nodes as any other node. This will lead to a delay when the updates advertise the high-speed nodes. Processing updates coming from high-speed nodes quickly is necessary because these data lose their value quickly due to high diverse-velocity scenarios.

Chapter 4

Methodology

4. Chapter 4: Methodology

As previously mentioned there are several mechanisms which were proposed to enhance the DSDV protocol's stability. However, these mechanisms degraded the performance of the protocol, especially in the high diverse velocity environments. Therefore, in this work, we suggested a new mechanism based on modifying and including other performance parameters to the DSDV algorithm to enhance the performance of the protocol in the high mobility environments. To do that, we followed the scientific methodology in which we proposed the theoretical part and validated it using simulations. The methodology followed consists of the following five procedures:

- The nodes which receive an update routing information about neighbors within the scope or two hops away should advertise the received updates immediately without any delay.
- High speed nodes should gradually reduce the update intervals and settling time according to the speed.
- High speed nodes should inform other nodes about their speed mode to help them calculate settling and Hold Down Times.
- The nodes that detect a broken connection will try to recover it by sending a route request to the neighbors only.
- The nodes will prefer the routes through the lowest velocity nodes when they receive several routes to the specific destination with the same hops count. The age of the link between any two nodes depends on the speed of their movement and

direction. In case there is two fixed adjacent nodes, the link between them remains available. In the other hand, if these nodes are moving and in different directions, the age of the link is reduced. To increase the age of the link, we must rely on the slow nodes to forward information to ensure the stability of the communication links.

4.1. Discussion

In the DSDV internal operations, the goal of settling time is to ensure that the node has the shortest path to another node in the network. We found that the settling time should not be applied to all types of routes. For example, as illustrated in Figure 4.1, when node (A) received a routing information about any of its neighbor, it will wait for the specified settling time before rebroadcasting it to the other neighbors. Although node (A) will wait for the specified settling time, it will not get a shorter path to the neighbors because it is already having the best path. The shortest path in this case is only between the node and itself. This is how we applied the first step in our methodology.

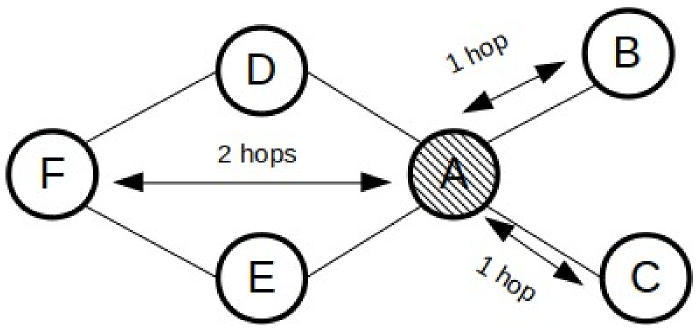

Figure 4.1: Applying settling time to one-hop or two-hops neighbors will not guarantee a shorter route.

The second and third steps in our procedure will affect nodes having high velocity. -The update period in the DSDV is fixed, and in most applications its value is fixed to 15 seconds. This period is considered very long in high diverse velocity situations. For example, Figure 4.2 illustrates a scenario where the node (M) is moving in high velocity and the other nodes having a fixed place or moving with low mobility. An intermittent line represents (M) signal range. At some points, node (M) will send its update to all nodes through its neighbors (E and F, in this case). Node (M) will leave the area and its neighbors will be changed into a few seconds later. The nodes in the network will lose the route to node (M) quickly, and node (M) will resend a new update after the update period expires. In our approach, we take care of this problem and suggest that the update time must be variable and mainly it depends on the node's velocity. The place of high velocity node is changed rapidly which causes nodes with high velocities to send their new routes more quickly to keep the nodes always connected with the remaining nodes in the network

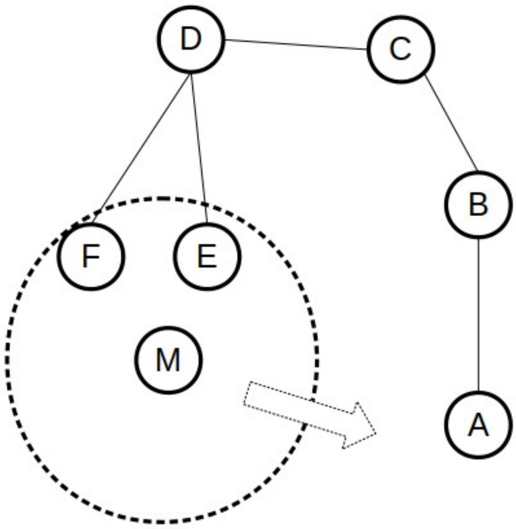

Figure 4.2: Applying Settling time on fast-motion nodes routing information leads to lose communication link before making use of it.

To consider the node's velocity in the DSDV calculations, we have modified the update time by including another parameter, *i.e.,* the speed of the node. The new suggested formula of the update time is as follows:

$$Updatetime = T_d - \frac{V_n}{V_{max}} \times (T_d - T_{min}) \qquad \text{Eq. (4.1)}$$

where:

T_d represents the default update time.

V_n represents the actual node velocity.

V_{max} is the maximum node velocity.

T_{min}: is the least update time period

In case the velocity of the node is low, or the node is fixed $V_n = 0$, and this means that the value of the update time equals the T_d value which is the default value in this case. Furthermore, when the velocity of the node is increased, the value of the update time will be decreased according. To keep the update time above zero the lower limit to the T_{min} value has been added.

Back to Figure 4.2, when nodes E and F receive an update routing information about node M, they will wait for the expiry of the settling time before re-sending this update to the other nodes. For every node which receives this update, it will apply the same policy which will lead to a considerable delay of receiving updates by the remote nodes. This type of delay can affect the performance of th DSDV protocol, especially when nodes move in high velocity. In Figure 4.2, the routing information of node M will reach node A after node M leaves the area, and its neighbor nodes are changed. Thus, we suggest that every node should inform every node about its velocity. The nodes that receive the routing updates should set their own settling and hold down times for the received record based on the velocity of the source node. The following formula will be suggested to adjust the settling time.

$$SettlingTime = T_s - \frac{V_s \times T_s}{V_{max}} \qquad \text{Eq. (4.2)}$$

where:

T_s: represents the default settling time

V_s : represents the velocity of the sender.

V_{max}: represents the maximum velocity.

The previous equation (Eq. (4.2)) estimates the settling time, and it will inversely proportional to the velocity of the source node. In this way, we can improve the availability of the routing information about high velocity nodes through the network for a shorter time. Furthermore, the velocity of the source nodes can be used for tuning the hold down time interval. We note that the routing information about the fast points will expire early. The following equation is suggested to set the holding down timer for the received routing records:

$$HoldsTime = \frac{T_d \times V_n}{V_{max}} \times (\alpha - \gamma) \qquad \text{Eq. (4.3)}$$

Where γ is the minimum limit and α is a constant value., which has the default value of 3. We can also use the added node's velocity to optimally select the most stable paths. For example, as illustrated in Figure 4.3, node A has two paths to node D, and the two paths have the same hops count. In this case, node A) will use only one path to send data to node (D. When node A receives routing information about node D through node C first, it will use this path to send data to node D. In this case, we argue that this node which has two paths to the same destination, and the two paths have the same hops count, it will select the neighbor with the slower velocity since it has more updated and correct entries.

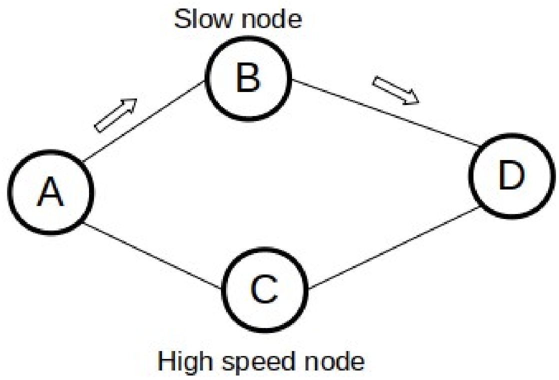

Figure 4.3: Reliability is improved by choosing the lowest speed nodes to pass data.

The last enhancement will that be considered in this study, is the ability to recover the broken connections. When a connection between two nodes is broken, this connection will not be recovered until receiving a new routing information even though there is a possibility to recover this connection in a shorter time. For example, as illustrated in Figure 4.3 the connection between node A and D is broken because of node's A movement, node A has another two paths to node D, but it will not know about these paths until node D sends its next periodic update. To overcome this situation, we suggested a new mechanism to send a recovery request to other neighbors to keep the link between two nodes connected if possible. Thus, in Figure 4.4 node A will send requests to both node B and C. In case node B or C has a connection to node D it will reply to the request otherwise it will do nothing.

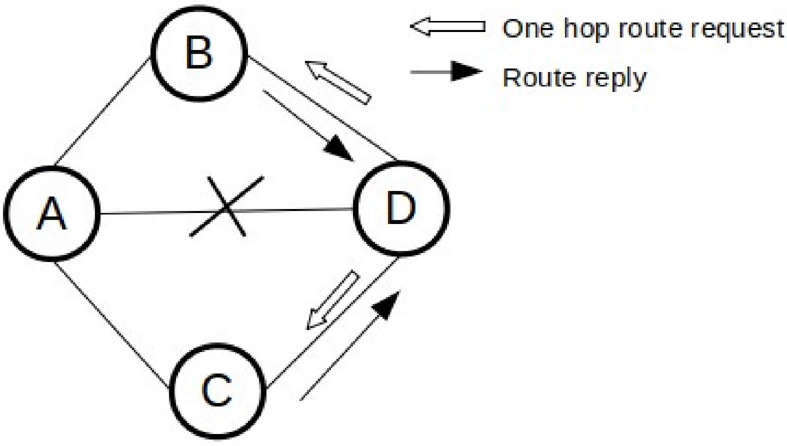

Figure 4.4: Some broken links can be repaired without having to wait for the next update

To consider all these modifications, in this work we have modified the generic DSDV message header format by including another two parameters they are node's speed and message type. The node's speed parameter will be used to include nodes' velocity, and the message type parameter which will be used for identifying the message type (normal update or recover connection request). Both parameters will be added by the source node in every update message.

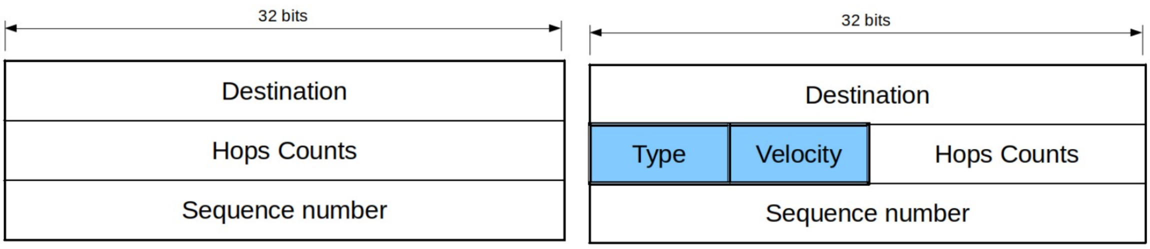

Figure 4.5: The DSDV header structure: (a) the generic format, (b) the proposed header format.

It's worth noting that, and as illustrated in Figure 4.5, the size of the header remains constant. After studying the generic DSDV header, we found that 4 Bytes (32 bit) have been allocated to the hop count parameter which is considered a huge number when compared it with the hops count size of other routing protocols like the OLSR and AODV, where the hops count size is 1 Byte in both of them. Therefore, we found that the size of the hops count argument in DSDV header can be exploited to achieve the goals of this work. In the new modification, we argue that 2 Bytes which are considered enough size which represents more than 65000 hops. We use the remaining two bytes to implement the new parameters speed and type. By using this technique new features will be added without increasing the header size.

As shown in Figure 4.5, the size of the new update message is still the same (12 Bytes). The proposed message has now two new parameters; type and speed mode. The type parameter will have two states: UPDATE or REQUEST. Thze same message will be used for sending updates or sending a route request. The second parameter (speed mode) will be used for informing the nodes about the current speed of the source node.

4.2. Mathematical Model to Estimate the Path Duration of Ad Hoc networks

To study the effect of the modifications we have applied to DSDV protocol. There are many tests that can be done, for example, a network can be built physically. We can also test the performance of the protocol using simulation applications or by building mathematical models that simulate the protocol mechanism. In our thesis we used two methods to verify the performance of the new approach (simulation and mathematical model).There are many studies that have focused on building mathematical models to study and analyze routing protocols for MANETs [20]. Nevertheless, existing models did not consider all factors that affect the duration of the course. This is due to the fact that including all factors make the construction of the mathematical model is a complex task.

Most of the previous studies analyzed the path duration in Ad hoc networks that rely on the reactive routing protocol such as DSR [9] and AODV [39]. For example, R. Raw et al. [32] built a mathematical model to estimate the path duration in Vehicle Ad Hoc Networks (VANET). The study was based on the protocol called Border-node based Most Forward within Radius (B-MFR). In this protocol, the border nodes are selected as a next hop whenever needed to direct the data. The study found that the duration of the path increases with increasing the signal range and decreases with the increase in the number of hops. However, the study assumed that all nodes move using the same speed and assumed that the link duration is measured for the nodes that move away from the source node.

G. Lim et al. [11] presented a new approach to estimate data path stability based on signal strength. The study analyzed the phenomenon of “edge effect” which occurs in dense networks because of the possibility of choosing the border nodes as the next hop node is greater. The study suggested that the selection of the next hop node should be based on the signal strength. The node having the strongest signal within node signal range is selected. A node whose signal strength is increased over time is also preferred because it moves towards the node.

K. Namuduri et al. [20] presented a mathematical model for studying the effect of the speed of the nodes, the range of their signals and nodes’ density on the path duration in reactive protocols. The study assumed that the selection of the next hop is a function of the Least Remaining Distance (LRD) to the intended destination. This study is considered as the first study that built a mathematical model to analyze the effect of nodes density on the path duration.

Narayanan Sadagopan et al. [28] analyzed the effect of mobility on the path duration in MANETs. The study considered the effect of relative velocity, signal strength and number of hops on the path duration. It analyzed these factors on various mobility models. The researchers combined mathematical modeling with simulations, where a number of statistics were collected from simulation applications and the mathematical model was constructed based on them. The study found that the path duration has a significant impact on the wireless network performance parameters such as throughput, packet delivery ratio and routing overhead. Furthermore, it found that for moderate and high velocities, and based on the mobility models used in their study, the Probability Density Function (PDF) of the path duration for paths of two or more hops can be approximated by an exponential distribution.

To the best of our knowledge, we did not find a mathematical analysis of path duration and the factors that effect on it that is targeting the proactive routing protocols, and especially the DSDV protocol. Therefore, in this research, we propose a mathematical model to estimate the path duration of the DSDV routing protocol and our modified version.

As noted in the background chapter, the mobility nature of the nodes significantly affects the performance of routing protocols. The most important metrics that can be used for estimating the effect of mobility are the link duration and the path duration. In this section, we present a mathematical model to estimate the duration of the link. Link duration is the amount of time the node has an active link to neighbors within the signal range. This period is affected by the distance of the neighboring node, mobility speed, and mobility direction. During this period, both nodes can exchange data. In the case that data is required for a node that is not adjacent, the duration of the path depends on the duration of the links between the nodes connecting the source and the target. However, the duration of the path depends on the shortest link duration within this path [28].

4.2.1. Assumptions

To simplify the process of finding a link duration we have developed a number of assumptions. In this mathematical model we assumed that the nodes within the scenario were uniformly distributed, and move in a random direction, as in the random way point model (RWP) because it is the most common used in the research community [20]. The DSDV protocol constructs the routing table based on the shorter path, *i.e.,* the path with the least number of nodes. In this mathematical model, we assumed that the nodes within the path between source and destination is located on a straight path so that we can find an approximate count of hops between the source and the target. The objective of this model is to study the effect of the mobility on the performance of the DSDV protocol and to compare its performance with the new protocol. Therefore, this study was not taken into consideration the effect of the number of nodes in the scenario, The effect of network congestion or the effect of other protocols on performance.

4.2.2. Probability Density Function of Relative Velocity

The relative velocity of a node A with respect to another node B is the velocity that node A would appear to have to an observer situated on node B moving along with it (Figure 4.6.

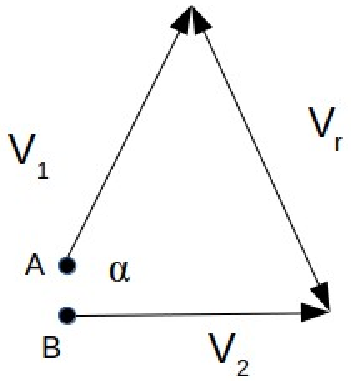

Figure 4.6: The velocity at which the nodes A and B diverge.

The relative velocity value can be found using the following rule [32]:

$$v_r = \sqrt{v_1^2 + v_2^2 - v_1\ v_2\cos(\alpha)} \qquad \text{Eq. (4.4)}$$

where:

V_r is the relative velocity

V_1, V_2 are the velocity of node A and node B

α is the angle between V_1 and V_2

The angle between the two moving nodes is between 0 and π. The Probability density Function (PDF) of α is 1/π. To simplify the process of finding the probability distribution function of the relative velocity V_r, we assumed that the angle between the two nodes is fixed at π/2. This value represents the average values of possible angles. In this case, the relative velocity V_r equation becomes:

$$V_r = \sqrt{V_1^2 + V_2^2} \qquad \text{Eq. (4.5)}$$

The equation of relative velocity in this form is identical to the circle equation. Whereas the equation represents a circle of radius of V_r as shown in Figure 4.7. Therefore, we can use the rules of the circle to find the Cumulative Density Function (CDF) of the relative velocity.

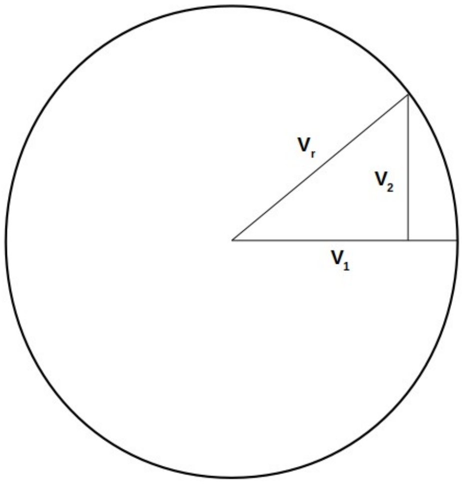

Figure 4.7: The relative velocity representation by using equation of circle graph.

The minimum value of the relative velocity can be represented by the equation:

$$V_r = \sqrt{V_{1(min)}^2 + V_{2(min)}^2} \qquad \text{Eq. (4.6)}$$

where:

$V_{r\ (min)}$ is the minimum relative velocity.

$V_{1(min)}$, $V_{2(min)}$ are the minimum velocity of node A and node B.

The highest relative velocity between the two nodes (A and B) is represented by the equation:

$$V_r = \sqrt{V_{1(max)}^2 + V_{2(max)}^2} \qquad \text{Eq. (4.7)}$$

where:

$V_{r\ (max)}$ is the minimum relative velocity.

$V_{1(max)}$, $V_{2\ (max)}$ are the maximum velocity of node A and node B.

From the above we can conclude that the relative velocity V_r will be limited between the value of $V_{r(min)}$ and the value of $V_{r(max)}$, therefore, the cumulative function of the relative velocity V_r will be represented by the following equation:

$$F_{VR}(vr) = \frac{\pi\left(Vr - V_{r(min)}\right)^2}{\pi\left(V_{r(max)} - V_{r(min)}\right)^2} \qquad \text{Eq. (4.8)}$$

CDF in this situation is the ratio between the area enclosed between circle with Vr radius and the circle with $Vr_{(min)}$ radius to the area enclosed between the circle with $Vr_{(max)}$ radius and the circle with $Vr_{(min)}$ radius as shown in Figure 4.8

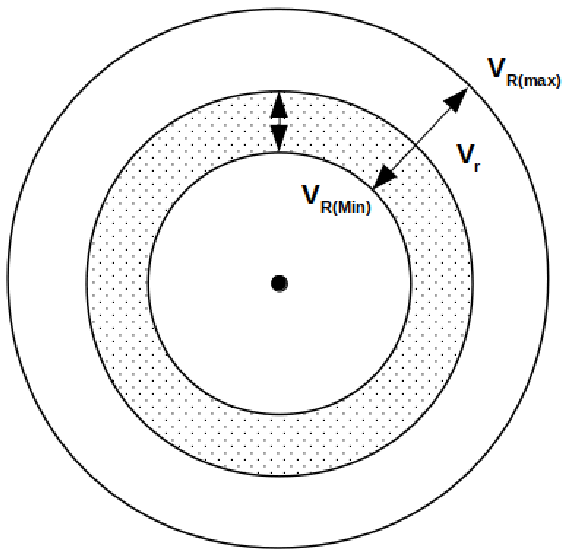

Figure 4.8: Relative velocity cumulative function: The ratio between the shaded area and the area confined between V(min) and V(max)

We can find the PDF of the relative velocity $f_{VR}(Vr)$ by finding the derivative of the cumulative equation (Eq. 4.8). Therefore, the probability distribution equation is represented by the following equation:

$$f_{VR}(vr) = \frac{2\,(Vr - V_{r(min)})}{(V_{r(max)} - V_{r(min)})^2} \qquad \text{Eq. (4.9)}$$

From Eq. 4.9, we can find the expected value of the relative velocity $E_{VR}(Vr)$ based on the following equation:

$$Expected_{VR}(vr) = \int_{V_{r(min)}}^{V_{r(max)}} 2\ Vr\ \frac{(Vr - V_{r(min)})}{(V_{r(max)} - V_{r(min)})^2}\, dVr \qquad \text{Eq. (4.10)}$$

4.2.3. Probability Density Function of Distance

Given two adjacent nodes, they can exchange the data directly as long as they are within the signal range of each other. Since the nodes in MANETs are always moving, the traveled distance of a node to get out from the range of another node depends on two parameters: the distance between the two nodes and the direction that the node will take during the movement. In Figure 4.9, node A broadcast range is a circular area with radius R. The node B falls within the range of node A coverage area. In this case, the probability of the distance r between nodes A and B can be found by finding the CDF, which is the following equation:

$$F_R(r) = \frac{\pi\, r^2}{\pi\, R^2} \qquad \text{Eq. (4.11)}$$

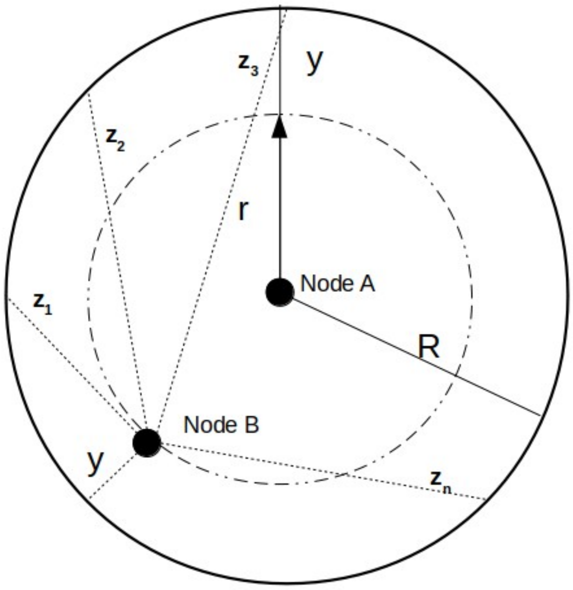

Figure 4.9: An example shows the probability of the length of the distance between two nodes and shows the paths that the node can take.

By finding the derivative for the CDF of the distance between nodes A and B, we can obtain the PDF for the distance between the two nodes as follows:

$$f_R(r) = \frac{2\,r}{R^2} \qquad \text{Eq. (4.12)}$$

From Eq. (4.12), the PDF of the shortest distance to leave the range of node (A) can be expressed by the following equation:

$$f_Y(y) = \frac{2\,(R-y)}{R^2} \qquad \text{Eq. (4.13)}$$

As a result of the movement of th two nodes, node B can take any path as it moves ($d1$, $d2$, $d3$, ... dn). The probability of any path being used uniformly distributed over all distances ranging from the minimum distance needed by node B to exit the signal range of node A represented by (y), and the longest distance that node B can pass before exiting the range of node A represented by distance ($2R$). Therefore, the PDF of choosing a path from the set of paths to be followed by node B will be according to the following equation:

$$f_M(m)=\frac{1}{2R-y} \quad \text{Eq. (4.14)}$$

As noted above, the distance needed by node B to leave node A coverage area depends on two factors: the probability of the distance between node B for node A P(r) and probability of the path to be followed by node B P(m). Since both variables are independent, the PDF for the traveled distance (z) will be:

$$f_Z(z)=\frac{1}{2\ R-y}\frac{2\ (\ R-y\ )}{R^2} \quad \text{Eq. (4.15)}$$

The expected distance is as follows:

$$E_Z(z)=\int_{y}^{2R} z\cdot f_z(z)\ dz \quad \text{Eq. (4.16)}$$

4.2.4. Estimation the number of hops from source to destination

In this mathematical model we have assumed that the nodes move within a square-dimensional area. If we assume that the nodes in a square area having side's length of one-unit. Therefore, as illustrated in Figure 4.10 the average distance between any two nodes within this square area is as follows:

$$D\approx 0.52140543316472067833 \quad \text{Eq. (4.17)}$$

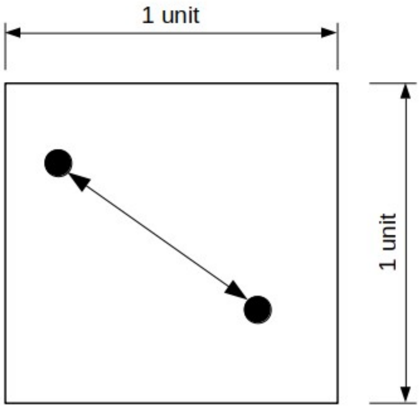

Figure 4.10: Average distance between two nodes.

If the length of square base is L, the average distance between two nodes within this area is:

$$AverageDistance \approx 0.52140543316472067833 \times L \qquad \text{Eq. (4.18)}$$

From Eq. (4.12) we can find the expected distance between two adjacent nodes as follows:

$$E_R(r) = \int_0^R \frac{2r^2}{R^2}\, dr \qquad \text{Eq. (4.19)}$$

Figure 4.11 shows an example to illustrate both concepts where r represents the distance between two adjacent nodes and the average distance represents the distance between the source and the destination.

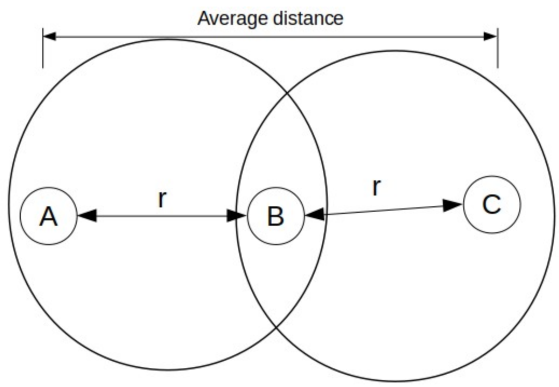

Figure 4.11: Number of hops equals the average distance between the nodes in general and the expected distance between two nodes

From the above we can find the expected number of hops as follows:

$$E_H(h) \approx \frac{AverageDistance}{E_R(r)} \qquad \text{Eq. (4.20)}$$

4.2.5. Probability Density Function of Link Duration

Based on the relationship between distance, velocity and time, the link duration will be according to the following equation:

$$t = \frac{z}{vr} \qquad \text{Eq. (4.21)}$$

Since the link duration value is based on two random variables V_r and z, the probability density function of the link duration is represented by:

$$f_T(t) = \int_{Vr_{min}}^{Vr_{max}} Vr \ f_{z\,Vr}(Vr.t\ ,\ Vr)\ dVr \qquad \text{Eq. (4.22)}$$

Since Vr and z are independent variables We can rewrite the equation as follows:

$$f_T(t) = \int_{Vr_{min}}^{Vr_{max}} Vr \; f_Z(Vr.t) \; f_{VR}(vr) \, dVr \qquad \text{Eq. (4.23)}$$

4.2.6. Probability Density Function of Path Duration

The path duration depends on the links' duration of the nodes that are located between the source and the destination. In Figure 4.12 the duration of the whole path equals to the shortest links' duration because any interruption along the path leads to stopping the transfer of data from the source to the destination [20]. Therefore, the path duration can be expressed as follows:

$$t_{path} = minimum\ (t_1, t_2, t_3, t_4, \ldots\ldots, t_{n-1}) \qquad \text{Eq. (4.24)}$$

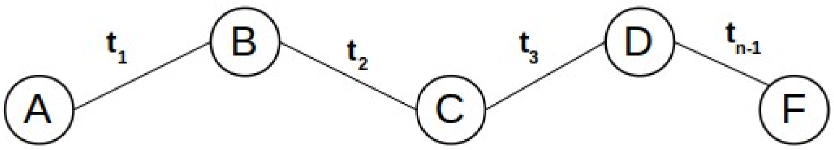

Figure 4.12: Path duration depends on the least link duration between path's nodes

By using Baye's theorem [20], the PDF of t_{path} can be expressed as follows:

$$f_{T\,path}(t\;path) = E_h \cdot f_T(t) \cdot C_{T\,path}^{E_h - 1} \qquad \text{Eq. (4.25)}$$

Where C_{Tpath} is the complementary CDF of T_{path}. Which can be expressed as follows:

$$C_{Tpath} = 1 - F_{Tpath} \qquad \text{Eq. (4.26)}$$

By substitution Eq. (4.26) in Eq. (4.25), The equation becomes as follows:

$$f_{T\,path}(t\,path) = h \cdot f_T(t) \cdot (1 - \int_0^{t\,path} f_T(t))^{h-1}$$ Eq. (4.27)

Therefore expected path duration is given by:

$$E_{Tpath}(tpath) = \int_0^a t_{path} \cdot f_{Tpath}(t_{path})\, dt_{path}$$ Eq. (4.28)

4.2.7. DSDV Path Duration

Each node between the source and destination that receives new information about a new path is waiting for a specific period (settling time) to make sure that the node got the shortest path before re-sending the new path information. The actual path duration does not include the waiting periods in the nodes between the source and the destination. Therefore, the path duration of the DSDV protocol is:

$$DSDV_T = E_{Tpath} - (E_h - 2) \times settlingTime$$ Eq. (4.29)

In this equation, we exclude the duration of settling time in both the source and the destination because the source does not apply the waiting period on its routing information. As for the destinaion node, it uses the routing information as soon as it arrives and does not wait until the settling time period is over.

The nodes that use the DSDV protocol update the routing data and their locations within the network every specific time period (update period). The beginning of the actual path duration starts from the moment the updates are received, and in case that the path duration has expired, the protocol does not renew the path until the end of the update period. Thus, the percentage of useful time is:

$$Useful\ time = \frac{DSDV_T}{Update\ \ period} \qquad \text{Eq. (4.30)}$$

4.2.8. The New DSDV Path Duration

In DSDV protocol, the settling time parameter is used for ensuring that the node receives the shortest path. However, in our approach this parameter is not used (settling time =0) in the case of dealing with nodes' routing information that is away one or two hops, so the path duration of the new DSDV in this case is as follows:

$$NewDSDV_T = E_{Tpath} - (E_h - 4) \times settlingTime \qquad \text{Eq. (4.31)}$$

The settling time in the new DSDV related to velocity according to the following equation:

$$SettlingTime = T_s - \frac{V_s \times T_s}{V_{max}} \qquad \text{Eq. (4.32)}$$

The expected velocity of sender nodes in the mathematical model can be expressed using the following equation:

$$E_V(V_s) = \int_{V_{min}}^{V_{max}} \frac{V_s}{V_{max} - V_{min}} dV_s \qquad \text{Eq. (4.33)}$$

The value of settling time for the nodes which is more than two hops away from destination are less in this protocol as its value decreases with the increase of the velocity of the node. Thus, in this case it is expected that the lost period is lesser, and the path duration is longer.

It is also expected that the duration will be greater because the value of the update period decreases with increasing the node's velocity to keep it consistent with the path duration. The update period in the new DSDV related to velocity is calculated according to the following equation:

$$Updatetime = T_d - \frac{V_n}{V_{max}} \times (T_d - T_{min}) \qquad \text{Eq. (4.34)}$$

The expected velocity of receiver nodes in the mathematical model can be expressed using the following equation:

$$E_V(V_n) = \int_{V_{min}}^{V_{max}} \frac{V_s}{V_{max} - V_{min}} dV_s \qquad \text{Eq. (4.35)}$$

Finally, the useful time of this protocol can be expressed as follows:

$$Useful\ time = \frac{NewDSDV}{Update\ \ period} \qquad \text{Eq. (4.36)}$$

4.2.9. Performance Analysis

To compare the path duration of both the new extended version of the DSDV and the generic DSDV, we have built two scenarios as follows. As we assumed at in section 4.3, the scenario will be in a square area, and its diminsions are 1000m * 1000m. The node signal range is the same for each node and fixed at 250 meters. The node speed is between 0, 5, 10 and 30 m/s. These values were adopted to match the values used in [20]so that we can compare the results later. Table (4.1) summarizes the parameters and their values.

Table 4.1: Mathematical model parameters

Parameter	Value
Simulation area	1000m * 1000m
Signal range (Radius)	250m
Nodes' velocity	5, 10, 15 , 20, 25, 30

After making the necessary calculations we got the following results.

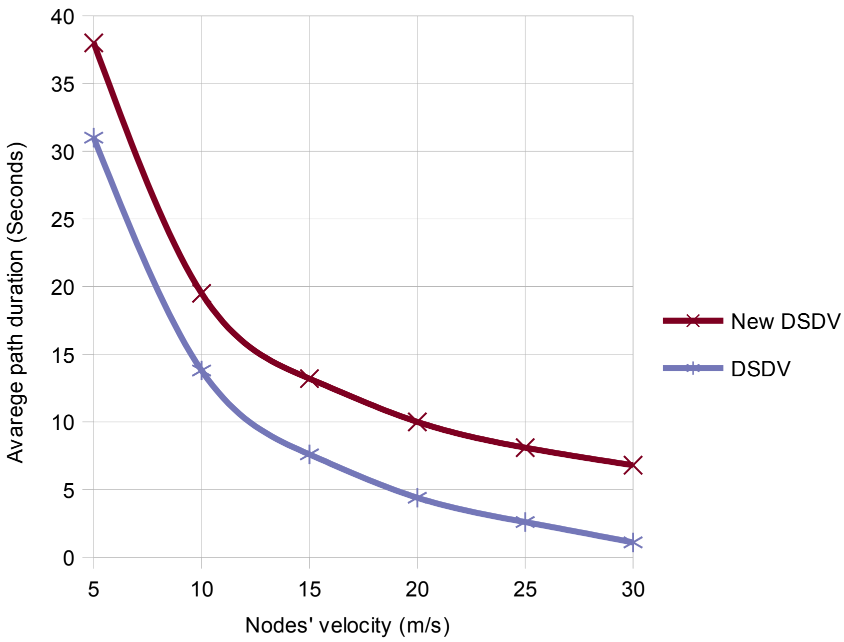

Figure 4.13: Comparative study using the mathematical model: Path duration vs. nodes velocity.

Figure 4.13 illustrates the relationship between the duration of the path and the change in nodes' speed. It is clear from Figure 4.13 that the path duration decreases with increasing speed, and the path duration is significantly reduced when the speed exceeds 10 m/s. It is also noted from Figure 4.13 that the path duration in the new DSDV was better than the generic DSDV since the new DSDV does not apply the same settling time on all routing information in the same amount.

Figure 4.14 illustrates the relationship between nodes' speed and utilization rate of path duration. As for the time utilization rate of the node, both protocols behave very well and have good path duration at low speeds. At high speeds, the utilization rate of path duration was relatively low. It is also noted that the new DSDV showed a higher utilization of the duration of the path compared to the DSDV, because the periodic update in the new protocol is not fixed and decreases with increasing speed, which reduces the wasted waiting time.

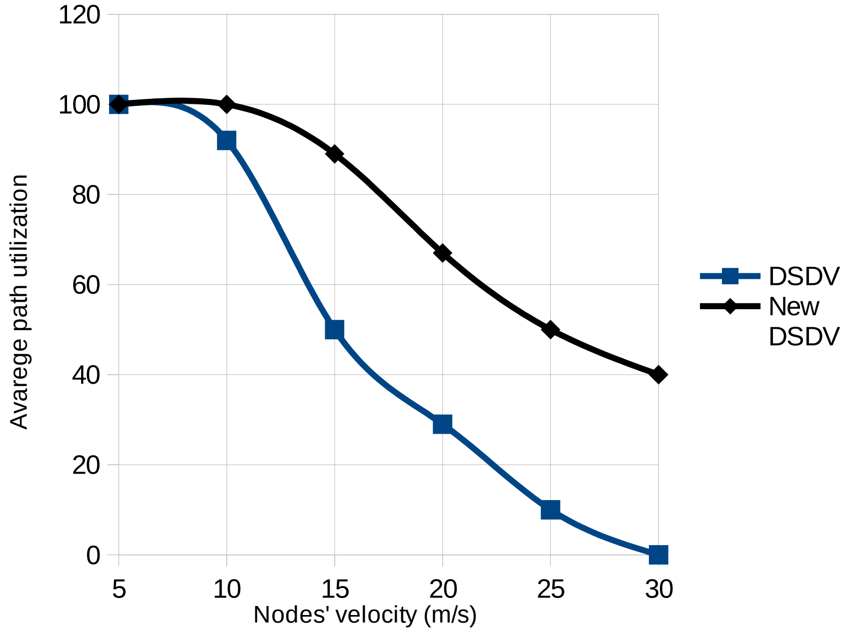

Figure 4.14: Comparative study using the mathematical model: Path utilization vs. nodes velocity.

Chapter 5

Simulation Results and Analysis

5. Chapter 5: Simulation Results and Analysis

To make sure that our modifications to the DSDV protocol will improve its performance of DSDV routing protocol we have done a number of different scenarios for MANETs using NS3 simulation application. In these scenarios, we applied the same conditions to a number of routing protocols, including the proposed protocol. Initially, the proposed protocol was compared with the original protocol DSDV. We have also compared it with a number of DSDV subsequent protocols such as I-DSDV, E-DSDV and O-DSDV. The addition of these protocols to our comparison study because these protocols are similar to our proposed approach in some characteristics. We have explained the characteristics of these protocols in the related work chapter and explained their shortcomings from our point of view.

There are many techniques to analysis and modeling network components such as mathematical modeling, software simulating, hardware emulating or real-life measurements and experiments. Most of these techniques are expensive, complex and time-consuming except simulators. Simulators are software used for modeling network systems to identify, analysis and quantify the interaction between various network devices and software.[30]

Ns3 is a new simulator written from scratch for research and educational purposes. Intended as a replacement for the popular NS2. It has been developed as an open source discrete event network simulator which is model the working of a system as a discrete sequence of events in time. The simulator is licensed under the GNU GPLv2 license. Unlike commercial simulators ns3 does not come with a GUI interface, the users need to write scenarios' scripts using python or C++. NS3 is actively maintained and well documented while NS2 is only lightly maintained. Ns-3 provides a lower base level of abstraction compared with NS2 [30].

5.1. Main Simulation Objects

the users of NS3 need to write a script in C++ describing the main element in their scenario. They should describe number of elements, the area where the scenario where applied and every protocol and devices need to be used. One of these elements are nodes. In a communications network, a node is a device that can receive, create, store or send data along distributed network routes. Nodes in NS3 can be described as a container that hold the devices, applications, protocols etc for every element in the scenario. Thus, every element is represented by a node and every node contains the elements Software, devices protocols etc. [29].

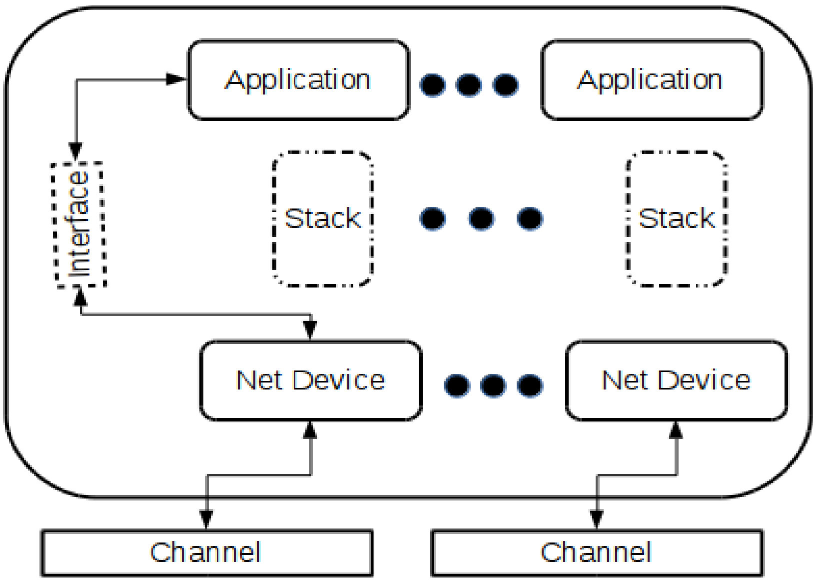

Figure 5.1: NS3 node architecture.

The applications in NS3 are an abstraction of real-life user programs that generate some traffic while using them on the network. These applications are used for generating and consuming packets through the network where the packets are generated in the sender nodes and consumed in the receiver nodes. In NS3 net devices are represents the physical interface on a node (such as an Ethernet or WiFi) and the software driver for this interface. The net devices are used in nodes in order to enable the Node to communicate with other Nodes in the simulation via Channels. The researchers have also to specify the channels between nodes which is in NS3 are an abstraction of a physical connector between a set of net devices [29].

In order to simulate the reality, the mobility should be added to the nodes in the scenarios. Many mobility models are available in NS3 to describe the nodes' mobility like Random Waypoint Mobility Model, Gauss-Markov Mobility Model, Exponential Correlated Random Mobility Model and others. These models are used to place nodes, track and maintain the “current” Cartesian position and speed of a node, trace source which can be used to trace the course changes of a mobility model [29].

5.2. Network Tracing

The purpose of simulating network systems is to collect and analyze data about a part of the system, or a specific protocol within the system or the mechanism of transmission of data within the system, which enables us to analyze the performance of the system and determine the impact of the modification of the system on the performance. The Ns3 Simulator provides a set of per-configured trace sources. Users also may add their own trace sources and sinks. Users provide trace sinks and attach to the trace source. The trace source will collect information about the event that has been tracked and send this information to the connected trace sink. In the trace sink users can add their code to an analysis and collecting data that sent from all trace sources. There are multiple trace levels in NS3 high level where the trace source and trace sink are predefined. Users only need to connect the required source to the required sink. In the mid-level the trace sources are predefined, and the user has to build their own trace sink. The user has to modify the core of the system to add new trace sources and sinks in low level methods. NS3 provides the ability to record all the traced information in a (.tr) or (.PCAP) files. The size of these files may reach a couple of gigabytes. These files may contain many unnecessary data for an analyst. Therefore, its better of the user to build its own tracing methods of functions[29].

5.3. NS3 Visualizer

Mentioned previously ns3 has not GUI interface. The simulator also does not visualize the desired scenario while it gives us the ability to use other application. The simulator can save all the required information for visualizing the scenario in (.xml). These (.xml) files can be used by NetAnim to visualize NS3 scenarios. NetAnim is an offline network animator tool which now ships along with the NS3 packets. It can animate the ns-3 network simulation using an XML trace file that is generated as an output during simulation. Therefore, Scenarios can be visually monitored and analyzed[29].

5.4. Performance Evaluation

To evaluate the performance of our approach and compare it with the performance of Protocol DSDV and its subsequent versions. We adopted a number of quantitative metrics. This section contains a brief description of these metrics that will be used for evaluating the performance of MANET routing protocols. We have used these metrics to evaluate the performance of the four routing protocols in this research (DSDV, I-DSDV, E-DSDV, O-

DSDV, and NEW-DSDV)

- *Packet delivery ratio*: It is defined as the ratio of data packets delivered to the destinations to those generated by the constant bit rate sources CBR.
- *Throughput*: It is the total number of bits that are successfully delivered to the destination in a given time period.
- *End-to-End delay*: It is defined as the average time delay for data packets to reach from the source node to destination node, this includes all possible delay that was caused by buffering, interface queuing and data re-transmission.
- *Normalized routing overhead*: It is defined as the total number/size of routing packets transmitted per data packets.

5.5. Simulation Setup

We built three different simulation scenarios to measure the performance of the modified version of the DSDV protocol and compare the results with four routing protocols considered in this study. The first scenario was built to measure the performance in diverse load environments. We repeated every experimenttwelve times using different number of nodes. The second scenario was built to measure the performance in diverse velocity environments where every node in has a different speed. The scenario was repeated multiple times with different pause time. The last scenario was carried out to compare the performance among the routing protocols based on different speed environments. All the nodes in this scenario have the same speed. The experiment was repeated several times with a new speed value for all nodes in each iteration. The simulation area in the three scenarios is fixed to 750m x 750m, This area is represent a small residential district, a football stadium or a traffic intersection whereas they are the most suitable places for Ad hoc networks. The transmission range of each node is set to 250m(ns3 defult value). The UDP control protocol has been used in our scinarios because it is used in many Ad Hoc network applications because its energy saving, since nodes in Ad Hoc networks are limited in resources The duration of each scenario is fixed to 100s. Nodes mobility was based on random waypoint model. Table (5.1) summarizes these parameters along with their values.

Table 5.1: Simulation parameters and their values.

Parameter	Value
Area	*750mx750m*
Transmission range	*250m*
Duration	*100s*
Traffic sources	*CBR (512 Bytes)*
Mobility model	*Random Waypoint*
Transport protocol	*UDP*

The results of our study were split into three scenarios as in the following sub-sections.

5.6. Dense vs. Sparse MANETs

In this scenario, the number of nodes varied from 10 to 60 with an increment of 10 nodes per each experiment run. The pause time is initially set to zero and node's speed is fixed (30 m/s). The rest of the parameters remained unchanged and given values as described in Table (5.1). The objective of this scenario is to study the effect of increasing the number of nodes on the performance. Therefore, we kept the rest of the variables constant except for the number of nodes. The reason for our choice of speed is 30 m / s is that there is no significant difference in the performance of these protocols at low speeds. The simulation results of this experiment are shown in the Figures (5.2, 5.3, 5.4 and 5.5) where Figure 5.2 illustrates the effect of increasing the number of nodes on the Packet Delivery Ratio (PDR); Figure 5.3 shows the effect of increasing the number of nodes on the network throughput; Figure 5.4 displays the relationship between increasing number of nodes and the average End to End delay; And finally, Figure 5.5 presents the relationship between increasing the number of nodes and the routing overhead.

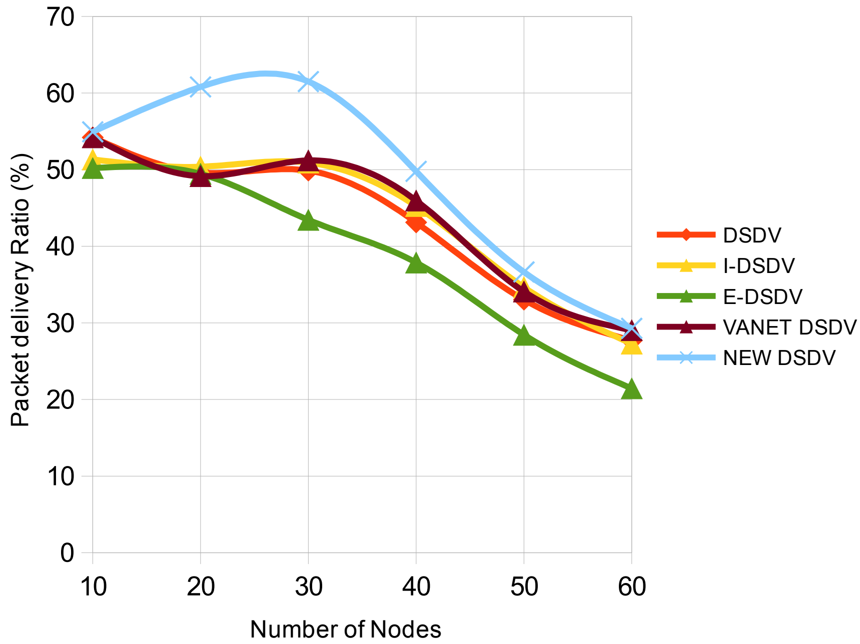

Figure 5.2: Performance comparative chart - packet delivery ratio vs. number of nodes.

The increase in the number of nodes will increase the number of effective links between the source and the destination. Figure 5.2 shows that the ratio of delivery of the package increases with the increase in the number of nodes, However, the high rate of delivery of the package will decline as a result of increasing the number of nodes to a certain limit (in this scenario was 25). increasing the number of nodes leads to an increase in the volume of control data exchanged over the network, which in turn leads to loss of part of the transmission bandwidth.

The same applies to network throughput, where the increase in the number of nodes leads to increased throughput due to the increase in the number of available links between the nodes. The large rise in the number of nodes leads to network congestion, which in turn leads to a decline in network throughput.

By refereeing to Figure 5.2, we observed that the E-DSDV protocol had a PDR and throughput similar to other protocols' when the number of nodes was few. This is because the presence of a few nodes means that there are only a few paths available between them. These tracks are often considered shorter because they are the only available tracks. In this case there is no difference between the performance of the E-DSDV protocol and the rest of the protocols. As the number of nodes increases, the number of available routes increases. In this case, the other protocols are distinguished because they were designed to select the shortest path. On the other hand, E-DSDV protocol was designed to select the first available path.

We also observe from Figure 5.4 that the increase in the number of nodes leads to delay of packets delivery. The increase in the size of the control data transmitted over the network Causes network congestion, which leads to delay in data delivery to the destination.

Figure 5.5 shows that the routing overhead increases with the increase in the number of nodes, this applies to all considered protocols. This increase was lower in both the E-DSDV protocol and our modified version. In case of the E-DSDV protocol, the nodes update the routing tables only if the routing information updates has a sequence number higher than the sequence number of the available data. The nodes do not re-broadcast routing information unless there is a higher sequence number updates. All these factors led to a lower routing overhead for the E-DSDV protocol. In case of our modified protocol, the ability to select more stable routes enabled the protocol to reduce the routing overhead.

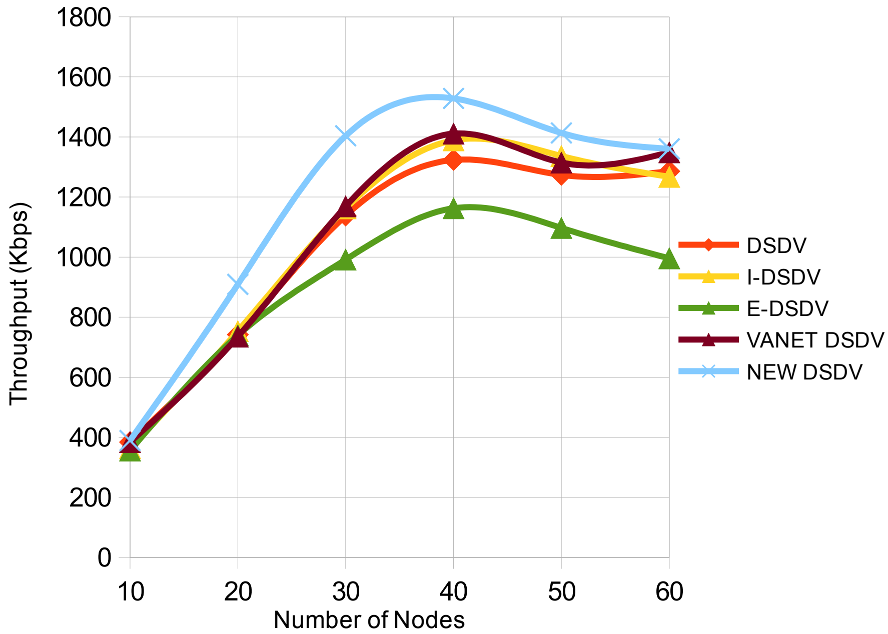

Figure 5.3: Performance comparative chart - Throughput vs. number of nodes.

Based on the above discussion we have the following findings: *(i)* The new DSDV version has the same behavior as the other protocols, but it showed a noticeable improvement in terms of PDR; *(ii)* The overall performance of the new modification is better in sparse networks compared to dense networks, whereas the difference in packets delivery ratio was about 10% when the number of nodes was fixed to 30; *(iii)* In terms of throughput, the new protocol outperforms the others in all cases, but the results were close to the others when there are very few or very high number of nodes;

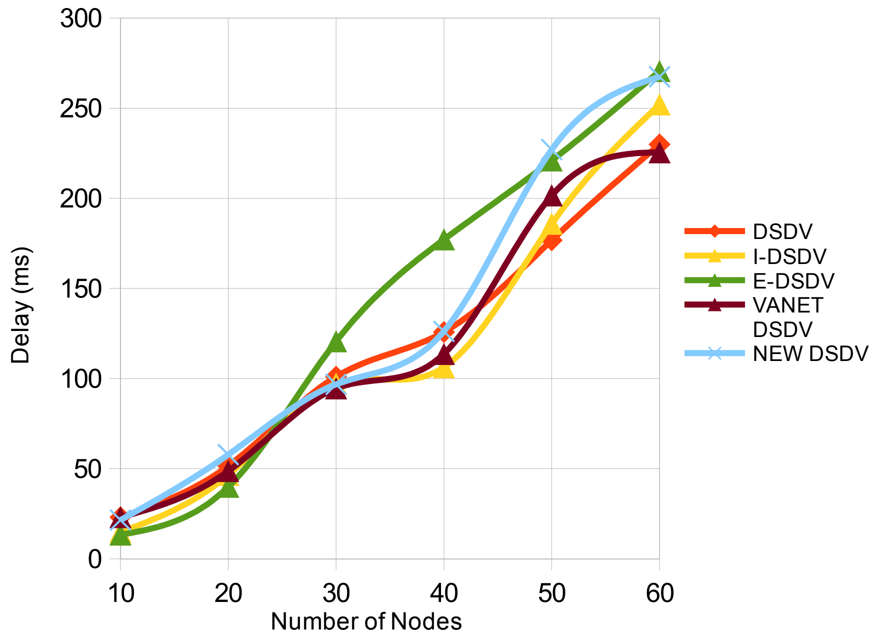

Figure 5.4: Performance comparative chart - end to end delay vs. number of nodes.

(*iv*) The average End to End delay in the new protocol was not improved since the average delay was close to other protocols, but when the number of nodes was increased, the average delay was also increased significantly compared to the others; (*v*) And finally, the routing overhead analysis showed that the new protocol outperforms the others except for the protocol E-DSDV which showed a low level of routing overload.

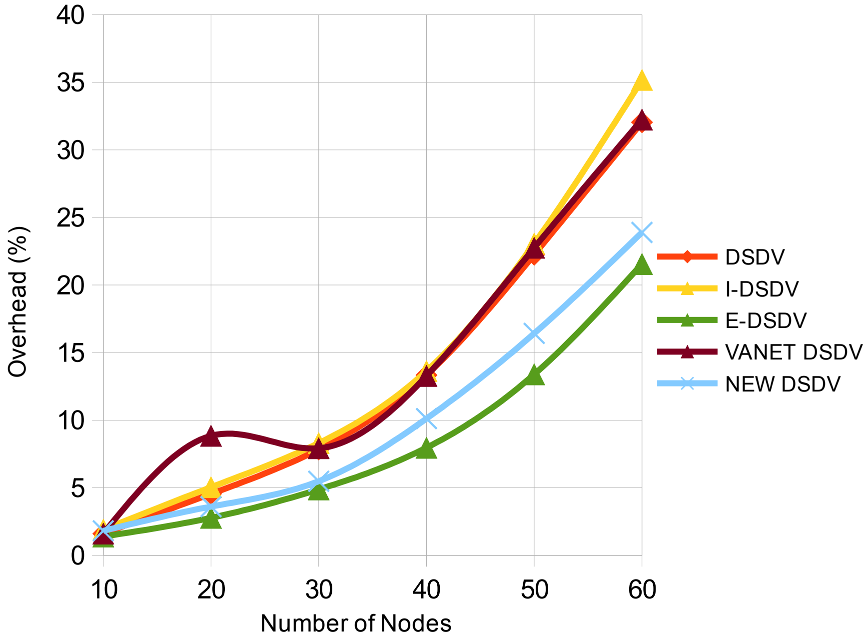

Figure 5.5: Performance comparative chart - routing overhead vs. number of nodes.

In summary, the performance of all the protocols was better in the sparse networks than in the dense ones. The new protocol also showed a remarkable improvement in all the performance metrics except for the average delay which was close to the other protocols.

5.7. Continuous vs. Discrete Mobility MANETs

In this scenario the pause time was varied from 0 to 100 with an increment of 20 seconds by each run. All the nodes in this scenario are moving in a fixed speed (30 m/s). The nodes stop moving at several random location for the specified pause time. When the pause time is set to zero, the nodes move without stopping.

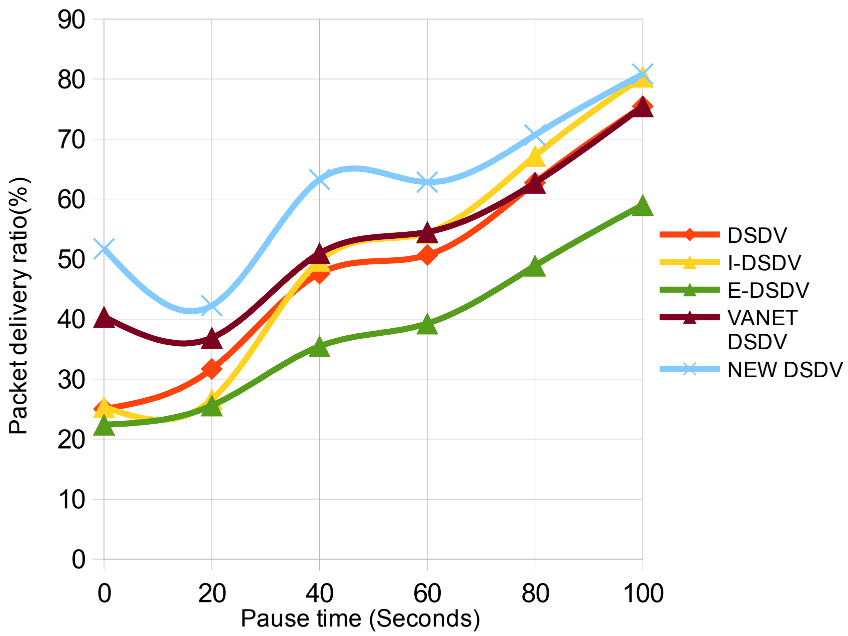

Figure 5.6: Performance comparative chart - packet delivery ratio vs. pause time.

This scenario has a duration of 100s, which means that when the pause time was set to 100s, the nodes will stay in fixed places. The rest of the parameters are unchanged. The results are shown in Figures (5.6, 5.7, 5.8 and 5.9) where Figure 5.6 illustrates the effect of increasing pause time on the (PDR); Figure 5.7 shows the effect of increasing pause time on the network Throughput; Figure 5.8 displays the relationship between increasing pause time and the average End to End delay; And finally, Figure 5.9 presents the relationship between increasing pause time and the routing overhead.

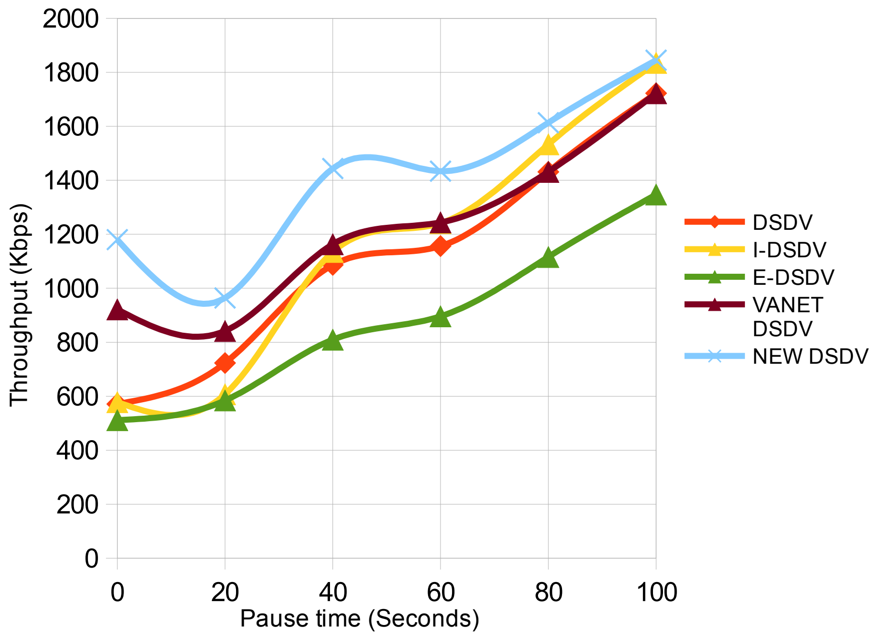

Figure 5.7: Performance comparative chart - throughput vs. pause time.

In this scenario, the nodes move in a continuous movement, interspersed with random stops. Their duration is shown in the graph. Increased paused time intervals' means greater stability of data transmission paths, which improves the performance of the routing protocols.

The increase in pause time simulates the movement of people during their daily commute, where they stop several times during their journey and this pause time interval is different from one place to another. As we explained earlier, the slow movement or the cessation of movement increases the age of communication links between the nodes. Note from Figure 5.6 that the PDR increases with the increase of pause time. The same is true for throughput, Figure 5.7 which increases with the increase in pause time.

The performance of all protocols is improved with increasing the pause time's period. The charts also show an increasing in the PDR, especially in the new modified version, where performance outperforms the others in all stages.

The same applies to throughput as it value is directly proportional t to the pause time interval, but it is noted that the performance of the protocol I-DSDV is approaching the performance of the new protocol with the increase of the pause time interval.

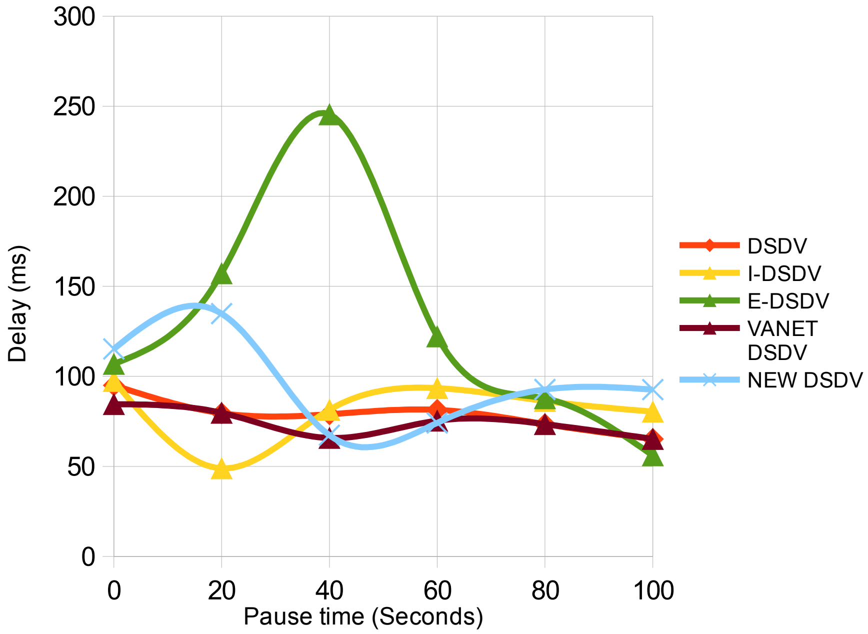

Figure 5.8: Performance comparative chart - end to end delay vs. pause time.

For the average End to End delay, it was almost constant regardless of using various paused time intervals for all protocols except for the E-DSDV one. For the new modified version, a high average delay was observed when the stopping periods were short. The performance is then similar to the other protocols after increasing pause time interval. Routing overload is inversely proportional to pause time, because the lifetime of transmission paths becomes longer. Therefore, the routing overhead has decreased for all protocols with increasing the pause time interval. The new protocol showed a considerable improvement with increased pause time and was better than the others.

For the routing overhead, we notice that overhead decreases with the increase of pause time. This is due to the fact that low mobility means greater stability in the network topology, which reduces the need to send a large quntity of control data over the network.

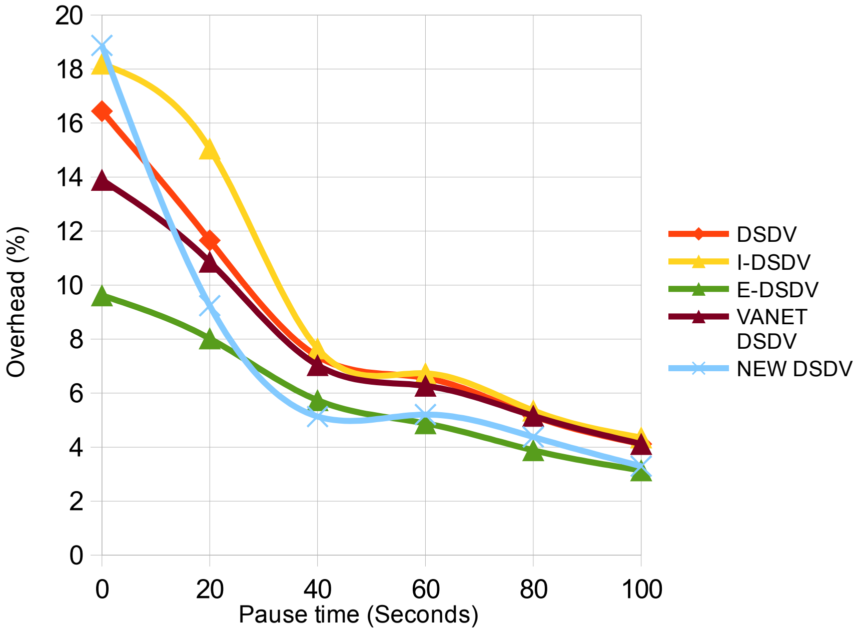

Figure 5.9: Performance comparative chart- routing overhead vs. pause time.

5.8. Low vs. High Mobility MANETs

In this scenario the speed of nodes varied from 5 to 30 with an increment of 5 m/s. The scenario has 30 nodes in all cases. The pause time is zero for all nodes. The rest of the parameters are described in the Table (5.1.) After applying this scenario, we got the results shown in Figures (5.10, 5.11, 5.12 and 5.13). The same analysis is also applied here, but in this case, we study the effect of varying node's velocity on the four measured parameters.

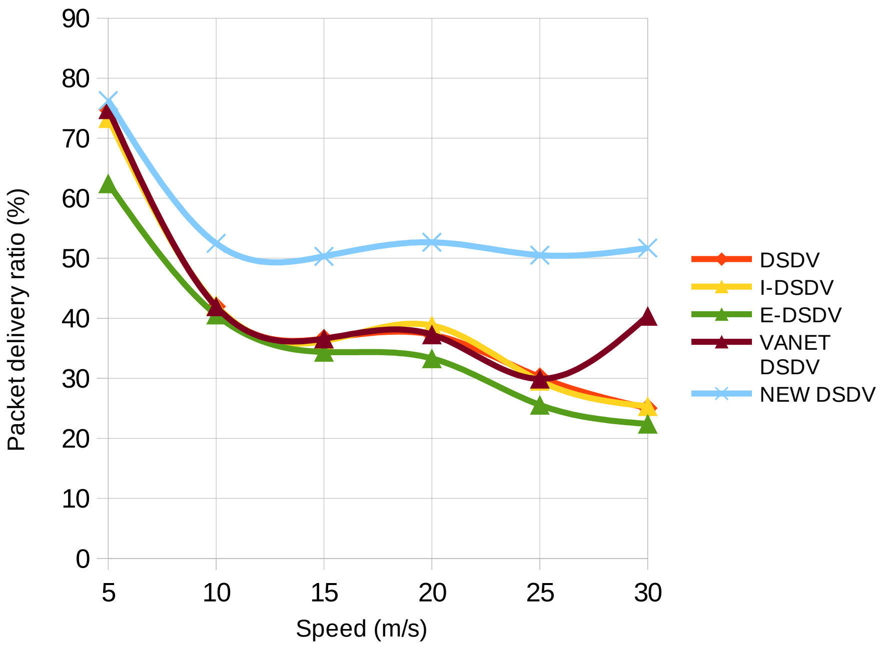

Figure 5.10: Performance comparative chart - packet delivery ratio vs. speed.

This scenario is designed to study the effect of increasing the speed of the nodes on the performance of the protocols under study. It is known that increasing the speed of the nodes constantly changes the topology of the network. Thus, from Figure 5.9 and 5.10, the PDR and the throughput are inversely proportional with node speed. The regression curve varies from one protocol to another according to the response of these protocols to the change in speed.

By changing the network topology. The nodes are constantly forced to increase the exchange of control data in order to keep the routing information in these nodes up to date.

The O-DSDV protocol showed a significant improvement in the PDR and the throughput after the nodes speed exceeded 25 m/s. This is because the protocol was designed only for high speeds enviroments. In case of low speeds, it has a behavior identical to the DSDV protocol.

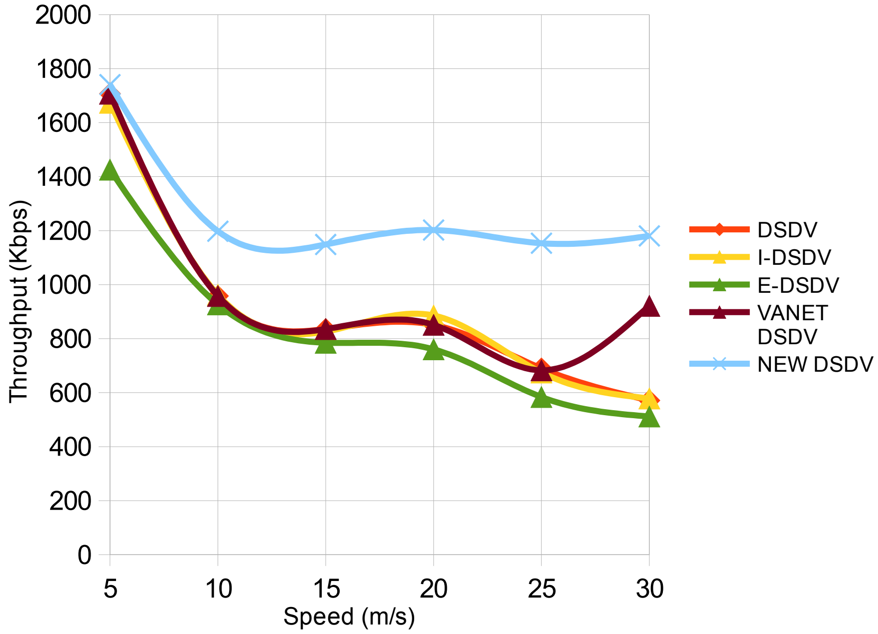

Figure 5.11: Performance comparative chart - throughput vs. speed.

The rapid movement of the nodes leads to the breaking of links between them constantly, and to repair the broken links there is a wasted time, which will lead to a delayed delivery of data. Network congestion is another reason to delay the delivery of data whereas a larger part of the transfer range will be reserved for transmission of control data. We conclude from Figure 5.11 that the delay in this scenario is the highest of the three scenarios.

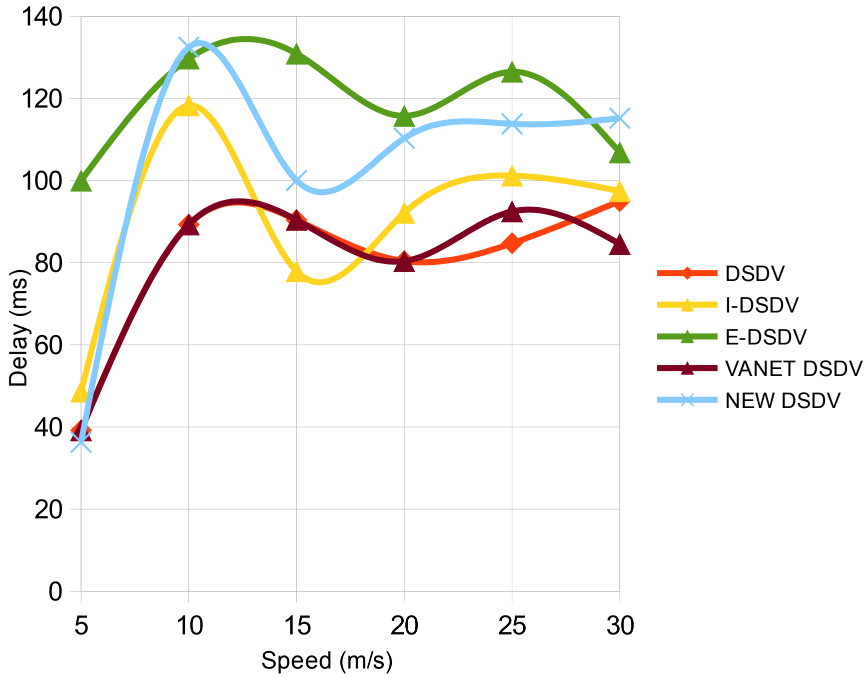

Figure 5.12: Performance comparative chart - end to end delay vs. speed.

Also, we observe that increasing the volume of data exchange control will increase the burden of guidance. This increase depends on the mechanism in which the protocol responds to the speed, so we see that the load burden of the modified protocol was the highest because it responds to the speed increase by increasing the deployment of updates.

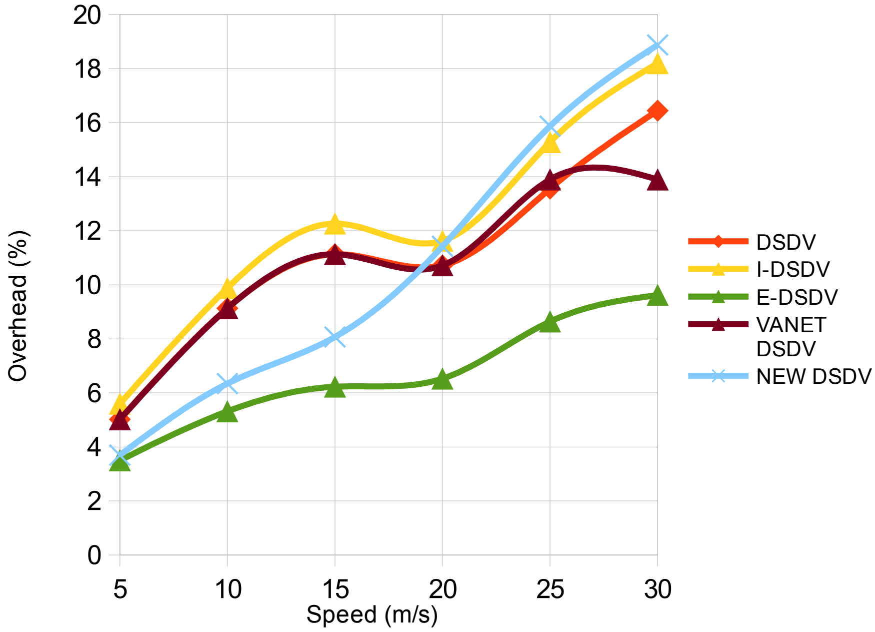

Figure 5.13: Performance comparative chart - routing overhead vs. speed.

As in the previous scenarios, the new protocol showed a significant improvement in the PDR compared to the others, and this enhancement clearly appears as the node's speed gets large values. It is also noted from Figures (5.10, 5.11, 5.12 and 5.13) that the performance of the protocols in general was less than the new modified version when the movement included different pause time periods. For the delay rate, all protocols showed a noticeable increase, especially in continuous movement environments. The new protocol showed a higher average delay compared to the others. This can be explained by the fact that the new protocol fixes the broken links with other links even if it has longer paths which increases the required data arrival time. For the routing overhead, it increased for all protocols. The new protocol showed better performance than the others except for the E-DSDV.

Chapter 6

Conclusions and Future Work

6. Conclusions and Future Work

DSDV protocol is one of the most popular routing protocols in Ad hoc networks. It is extensively used by the research community with many variants proposed in the past and others are still appearing. In this thesis, we proposed a novel extended version of this protocol by modifying the message header format and its internal operations. One of these modifications is to add two new parameters to the message header, namely: node velocity and message type. These two parameters had enabled us to fine-tune the measured update and settling time intervals which are considered crucial to the internal operations of this protocol.

Studying routing protocols and analysis of their performance are key steps in the maintenance, modernization and development of these protocols. There are many methods of analyzing the installation of routing protocols and evaluating their performance. Some pf them are based on simulation application and others are based on building mathematical models to analyze their performance.

In this thesis we have used both methods (mathematical model and simulations). As for the mathematical model we have built it to analyze the DSDV protocol and our DSDV modified version. Our model shows that the increase in the number of hops has a significant impact on the DSDV protocol. This effect was reduced in the new approach by applying different values on settling time parameter depending on the nodes' velocity. The model also shows that reducing the period of periodic update increases the utilization rate of the track duration.

We have implemented various scenarios to test the performance of the new modifications using NS3: using variable number of nodes (Dense vs. Sparse Network), using different pause time intervals (Continuous vs. Discrete Mobility Patterns), and finally, testing the protocols using different values of nodes' speeds (Low vs. High Mobility Networks).

The simulation results have shown that the new protocol can provide significant improvements in all scenarios. In terms of packet delivery ratio, the new protocol was the best in all cases. The new protocol outperforms the others regarding the throughput. However, it did not show any improvement in the average End-to-End delay due to the broken link repair mechanisms. Nevertheless, we think this issue is already compensated by the fact that the protocol can fix broken links (even with non-optimal paths) to keep the nodes connected and we believe this is a good compromise. Finally, as all proactive routing protocols considered in this study have demonstrated high routing overhead relative to the actual data that was transmitted, our protocol has actually reduced the overhead compared to these protocols.

As a future work, we intend to expand the proposed protocol by adding the node's coordinates and its direction of movement. Obviously, this will increase the header size and thus increase the overhead of routing updates, but we believe that having this new information at hand will enable each node to take smarter decisions which can impact other performance metrics.

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