A Holistic Framework to Improve Message Delivery in Vehicular Ad-Hoc Networks

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Copyright Statement

Dedicated to my family
For their endless love, support and encouragement.

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Publications

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- Poster presented in the College of Science and Technology, Nottingham Trent University, 8th Science and Technology Annual Research (STAR) Conference on 7th-8th May 2014.
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Abstract

Vehicular Ad-hoc Networks (VANETs) are wireless communication networks for vehicles that do not require any fixed or central infrastructure. It forms an important part of the intelligent transport system (ITS) which is the convergence of telecommunications, computing and wireless systems with the aim of improving transportation regarding efficiency, safety and management. In addition to the uses of ITS, VANETs will contribute in service access, cooperative driving, entertainment and navigation for cars of the future.

Due to the varied use of VANETs, it becomes slightly cumbersome having a "one-fits-all" solution to challenges facing message dissemination in VANETs. While some applications might require a fast and reliable way of disseminating messages amongst members of the network, other applications might be more delay-tolerant without adding extra risks to the dependents of such application. Data dissemination methods are therefore important aspects of VANET that ensure messages are delivered to areas beyond the scope of the originating node.

However, several types of research have shown that message propagation for each geographical route is unique to that route, owing to the number of network participants, their speed, and distribution of objects on that route. Many research designs do not consider the vehicles and their traffic characteristics and as such vehicular ad-hoc networks are under-utilised.

One of the problems present in the emerging field of vehicular communications is that of optimally disseminating messages within the network to support services such as collision warnings, traffic management, and driverless vehicles amongst others. This problem is a unique research area which involves the entire network and its ability to support the efficient propagation of data.

Message dissemination in VANETs could be viewed as routing on much higher macroscopic level, however, the techniques usually applied to data routing on a microscopic level does not utilise available data to efficiently disseminate messages within a vehicular ad-hoc network.

Some work done in literature addresses a few constraints at a time; for example a focus on junctions, thereby ignoring vast areas of the wireless network which could have been otherwise used to improve the overall ability to efficiently deliver messages within the road network. For this reason, this thesis investigates the effects of several vehicular factors, how these factors affect the quality of the wireless network on each road, and how this knowledge is advantageous in improving the delivery of messages from a source to its destination within a vehicular ad-hoc network. In proposing a solution that uses otherwise largely ignored road traffic data to improving efficient message delivery, a holistic framework that utilises road traffic information in a unique way is presented. The quality of a wireless network for each road in terms of packets delivered is seen to be influenced by the number of vehicles and their speed which is seen to be unique for each road segment; therefore, allowing the generation of a wireless packet delivery map offline (wireless network map) based on varying number of vehicles and speeds. Current road traffic data can then be compared against the wireless map in order to determine which routes have good network quality and hence the ability to support better message dissemination

This framework is also aimed at helping to fully utilise the VANET bandwidth available by reducing network noise caused by multiple retransmissions of nodes in the network by picking the right path and using only the furthest node on each path. It aims to reduce messages delivery failure, reduce delays in the message delivery where possible and improve the utilisation of vehicles as communication nodes and relays.

The Framework for Improving Message Delivery in VANETs (FIMDEV) proposed in this thesis shows the benefit of using the wireless communication database information processed by each vehicle to support message delivery from source to destination within the VANET. Experiments show improved overall packet delivery ratio when compared to standalone routing protocols as FIMDEV uses the wireless network database along with a set of rules for propagating messages within the network.

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Abbreviations

3G,4G	Third Generation, Fourth Generation
3GPP LTE	3rd Generation Partnership Project - Long Term Evolution
AODV	Ad Hoc On-Demand Distance Vector
AP	Access Point
BSS	Basic Service Set
C2C	Car-to-Car
C2I	Car-to-Infrastructure
C2X	Car-to-Car/Car-to-Infrastructure
CCH	Control Channel
CDMA	Code Division Multiple Access
DCF	Distributed Coordination Function
DP	Direction-based Priority Scheme
DSDV	Destination-Sequenced Distance Vector
DSR	Dynamic Source Routing
DSRC	Dedicated Short-Range Communications
DSSS	Direct Sequence Spread Spectrum
FIMDEV	Framework for Improving Message DElivery in VANETs
GPRS	General Packet Radio Service
GPS	Global Positioning System
ITS	Intelligent Transportation System
MAC	Media Access Control
MANET	Mobile Ad hoc Network
NS 2	Network Simulator 2
NS 3	Network Simulator 3

OBU	On-Broad Unit
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open Systems Interconnection
RSU	Road Side Unit
SCH	Service Channel
SUMO	Simulation of Urban MObility
TDMA	Time-division multiple access
UMTS	Universal Mobile Telecommunications System
VANET	Vehicular Ad hoc Network
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
WAVE	Wireless Access in Vehicular Environment
WSM	WAVE Short Message
WLAN	Wireless Local Area Network

Chapter 1: Introduction

This chapter introduces the research background to provide some context as to the usefulness of VANETs, hence, the motivation in carrying out this research. The chapter also states where this research lies on the VANET paradigm with identified issues in VANETs' usage and the aim of this research project.

1.1 Background and Context

There is an increase in the number of vehicles on roads nowadays; figures from the Driver and Vehicles Licensing Agency (DVLA) in the United Kingdom show that in the first quarter of 2016, 916,000 vehicles were registered for the first time in Great Britain and was up 5% during the same period in 2015. At the same time, vehicle usage in Great Britain rose by 2.5% to 36.7 million (Gov.uk, 2017). The growth in vehicle usage can and has caused severe challenges to road traffic management leading to increased levels of road accidents, traffic jams and so on. With this in mind, researchers have sought out ways to improve traffic management with one method being the formation and subsequent use of a wireless network for vehicles to gather, disseminate and utilise road and vehicular traffic data. It is envisaged that relevant data can both be gathered and disseminated amongst the vehicles when vehicles have the capability of communicating with other vehicles (and roadside infrastructure) directly within short distances. The network described above is known as a Vehicular Ad-hoc Network (VANET) (Figure 1.1). To further highlight the awareness of the transport industry to the above situation, 16 vehicle manufacturers organised in the CAR 2 CAR Communication Consortium have consented to an agreement to jointly bring cooperative Intelligent Transport Systems and Services to the European market as soon as possible. The consortium is pushing for the deployment of solutions for as early as 2019 (Car-2-Car, 2017).

The term VANET was first coined at the Association for Computing Machinery (ACM) international workshop on Vehicular Ad-hoc Networks (Hartenstein and Laberteaux, 2010). Though Vehicular Ad-hoc Networks has been previously compared to Mobile Ad-hoc Networks (MANETs) due to their similarities, several researchers have pointed out that there are more differences than resemblance between both sciences (Dietzel et al., 2014). What this means is that while some techniques can be transferred from MANETs to VANETs, the latter has several unique and differentiating characteristics such as high node speed, rapidly changing topologies, and short connection lifetimes which makes the former's techniques somewhat improbable to apply. The solutions to MANETs were made for networks with more stability and lower mobility than typically found in a VANET. Though mobility may be higher in VANETs, they are fixed and deterministic since each vehicle is bound to the road it travels on. This fact amongst several others has led to the crux of this research.

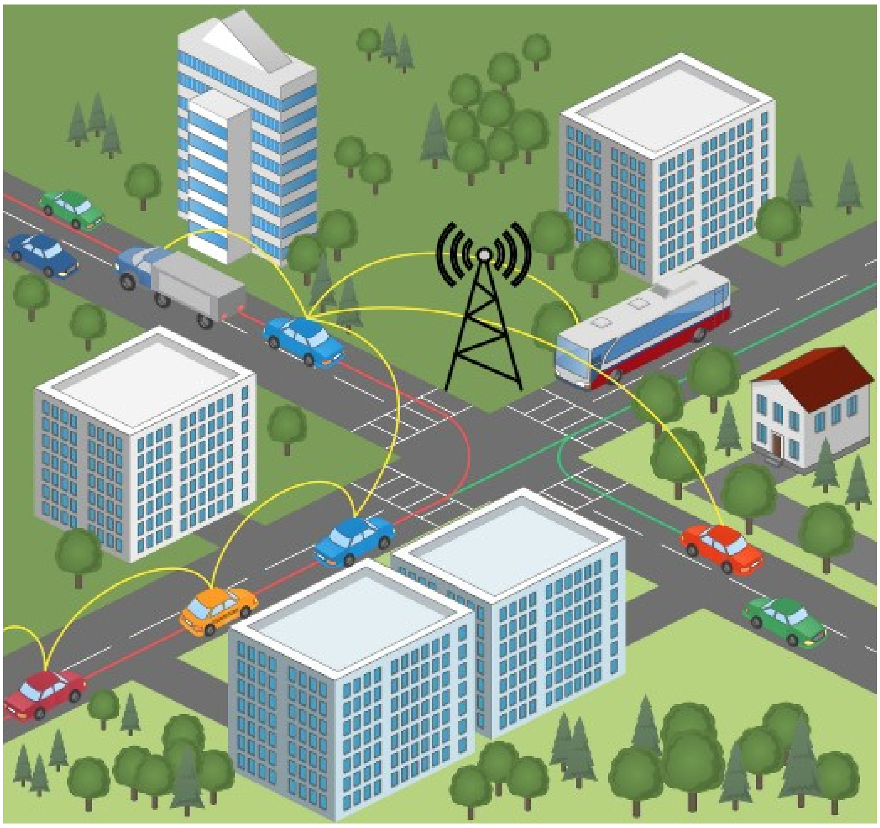

Figure 1.1: VANET Concept

Historically, the concept of combining radio communication and transportation was made public in the 1939 New York World's Fair presented by General Motors (Lasky and Ravani, 1993). It was the most advanced idea submitted to the fair at that time and described the basic concepts of the use of communication between vehicles and communication between road side infrastructure highlighting the advantages in improving traffic control and transport safety even at relatively high speeds. Other early research includes the European Programme for European Traffic with Highest Efficiency and Unprecedented Safety aka PROMETHEUS which started in 1988 and greatly promoted development activities in the field. As with all European projects, it was supported by several participating countries and covered a variety of research activities such as vehicle to vehicle communication, vehicle to infrastructure communication and amongst others. Several findings such as some highlighted by (Dabbous and Huitema 1988) from this initial research are still influential till today. Other regions such as the United States and Japan also had researched in the field (Sachs and Varaiya 1993) (Kawashima, 1990).

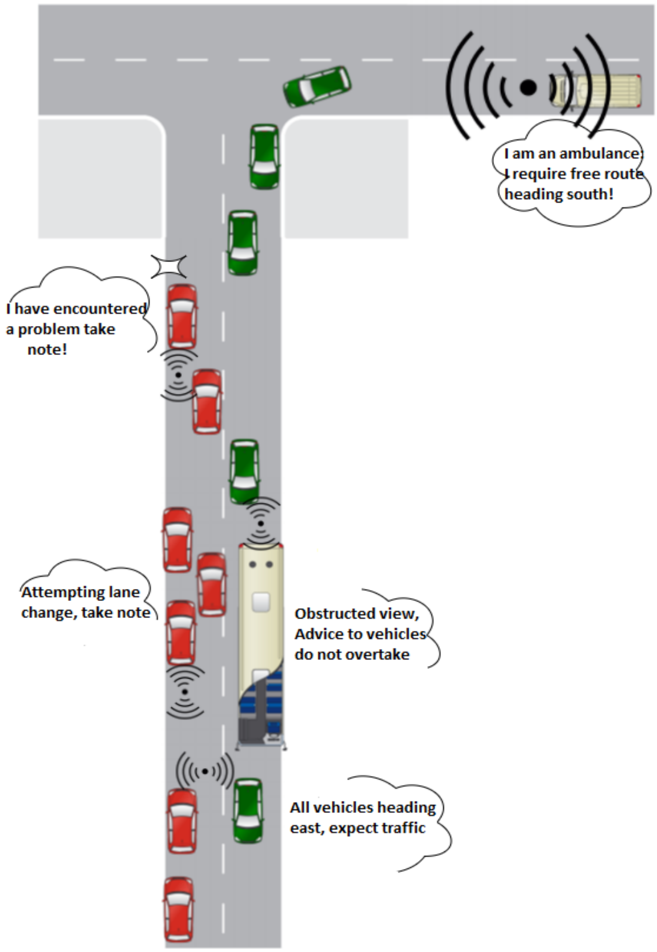

Figure 1.2: Vehicular Ad-hoc Network example scenario

With the allocation of 75 MHz bandwidth from the 5.9 GHz band to Dedicated Short-Range Communication (DSRC) ARIB (2001) by the United States Federal Communication Commission in 1999 to cater for short range wireless communication between vehicles and vehicle to infrastructure, research gained traction, and a lot of progress was made. Similarly, DSRC work was carried out by the European Committee for Standardisation (CEN) in 2003 (CEN). The European standard for cooperative communication indicates the availability of 150 MHz in the 5.8 GHz band, covering a broad range of activities and services (ETSI, 2015). This prompted the Institute of Electrical and Electronic Engineers (IEEE) to begin work on the standards to complement DSRC, and this was called Wireless Access in Vehicular Environments (WAVE) (Jiang and Delgrossi, 2008). WAVE can support vehicle to vehicle or vehicle to infrastructure applications, providing high data rates of up to 54Mbps thereby relaxing the need for other technologies such as mobile phones, etc. in a localised scenario. The early 2000s saw major projects such as those from the Car-to-Car Communication Consortium in 2001, Vehicle Safety Consortium 2002, and Japan Automotive Research Institute (JARI) in 2003 push the boundaries of advancement in the field. This introduction does not provide an exhaustive list of all projects in vehicular communication but indicates major projects that might have influenced the shape of the area as we have it today.

In today's data-centric world, information is vital, and the use of data usually leads to more efficient processes, hence, in VANETs data gathered and shared with neighbouring vehicles wirelessly allows them to warn each other about any abnormalities, provide useful information or potential dangers. This can be considered as superior to older methods, for example turning on the hazard lights of a vehicle, especially when visibility is poor due to bad weather conditions. Another scenario is the ability service providers to inform vehicle owners of nearby services for their vehicles whenever the need arises using vehicle to vehicle communication (V2V). Furthermore, road traffic-wise, vehicle to vehicle communication can allow other vehicles heading to that route find alternate routes to their destinations, thereby reducing further traffic bottlenecks (Figure 1.2).

Due to its nature, vehicle to vehicle communication allows for short and medium range communications with little cost in setting up the ad-hoc network upon which it runs, thereby providing a system with minimal latency in the communications link. However, V2V communication does have some drawbacks including; frequent topology changes due to constant mobility, difficulties in long range communication, inability in utilising traditional (MANET) routing protocols, and broadcast storm problems in high vehicle density situations.

As stated earlier in this thesis, Vehicular ad hoc networks (VANETs) are a subset of MANETs and represent a rapidly emerging research field considered essential for cooperative driving among communicating vehicles. Vehicles function as communication nodes and relays, forming dynamic networks with other nearby vehicles on the road and highways. It enables peer-to-peer mobile communication among vehicles (V2V) and communication between vehicles, and the infrastructure (V2I) and is widely regarded as an emerging technology soon to be implemented (Figure 1.3).

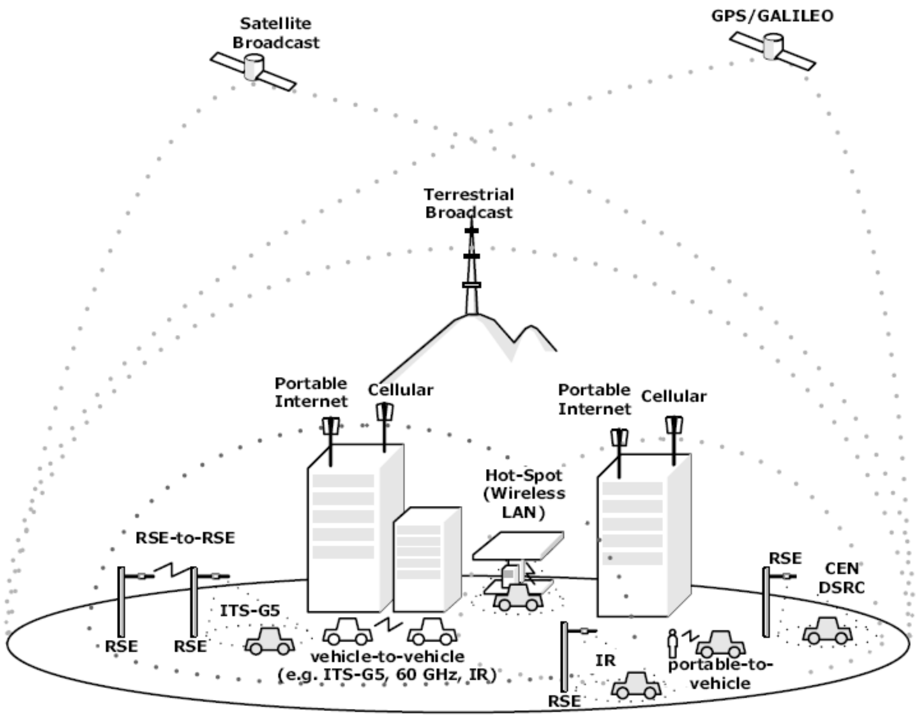

Figure 1.3: Intelligent Transport System (CALM, 2017)

ITS which is the integration of information technology, telecommunication and transport systems for, but not limited to the following purposes; navigation systems, electronic toll collection (ETC) systems, assistance for safe driving, optimization of traffic management, efficiency in road management, support for public transport, efficiency in commercial vehicles, support for pedestrians, and support for emergency vehicle operations (DoT, 2016). To further illustrate the importance or viability of this field's potential, recently (DoT, 2015) the United States Department of Transportation set aside about £35 million to support "technology in infrastructure and in vehicles to aid sharing and communication of anonymous information with each other and their surroundings in real time, reducing congestion and greenhouse gas emissions, and cutting the unimpaired vehicle crash".

In order to provide the above visions, research has shown that though smartphones can be used as a source of wireless connection for the vehicles, the use of cellular networks e.g. 2G, 3G is not the most efficient solution (Vinel, 2012). This is because of its dependence on a central network infrastructure (and base station, BS) through which all data must travel even when the communicating vehicles are in the same geographical region. It is also unsuitable because it is not an ad-hoc standard, therefore not quite suitable for direct communication. Vehicles can be equipped with wireless network equipment which would give them the ability to connect to other vehicles similarly equipped. A situation whereby two or more vehicles are connected wirelessly is known as a vehicular ad-hoc network.

To understand the issues involved in developing a VANET solution means to realise that there are multiple scenarios to cater for, each with its requirements. For example, cities and highways have different mobility patterns and speeds (Viriyasitavat, Tonguz and Bai, 2009), also various possible VANET applications, for example, safety or non-safety application can also influence the method a research or development solution proposed to optimise VANET behaviour. However, in all these different scenarios, there are several common elements which can be utilised; the pattern of travel mobility (based on the number of vehicles and their speed) will be repeated over time and can be determined; also, the wireless communication behaviour based on the former will have a relationship over time. This leads to an interesting point of whether this information can be used in improving message delivery within the network.

Vehicular networks will allow for the growth of several information dependent services and applications as already mentioned. To that end, this research will develop a framework which includes a model for message dissemination using historical vehicular network wireless communication data. This proposal aims to reduce the effects of the challenges mentioned in section 1.1 above, to also reduce broadcast storm problems while maintaining a high message dissemination effectiveness to other areas of the network or connected networks.

1.1 Limitations in VANETS

Implementing vehicular ad-hoc networks come with a plethora of challenges, some which are common to wireless networks and others which are specific to VANETs due to its unique nature. It is important, however, to overcome these challenges as VANETs can change the way vehicles are viewed both technologically and otherwise.

Self-Organisation: The nodes participating in the network do so without the aid of a central management system. This lack of a central management system or central infrastructure can lead to poor network management and poor utilisation of network resources (Hartenstein and Laberteaux, 2010).

Data Propagation: With the presence of radio properties such as fading, non-line-of-sight, reflection, etc., the behaviour of messages disseminated in VANET will inevitably vary according to the locality where it is implemented. That is, every route will behave differently even when using the same routing protocol. Therefore, it can be deemed justifiable to have a record of the pattern of wireless network behaviour for each route which can be used to make adjustments.

Scalability: As implied above, implementing any protocol which was designed, for example, a straight road and a certain number of vehicles on another road with a different number of vehicles can be challenging. This quickly changing topology, speed and number of participants' nature of VANETs can be positive reinforcements to the network rather than major setbacks.

Standards: A lot of work has gone into acceptable standards for both software and hardware in VANETs. Many researchers include requirements that may deter manufacturers or other researchers in implementing their proposals (Hartenstein and Laberteaux, 2010). In this research, the aim is to use existing mechanisms to achieve efficient message distribution in the network, all standards already proposed by organisations such as ETSI and IEEE will be used without significant changes.

1.2 Aim and Motivation

The aim of this research is to critically investigate the effects of road traffic data on VANETs, in order to use key factors to design and develop an efficient message delivery framework for vehicular ad-hoc networks that utilise road traffic data to improve message dissemination in VANETs.

Firstly, consideration is given to the problem by proposing a traffic aware information dissemination protocol that is successful in reaching its goal of transmitting the information to its intended target. A lot of existing research in message dissemination in VANETs assumes that transmission in VANETs is ideal, that is, messages sent are received successfully while ignoring factors that affect communication. Experiments (Mireles et al., 2010) have shown that vehicles on the road interfere with the communication, weaken the signal strength from the transmitter, which leads to the condition that the vehicles are unable to receive the signal from the transmitter even if it is within the radio range.

Some other methods of message dissemination require the existence of a fully connected path between the sender and the receiver for the duration of a communication session to make the communication possible. However, in case of a highly dynamic network found in VANETs, this is difficult to achieve. An effective message delivery protocol may not need to sustain routes from source to final destination but can identify paths to take based on the prevailing vehicular traffic situation. This routing protocol should satisfy various types of VANET applications requirements as discussed in chapter 5 of this thesis. Due to rapid network topology changes, forwarding protocol needs to be resilient, ensuring high delivery rate.

This thesis seeks to demonstrate that the design framework proposed is adaptive and will compare favourably when used with existing traditional routing protocols. To network performance as expected is found to rely heavily on several factors like the vehicular traffic densities and the number if vehicles on the road, which invariably means all roads are unique and should produce unique network patterns which is a significant point on its own. Rather than attempting to cut through a network area that will produce very poor performance, time is saved by avoiding such routes. This is significant for some time sensitive applications and even for applications that need to ensure message dissemination.

The framework proposed will take into account the traffic situation of each road in an area by comparing the current vehicular speed and density values against previously measured values and produce a forwarding strategy based on this. The combination of that and a functional forwarding strategy allows for a reliable message dissemination method.

Another problem with message dissemination in VANETs was highlighted by Clayton C.J. (2016) in a research which measures the effects of junction layouts on network performance. The literature suggests that there was less received power and poorer network performance at intersections with single/dual lanes and that network performance was unique to each intersection or road that was tested. From this, it can be deduced that network behaviour is unique to each road, junction, or intersection that exists, particularly for each unique number of vehicle and speed combination.

Furthermore, work done by Bargiela et al. (2004) gives theoretical and practical backing to the ability of gathering and using real-time traffic information data as was done in one project using traffic data gathered from Nottingham SCOOT system.

Tackling the issue identified by Clayton C.J. (2016) cited above by developing a holistic framework that uses traffic data such as this is envisaged to improve message delivery in VANETs. The reliability of the framework will depend on the context in which it is applied. We use a theoretical approach where the road map is modelled as a graph and the traffic characteristics are included to form a weighted graph, for any source and destination on the map we can therefore find the best way to disseminate messages.

1.3 Research Objectives

This research is focused on improving message delivery through the utilisation of road traffic data in inner city scenarios where the network may be more sensitive to broadcast storms because of the high density of broadcasting vehicles. Such scenarios may also exhibit network disruptions due to low vehicular traffic density, as well as the disruptions in propagation caused by buildings. The bandwidth available for VANETs is fixed and can be significantly impacted by unnecessary retransmissions of data which results in packet collisions.

The research gives an overview of vehicular network communications and the potential application areas of VANETs and a framework/model for VANET communication. After which a study is carried out to determine what road traffic factors influence vehicular network communication. This will lead to experiments using those factors to gather data to be used in designing and building the proposed model for improved message delivery in VANETs. Finally, experiments will be carried out to check the validity of the new model in comparison with existing methods.

The objectives of this research project are;

- To study the state of the art of vehicular ad-hoc network communication and message delivery methods.
- Determine and investigate what factors with regards to road traffic data, influences vehicular network communication the most and how these factors influence the wireless network.
- Design experiments based on the determined factors to gather empirical data upon which a model for improved message delivery will be built.
- Develop and implement a framework for improved message delivery in vehicular ad-hoc networks.
- Develop a real-case model using the proposed framework.
- Investigate the viability of the framework and model against existing models through a series of experiments.

1.4 Contributions of this Thesis

The proposed contributions of this thesis are:

A proposed unique approach to utilising road traffic information in promoting improved message delivery in VANETs.

This approach involves the investigation of how various road traffic data such as the number of vehicles and their travel speed are differentiated on each individual route with regards to their effect on the quality of the wireless network. This differentiation is a unique characteristic of VANETs and will allow for the subsequent design of rules to take advantage of this knowledge that road traffic data is seen to uniquely impact the quality of the wireless network. Following this investigation, experiments to gather the effects of the aforementioned road traffic data will be performed for each route under analysis. All routes and representative data are those of the Nottingham City centre.

Design of a Holistic Framework for Improving Message DElivery in VANETs (FIMDEV)

The method described above is employed in the design of a new framework. The framework FIMDEV described in chapter 5, is a collection of rules and data used in improving message delivery in VANETs. It suggests ways of using existing data such as vehicular sensor data, road traffic data in maximising efficiency and reliability of message dissemination from source to destination whether by re-distributing messages along routes considered to be of better wireless network condition or in the absence of which, message broadcast suppression or a different protocol is employed. In designing this framework, the following are achieved;

- Defining optimal paths between the source and destination nodes by using shortest distance algorithm that define the cost of each path not as geographical distance but rather as the wireless network communication condition or quality of each individual route within the area being considered.
- Defining rules for how each vehicle performs its duty as a forwarding router by using data from its position sensor to calculate angles between itself and other vehicles relative to the route on which they are. Here, priority is given to certain angular and positional values in order to ensure that the next forward hop amongst several vehicles is the optimally chosen one.
- Ensuring that the framework incorporates routing protocols which can be switched to when needed, for example, in cases where there is a severe lack of options for improving efficiency.

Design and implementation of simulation models for the evaluation of FIMDEV

To evaluate and validate the proposed framework, a model based on real routes and representative data is designed and implemented in both road traffic and network simulators, Simulation of Urban Mobility (SUMO) and Network Simulator (NS-3) respectively. The evaluation of the designed model involves its performance against existing reactive and proactive routing protocols in NS-3.

1.5 Structure of this Thesis

In this chapter, Vehicular Ad-hoc Networks and Intelligent Transport Systems have been introduced. Also, the motivation and objectives of this research have been presented, as well as more practical details. The rest of the document is structured as follows;

Chapter 2 introduces the concept of vehicular ad hoc networks, its characteristics and applications as well as establishing the essential requirements for good transmission in the network. It also presents standards of VANETs and an overview of known message delivery techniques, and related work which utilises traffic data in some way is given. This background information leads to the system assumptions and the scope of the thesis.

Chapter 3 describes the methodology used in this research project. A detailed look at the methods and approaches used for conducting simulation studies by providing foundational reasoning for the simulation environments (both traffic and network) chosen for this work.

Chapter 4 introduces various factors that may affect wireless communication in vehicular networks and the determination of the most relevant factors using a 2^k factorial method. The chapter also shows experiments conducted to gather empirical data which forms the basis of the "wireless communication map" employed in the proposed framework.

Chapter 5 provides a detailed description of the proposed framework and model for improved message dissemination in vehicular ad-hoc networks.

In Chapter 6 the new design is implemented and tested for its viability especially in comparison to the functionality of the network without the model.

Finally, in Chapter 7, the main conclusions are summarised having come to the end of the research. Findings are discussed as witnessed and some future work is recommended based on this conclusion.

Chapter 2: Vehicular Networks and Related Work

Chapter 2: Literature Review and Related Work

This chapter provides information on vehicular ad-hoc networks, its characteristics and standards available in implementing VANETs. The chapter also discusses some selected methods of message dissemination in VANETs, identifying the strengths of each protocol as well as any gaps discovered in the protocol. It ends with a summary of the chapter having identified where this research project can contribute to improving message dissemination.

Chapter Overview

VANET is considered as a major part of the Intelligent Transport Systems, and its application can either be for safety and non-safety applications. Both applications can be time critical with the former having a stricter requirement. For non-time, critical applications such as entertainment and information dissemination, latency can be sacrificed in order to find more efficient means of message distribution.

In a VANET scenario, vehicles provide information about their speed, position and direction on a route, etc. Drivers can use such information in making decisions regarding what route to navigate, on the other hand, vehicles themselves can use this information to make decisions regarding how to disseminate messages.

In this chapter, the VANET concept and characteristics are discussed. There will also be a review of the current standards in VANETs. Finally, some research work in the field of message dissemination will be surveyed, discussing the processes and techniques applied.

2.1 Characteristics and Applications of VANETs

Vehicular ad-hoc networks (VANETs) are distinguished from other ad-hoc networks by; their trajectory-based motion along with predictable locations, a fluctuating number of vehicles having either independent or correlating speeds, constant uses of beacons for identification and network management, and fixed mobility patterns due to the roads they travel upon. As indicated in the first chapter, besides the research implications and the obvious uses of telecommunication in transportation there is the added influence of economic gains both by private organisations and governments, possible from implementing this sort of technology. Adverts can be directed at vehicle owners by car and goods manufacturers, leading to sales of goods and services. Also, by controlling traffic with up to date and instant information, there will be a reduction in traffic congestion thereby leading to improved quality of life which correlates with improved productivity, etc. (Taleb et al., 2007).

By utilising VANETs, several applications and services that cater to road users can be developed. These applications can be classified into two main categories;

- Safety applications that improve road safety by sharing relevant safety information via V2V or even Vehicle to Infrastructure (V2I) communications, through which knowledge that may affect the safety of the road users may be used to activate vehicular safety systems, or provide the users with options on the course of action to take. These applications obviously depend on a certain amount of information in order to help make decisions, some research on this is available at (Gamati, Germon and Peytchev, 2013) (Abufanas and Peytchev, 2015).
- There are also applications which are either commercial or comfort related that help improve the experience of the road users, route optimisation, toll collections and provision of commercial transactions are also part of this category (Jakubiak and Koucheryavy, 2008).

2.2 Standards for VANETs

Standardisation in VANETs has not come easy due to it being a relatively new field and with several 'large' bodies creating parallel protocols and standards for basically the same processes. It is important to understand some of these standards in order to have an overview of some of the research solutions presented for issues in VANETs. In this section standards from Europe and the United States will be discussed as these are the prevailing standards in place.

In the United States, the Department of Transportation (DoT) through its National Highway Traffic Safety Administration (NHTSA) has congressional authority to establish vehicle safety standards had in a research suggested that vehicle to vehicle communication can help reduce or avoid up to 82% of road crashes in the United States (Resendes, 2010). This was a build on previous developmental framework now known as the Intelligent Transportation System (ITS) services which began around 1996 by the DoT and the Intelligent Transportation Society of

America (ITSA). This framework served as a blueprint for ITS initiatives in the US for the past decade.

The ITSA, in 1999, therefore gained from the United States Federal Communications Commission (FCC) 75 MHz of bandwidth in the 5.9-GHz band with the specific goal of supporting Dedicated Short-Range Communications (ARIB, 2001) for ITS. The DSRC-based ITS radio services received 75 MHz of spectrum in the 5.85-5.925 GHz range. The frequency band is divided into seven channels of 10MHz each and a 5MHz guard band at the lower end (Resendes, 2010).

The DSRC uses a protocol stack similar to the traditional wireless protocols such as 802.11a, b, g, and n, adopting a single standard for the physical (PHY) and medium access control (MAC) layers of the architecture, as proposed by the American Society for Testing and Materials (ASTM). Mainly because, the 802.11 wireless standards were already familiar and could be more readily adopted, also, it meant research would be aided by the availability of resources such as simulators which could easily be made to test the new protocol.

By the mid-2000s, an IEEE task group p was formed by the IEEE 802.11 working group and began development of an amendment to the 802.11 standards to include vehicular environments. The document is known as IEEE 802.11p (Task Group P, 2006), with some fundamental differences between 802.11a and 802.11p being the ability to adapt to rapidly changing nodal environment and the absence of a Basic Service Set (BSS). Another IEEE team (working group 1609) began work on developing specifications to cover additional layers in the middle of the DSRC protocol suite.

The IEEE 1609 standards set consisted of several documents: the IEEE 1609.2 (2006), the IEEE 1609.3 (Std. P1609.3, 2007), and the IEEE 1609.4 (2006) which covers security, network and channel switching services respectively. Together the IEEE 802.11p (2010) and IEEE 1609.x is called wireless access in vehicular environments (WAVE) standard because of the aim it set out to accomplish.

On the European front, standardisation governed by ETSI promoting the development of vehicle to vehicle communication being a combination of several pieces of research which in turn depend on other developments such as; Intelligent Transport Systems working group for the International Standards Organisation, working groups for IEEE 802.11(p) and 1609 WAVE, Cooperative Vehicle-Infrastructure Systems (CVIS) as well as industry activities from the Car to Car Consortium (C2C-CC). As such, there are a lot more facets to the European standardisation, however, the main objective of the European research and standardisation is the development of Cooperative Intelligent Transport Systems (C-ITS) which covers all types of communication for transportation, several of which are outside the scope of this research. The aspect of the dealing with vehicle to vehicle communication is the Communications Access for Land Mobiles (CALM) by the ISO (ISO, 2012) and applied and validated by the CVIS project lasting four years (van Arem, 2007). The frequency allocated to Cooperative ITS use is further divided into two service channels (SCH) and one control channel (CCH) for service and safety related applications. For the ETSI model, there had to be a creation of Local Dynamic Maps within each vehicle which acts as a sort of database for information and data accumulated, more on this in later chapters.

The following are standards generally used for VANET application developments regardless of the region of development:

2.2.1 Wireless Access in Vehicular Environments (WAVE)

The Dedicated Short-Range Communications (DSRC), now termed WAVE operations was created to provide enhancements to the IEEE 802.11 family to provide, for example, the layers above the PHY and MAC are outside the scope of IEEE Std. 802.11. In other words, WAVE provides a communication protocol suite optimised for the vehicular environment by modifying an already proven standard, after a series of rigorous tests to determine what exactly needs to be added, removed or changed to the IEEE 802.11a Std. Some components of the WAVE suite are common to all 802.11 Std. and others are more customised. The elements of the system, as defined in standards, are shown in the figure below.

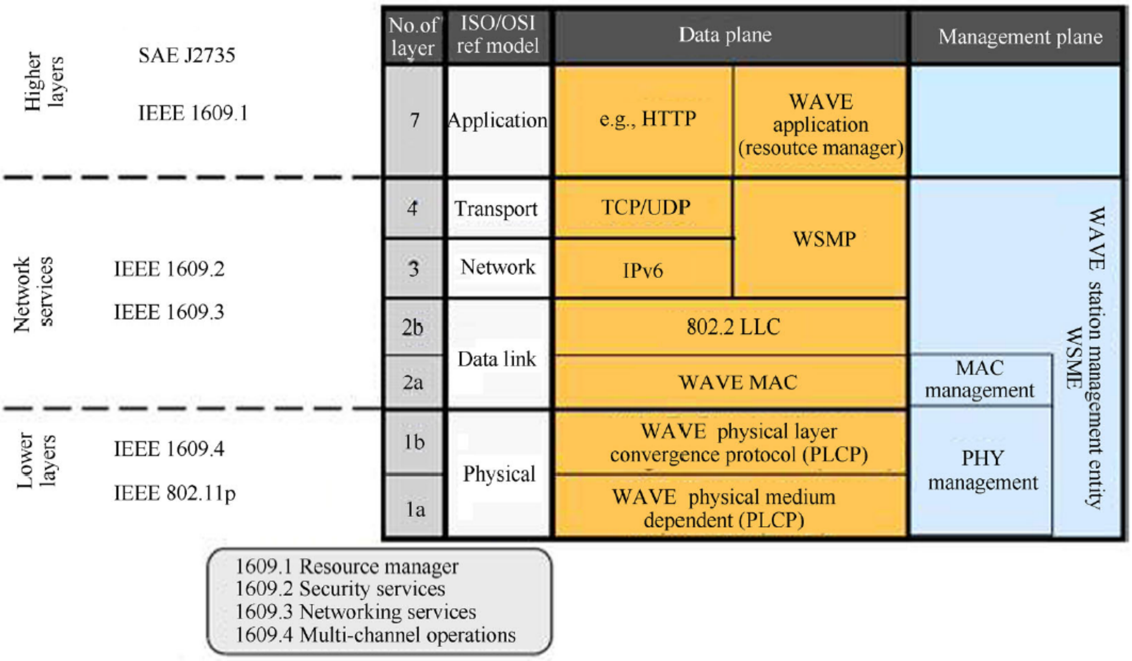

Figure 2.2: Wave protocol stack

The WAVE standard was defined to map out the scope of various services that make up the transport and networking layers in VANETs. Including higher application services for vehicle to vehicle communications and vehicle to roadside communications utilising the WAVE mode of transmission.

2.2.1.1 Procedure for WAVE

In WAVE operations, vehicles are to exchange information over different channels depending on the application. For example, service channels (SCHs) are used for non-safety data transfer, while control channels (CCH) are used for broadcasting basic safety messages and service advertisements at regular intervals. However, vehicles can also form clusters in a self-organised fashion otherwise known as WAVE Basic Service Sets (WBSS) as found in other wireless standards such as 802.11a. A major difference between 802.11a and 802.11p is that these sets may consist of the vehicles themselves or including road side units and this makes it easy to exchange messages between members of the WBSS (Uzcategui and Acosta-Marum, 2009).

Basically, during operation, a vehicle remains on the control channel while listening for safety messages from the SCHs or if the vehicle wishes to transmit its safety message. The act of listening is performed during pre-set intervals known as control channel intervals. Sometimes it is necessary to halt activities during transmission to perform channel monitoring activities after which the transmission may be allowed to continue (Uzcategui and Acosta-Marum, 2009).

2.2.1.2 Communication Protocols

In WAVE, devices can transmit and receive both IP and non-IP data. To accommodate non-IP data exchanges, a protocol called WAVE Short Message Service Protocol (WSMP) is used.

From figure 2.2 of the WAVE architecture, it is seen that there is support for both IP and WSMP. Both protocol stacks are situated above the data link as found in the OSI reference model. Hence, both IP and WSMP have transport and network capabilities but the same application, data link and physical layers allowing an easy switch between both protocols types. The WAVE stack does not have presentation or session layers as found in the OSI model which is replaced by the WAVE resource manager and security services.

Having two communication protocols is advantageous as it allows legacy applications in VANET operations by supporting Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) data exchanges, on the other hand supporting future message delivery services through the WSMP, allowing short messages to be exchanged with members of the same service set in a more capable manner.

With WAVE devices being capable of multi-channel operations between the CCH and SCH, some modifications have been included to manage the operations, especially switching between both channels. These modifications are discussed briefly in subsequent sections.

IEEE 1609.1: describes remote applications that interact with OBUs with limited computing resources, to provide more complex processing while giving the impression that the application is running on the OBU (IEEE Std1609.1, 2006).

IEEE 1609.2: specifies the WAVE security concepts and defines secure message formats and message processing as well as the circumstances where secure message exchanges are required (IEEE 1609.2, 2013).

IEEE 1609.3: provides routing and addressing services required at the WAVE network layer. Wave Short Message Protocol (WSMP) provides routing and group addressing (via the WAVE Basic Service Set [WBSS]) to traffic safety and efficiency applications. It is used on both control and service channels. The communication type supported by WSMP is broadcast (IEEE 1609.3, 2013).

IEEE 1609.4: In order to support a control channel and multiple-service channels, the IEEE 1609.4 provides multichannel operation for vehicular communication (IEEE 1609.4, 2013). The channel coordination is an enhancement to IEEE 802.11 MAC and interacts with IEEE 802.2 LLC and IEEE 802.11 PHY.

IEEE 1609.11**:** Over-the-Air Data Exchange Protocol for Intelligent Transportation Systems (ITS) defines the services and secure message formats necessary to support secure electronic payments (IEEE Std1609.11, 2013).

IEEE 1609.12: Identifier Allocations. This standard indicates identifier values that have been allocated for use by WAVE systems, including the Provider Service Identifier allocations harmonized with ISO, CEN, and ETSI (IEEE Std1609.12, 2016).

IEEE 802.11p: IEEE 802.11p is a VANET standard which is basically a modification of the normal IEEE 802.11 wireless standard (802.11p-2010, 2010). Several changes were made to improve the operation of devices in a vehicular environment and in the Intelligent Transport Systems (ITS) in general, for example, consideration of devices moving at faster speeds than in the traditional mobile ad-hoc network and to accommodate data transfer between vehicles and roadside networks.

IEEE 802.11p gave rise to DSRC (Dedicated Short Range Communication) which is a United States project as well other projects and ITS architecture by the ETSI (European Telecommunications Standards Institute).

Channel operations such as designation of various activities to channels are defined in the IEEE 802.11p standard. As noted earlier, the IEEE 802.11p standard is a modified standard, precisely the IEEE 802.11a standard which has similar Media Access Control attributes operating at similar wireless frequency with signals which are directed and small penetration depth. Which means data exchange should be directed at its target otherwise be lost to obstacles.

2.3 Dissemination of Data in VANETs

For VANETs, the vehicles are the important players in the network and they drive messages within the network and therefore support end-to-end communication. In this section, brief description of available processes through which data or messages can be disseminated in a vehicular ad-hoc network is given. Starting with simple methods that are commonly used in wireless environments and then complex designs proposed or implemented by researchers in tackling the issues of message dissemination will be described. Message dissemination can be divided into two broad categories, which are the push and pull models.

The push model typically used to describe a way of spreading safety messages that may be of interest to other nodes even beyond the scope of the initiating area. Examples of where the push model may be used are, road condition warning, traffic time estimation, etc. On the other hand, the pull model describes a method where message dissemination is only activated based on the request of another node, that is, information request from one node from another node in a different area. Examples of its usage include service discovery (perhaps parking, fuel station, etc.) and other comfort or value-added service application. The pull model is characterised by less overhead and some acceptable delay in the network.

2.3.1 Flooding Based Methods

Most wireless networks use a form of flooding in order to spread messages quickly and without much computational cost. Sometimes for simple applications in VANETs, flooding of broadcast messages is commonly used. The implementation of flooding involves broadcasts by the original sender and rebroadcast of those messages by other nodes in the network upon reception. This method while being the easiest to implement and least expensive computationally involves the transmission of redundant messages which will eventually lead to congestion in the network and hence causing broadcast storms (Muhlethaler, Laouiti and Toor, 2007). While this mode of propagation satisfies the push model above, albeit poorly, it does not satisfy the pull model at all as it makes little sense to flood a network with a single request considering that other vehicles may also have requests to make at the same time.

2.3.2 Cluster Based Methods

In order to limit the effects of flooding on an ad-hoc wireless network, clustering protocols have been proposed. In this mode of propagation, the characteristic of vehicles forming clusters or groups is exploited (Jiang et al., 1999). When vehicles form clusters, then spreading information can be managed to some degree, that is, messages are distributed between two elected members of two clusters which then share the message with members of its cluster. Therefore, fewer messages are transmitted within the network hence reducing the chances of network congestion and broadcast storms. Some cluster based methods such as Blum, Eskandarian and Hoffman (2003) and Li, Tizghadam and Leon-Garcia (2012) have proved successful; however, clustering is mostly possible on highways where vehicles tend to group on a stretch of road. Within cities with buildings and other obstacles, clustering is not always feasible.

2.3.3 Routing Protocols

Proactive routing protocols maintain and update routing information among all nodes of a given network at all times and build new routes by sharing periodic routing information. The advantage of this is that routes to a destination is known beforehand and therefore ready for use when needed. However, as can be imagined the disadvantage is the overhead of sharing this route information for which the nodes must wait for in small or medium sized networks. Convergence in large networks may never be possible due to the number of nodes; this is a true reflection of the size and density of the network as opposed to the actual useful routes in the system. Therefore, one way to mitigate this is by listing only the best routes between two nodes and discarding the rest. An example of proactive routing is the DSDV protocol (Perkins and Bhagwat, 1994) (Narra et al., 2011) which uses the Bellman-Ford algorithm to find and maintain a routeing table.

Reactive routing protocols, on the other hand, construct routes only when a route is required. The obvious disadvantage of this is the time taken for each data transmission to complete its cycle of route request, transmission and delivery at the destination. On the other hand, for reactive protocols, there is less data overhead for route table maintenance of all possible route between nodes. Examples of reactive routing protocol include, ad-hoc on-demand distance vector (AODV) (Perkins and Bhagwat, 1994) (Belding-Royer and Perkins, 2003) which operates by flooding route requests within the network whereby each receiving node reads the contained route and responds with its own route in relation to its connectivity to the desired destination node.

Vehicle movement in VANET is restricted to bi-directional movements along roads and streets. Thus, routing strategies that use geographical location information are practical and efficient for data delivery. Accordingly, geographic routing was considered a more promising routing approach for VANETs, as it provides scalability and robustness against frequent topology changes (Lo and Kuo, 2013) (Fonseca and Vazão, 2013).

The hybrid protocols are introduced to reduce the control overhead of proactive routing protocols and decrease the initial route discovery delay in reactive routing protocols. The various types of reactive routing protocols are GPSR, GPSR-L, GPCR, GpsrJ+. Greedy Perimeter Stateless Routing (GPSR) (Karp and Kung, 2000) (Ning et al., 2009). GPSR and its variants work in two forwarding modes, which are the greedy forwarding mode and perimeter routing mode. In a local maximum situation, where there are few nodes spatially dispersed in an area, the protocol switches to perimeter routing by sending the packets along the perimeter of the local maximum region in a clockwise. This process is stopped when a node close to the destination is found. While this process is not without flaws such as; sending packets on routes without assurance of delivery at its destination as the perimeter route may well be a route away from the intended destination since only the right-hand rule is employed. The GPSR algorithm also has a high chance of sending packets into routing loops while it performs the perimeter mode routing (Rothermel, 2002). Finally, the GPSR protocol does not consider overly congested routes in its decision making.

2.3.4 Protocols for Message Distribution in VANETs

The following sections discusses various proposed solutions by researchers to tackle the issue of efficiently disseminating messages in VANET.

2.3.4.1 Multihop Vehicular Broadcast (MHVB) (Osafune, Lin and Lenardi, 2006)

MHVB was proposed as a flooding solution for vehicular ad-hoc networks to efficiently disseminate safety application information, such as the positions and the velocities of the vehicles within a small geographical area of up to 300m while achieving maximum delays of up to 0.5s. It is presented as a flooding protocol with two main algorithms which are; a Congestion Detection algorithm which reduces unnecessary packets due to vehicular congested traffic by limiting packet spread and (ii) Backfire algorithm which efficiently disseminates the messages through the network by selecting the right receiver node based on the distance from the original node.

BackFire Algorithm

Among assumptions made for this algorithm are; the extent of the radio signal, estimated or fixed at 200m for 802.11 devices and the ability for devices to check their neighbours' positions to determine if they are within an area of interest. Following the latter, the receiving node calculates its distance from the sending node. Several steps must be followed to achieve optimum deployment including, storing the information in a database, ensuring that the originating node is not outside a specified D_{max} range, retransmission based on distance from the source node and dropping messages received more than once. The authors have not provided any equation for calculating the distances, nor concrete suggestions on how the algorithm works. Also, the selected distance of 200m may not work for every scenario as 802.11p devices can operate on various channels with varying distances.

Traffic Congestion Detection algorithm

Within this algorithm is the need to have a decent knowledge of traffic intensity by way of using vehicle short range object detection sensors on each vehicle hence eliminating the need for vehicle to vehicle communication, however this does not explain how the vehicles can know how dense the traffic is if they do not share information, as each vehicle can at best detect other vehicles bounded on each side to it. For the algorithm to function, it must have detected vehicles more than a stipulated N_{max}, the number of vehicles in front and behind must be more than a threshold of N_{fb}, and the vehicles velocity must be less than a threshold of V_{max}. When these three factors are satisfied, then an information dissemination period of T_{def} should be extended. As with the case above, there are no definite equations to support these suggestions.

Building upon this work is another called Enhanced Multi Hop Vehicular Broadcast (EMHVB) (Mariyasagayam, Osafune and Lenardi, 2007) to offer enhancement as the name suggests. In this case the backfire region is now defined as a section instead of the previous circle and vehicles will be assigned timers that control retransmission of messages based on an equation of position vectors with respect to the origin of the message as well as an angle theta defined as the backfire region angle, thus improving the dissemination by making it directional and less strict.

The Enhanced MHVB also provides dynamic scheduling of message transmission by allowing any vehicle more than 200m away from the sender to forward messages as soon as they can in order to improve latency and cover areas between the message origin and destination faster.

Algorithms and proposals were tested using a simulator covering scenarios such as a square area infused with nodes moving according to random waypoint algorithms, small grids and straight lines. Though this showed improvements upon the previous algorithms, it does not show that it would work with vehicular movements yet.

2.3.4.2 Urban MHVB (Mariyasagayam, Menouar and Lenardi, 2009)

In this case, the MHVB protocol described above is adapted to urban environments. Consistent with urban scenarios the protocol works with the assumption of the presence of obstructions, higher road traffic and intersections. The protocol works by setting sectors instead of circles as the next forwarding areas. The estimated traffic density is used to calculate the forwarding areas. The job of the receivers is to determine if they are within a forwarding region and upon that begin a back off timer based on distances between sender and receiver. At the expiration of the first timer, the vehicle forwards its message while inhibiting the others. The definition of the sectors is unclear, however, from the evaluation of the protocol using a generic square grid with random way point motion, the protocol fairs better than others in terms of efficiency depending on the traffic situation.

2.3.4.3 Ad-Hoc and Multihop Broadcast (AMB) (Korkmaz, Ekici and Ozguner, 2007)

In this work, the authors proposed two 802.11-based multi-hop broadcast protocols; ad hoc multi-hop broadcast (AMB) and urban multi-hop broadcast (UMB) (Korkmaz, Ekici and Ozguner, 2007), for vehicular ad-hoc networks. In order to address the broadcast storm, hidden node, and reliability problems in multi-hop transmissions. The protocols are made up of two stages, namely directional broadcast and intersection broadcast. In the first stage, the algorithm aims to select the furthest node in the broadcast direction and assigns the function of forwarding and acknowledging the packet without any prior knowledge of the topology in which it resides, that is, sending nodes select the furthest node as destination nodes without knowing the position of their neighbours. The second stage is the intersection transmission which uses installed repeaters as communication infrastructures at road sections to retransmit messages to all road segments if that particular road segment is obstructed by obstacles or constructed in such a way as it limits the selection of the furthest node as the destination node. The AMB protocol is made for roadways, and the UMB protocol is adapted for urban vehicular network environments.

Directional broadcast

In this algorithm, a handshake authentication procedure is employed by sending a message like 802.11's Request to Send called a Request to Broadcast message (RTB) to the furthest node in the direction of message delivery. This is achieved by dividing the road portion within the transmission range into N_{max} equal segments, if there are more than one vehicle within the furthest segment then the segments are further divided into segments of smaller widths until the furthest vehicle is achieved or by selecting a random vehicle in the last segment. By doing so, all vehicles in the disseminating direction will overhear those requests and at the same time calculate the distance between itself and the sending vehicle. Each receiver also sends a channel jam signal called a black burst whose length is a function of the estimated distance from the source node.

$$L_1 = \left\lfloor d \cdot \frac{N_{max}}{R} \right\rfloor \cdot SlotTime$$

Equation 2.1: Black Burst Length Equation

Where L is the length of the black burst, R is transmission range, N_{max} is the number of segments created and slot time is the length of each slot. The logic here is that the furthest vehicle by way of the above equation will have the longest black burst and hence win contention to the transmission medium thereby sending a Clear to Broadcast message to the original node. In this algorithm, it is probable to have more than one vehicle with the same black burst length thereby causing data collision, in this case, a new contention begins with only the vehicles with the longest black burst lengths competing again. While this ensures a certain degree of QoS, there must be some latency sacrifice in order to achieve this.

Intersection broadcast

For road segments with intersections, directed broadcasts will be initiated to all available road segments. If the intersections are obstructed, for example, within cities with tall buildings, then wireless repeaters are employed, where as if it is an open space, the ad-hoc protocol AMB is used. These protocols and even the use of repeaters means each vehicle must be aware of its precise location and position through the employment of maps and navigation system GPS.

In the first instance, when a node is selected as a forwarding node, and it is outside the transmission range of a repeater, it employs the directional broadcast protocol, as described above. If it is within the repeater's range, then the message is forwarded using the 802.11's point to point protocol fulfilling an RTS/CTS sequence with the repeater. Upon message reception, the repeater performs the directional broadcast in every other direction except that from which the message originated. Other than this the vehicles will switch to an ad-hoc mode described below.

AMB for Intersections

Here the road is divided into segments with the intersection taking priority and defined as (R/2) m from the centre of the intersection, where R is the transmission range of the wireless devices. A direction broadcast winner within the intersection region is called a hunter and in charge of finding the vehicle closest to the centre of the intersection. Like the RTB process described above, the hunter sends an I-RTB (intersection RTB), and the vehicle with the longest black burst is selected, and the winning vehicle transmits a broadcast in every other direction except that from which it received the original message.

In this protocol, it is not clear how this process is applied to fast moving vehicles at an intersection or how an issue with multiple black burst contenders deals resolve contention. Experiments were conducted using random distance based scheme without knowledge of surroundings but rather depending on contention for the medium. All tests were done by the authors using a custom-made simulator covering a simulation area of 2400m square with four intersections, coverage and overhead were criteria the authors identified as better performing in comparison to other schemes as AMB and UMB helps avoid hidden nodes and collisions.

2.3.4.4 Urban Multihop Broadcast (UMB) (Korkmaz, Ekici and Ozguner, 2007)

UMB is a protocol similar to the above AMB but specifically designed for urban environments. Just like the AMB protocol, it is a MAC level solution that seeks to eliminate or reduce broadcast storms, hidden nodes, and reliability problems in multi-hop dissemination of messages. Similarly, it is made up of two phases—directional broadcast and intersection broadcast. A directional broadcast is used in a free area, and intersection broadcast is used at intersections where there is no line of sight (transmission wise) between the sender and receiver of messages in the network. Trees, buildings and other infrastructure can block transmission signals, increasing the chances of delivery failure using directional broadcasts to other directions. The UMB protocol uses wireless repeaters that must be placed at such intersections to handle dissemination. The description is similar to that of the AMB above.

2.3.4.5 Dynamic Backbone-Assisted MAC (DBA-MAC) (Di Felice, Bedogni and Bononi, 2011)

In this protocol, a distributed cluster infrastructure is defined by providing nodes with a distributed protocol to proactively form a backbone. Formation of clusters can allow for efficient multi-hop message propagation among vehicles when used, as it allows reliable sharing of messages amongst its members and then with other clusters, thus adding a level of organisation to the network. In the DBA-MAC protocol the backbone refers to a virtual chain of vehicles in a vehicular scenario (e.g. a highway), with each node of the backbone connected to previous and next hop of the backbone chain. The proposed protocol also intends to achieve fairness and scalability within the vehicular ad-hoc network.

To achieve the BackBone (BB), the protocol utilises beacon messages which have added information such as transmission range, vehicle ID, speed, direction, location coordinates and risk zone limit known as the horizon. In the absence of reception of beacon messages from other vehicles during a time interval of RefTim, a vehicle can choose itself as a member of a new backbone and begins transmission of beacon messages. Any vehicle which eventually receives the beacon message and is going in the same direction as the sending vehicle can become candidates to become the next hop in the formation of the backbone. A MAC level contention is used to select the actual vehicle and it must be connected to the previous vehicle until such a time as when the backbone is refreshed at least. This means that based on speed, if a vehicle can determine it will not be in the vicinity of the previous vehicle by the next refresh period, it must leave the contention, leaving the rest of the contenders to calculate a fit factor (FF)

$$FF(A) = \frac{dist(A,B) + \Delta\nu \times BB\_REFR}{R}$$

Equation 2.2: Fit Factor Calculation

This gives an estimate of the distance between the contending candidate and the previous vehicle in the backbone after the backbone refresh with the transmission range as ratio factor. The fit factor is then used to regulate the contention window of the MAC back off scheme in order to send a candidate message:

$$CW = max\,\{0,(1 - FF(A))\} \times (CW_{MAX} - CW_{Min}) + CW_{Min}$$

Equation 2.3: Calculating Contention Window

Supposing a vehicle has a fit factor close to 1 it would have a higher chance of being the candidate as its congestion window is small. The backbone vehicle receives such a candidature message, it responds with an acknowledgement confirming the winner, other vehicles meanwhile will, therefore, end their contention once the winner is confirmed or overhead.

The other scenario is when a vehicle in a backbone receives a beacon message from another vehicle ahead of it, therefore presenting the opportunity to form a longer more connected backbone, the vehicle will send a candidature message and most likely win and form a continuous backbone.

Backbone members aid in message dissemination because they have priority in accessing the wireless channel; hence they can easily retransmit messages received. This ensures less contention amongst all nodes and reduces the number of forwarding nodes as the backbone members are ahead in terms of location anyway. Vehicles in the backbone may send messages via broadcast; the next hop immediately sends back a unicast ACK (it only waits until the SIFS is over). Next, without letting go of the channel control, it broadcasts the alert through a MAC scheme called Fast Multi-Hop Forwarding (FMF). Furthermore, there is a combined unicast and broadcast transmission concept to allow the fast advertisement propagation of alert messages in the risk zone. All messages relayed by backbone members are broadcast messages: in this way, every node will receive the advertised message information, but it works like a unicast system. If a backbone node does not receive a unicast acknowledgement from the next hop after broadcasting an alert, then the backbone is broken. In such a case, all the vehicles take part in a distance-based scheme. All vehicles begin a back off process after receiving an alert in order to broadcast it. If a vehicle which is a backbone node is identified then the congestion window is configured with a small value; otherwise, it is inversely proportional to the distance to the vehicle originating node.

When compared to other protocols, for example, Fast Broadcast Protocol (Palazzi et al., 2007) and simple flooding in a simulation area of 8km, the protocol fared better because simple flooding causes multiple retransmissions and collisions, and the use of the backbone nodes gave it an edge over the other protocol.

2.3.4.6 Distributed Vehicular Broadcast (DV-CAST) (Tonguz, Wisitpongphan and Bai, 2010)

DV-CAST is a distributed vehicular multi-hop broadcast protocol for highways, that is intended to handle all traffic conditions, which includes extreme scenarios such as dense and sparse traffic regimes. The protocol works by relying on local topology information for handling broadcast messages in VANETs. The main aim is to avoid broadcast storms and find a solution for sparsely connected networks, and it achieves these goals by applying a neighbour detection algorithm, a store and carry mechanism and broadcast suppression technique.

The neighbour detection mechanism estimates the local topology by monitoring periodic hello updates received from one-hop neighbours; these hello updates will contain certain information such as; coordinates and heading provided by a GNSS, in this case, GPS. The local topology is used as part of the rules determining how packets should be handled. While extracting the relevant information from the hello updates, each vehicle will according to the protocol, create three categories of neighbours in chronological order, namely; NB_FRONT, NB_BACK and NB_OPPOSITE, representing the neighbours in front of the vehicle, the neighbours behind the vehicle and the neighbours moving in the opposite direction respectively.

The categories are ordered and have a size limit of MAX_{NB}, with older entries removed, for simplicity the authors had limited the value to five. The various data gleaned can then be used to determine three binary flags:

- Destination flag (DFlg), which determines whether a car is the intended recipient of the message.
- Message direction connectivity (MDC), which determines whether a car is the last vehicle in the one hop group/cluster for the same direction of travel.
- Opposite direction connectivity (ODC), which determines whether a car is connected to at least one vehicle within one hop in the opposite direction.

Broadcast Suppression Technique

The techniques applied here are some from a previous work found here (Wisitpongphan et al., 2007). There are three choices namely: the weighted p-persistence, slotted 1-persistence and the slotted p-persistence.

The weighted p-persistence is a probabilistic algorithm using some form of flooding where the probability p is a ratio of the distance from the message source and the transmission radius. Both information as described earlier can be retrieved from GPS devices. Also, a priority is given to the vehicle furthest away by using a waiting period, for example, if multiple messages are received within the waiting period, the vehicle selects the smallest p value.

Slotted 1-persistence: in this case, rather than the calculation of a forwarding probability, each vehicle calculates a time slot Ts_{ij} during which it attempts transmission. This is done after the wait time period has elapsed. The vehicles avoid transmission if another is transmitting using an earlier time slot.

Slotted p-persistence: similar to the slotted 1-persistence process, the Ts_{ij} time slot is calculated along with a fixed probability p. Each vehicle can transmit messages within its own time slot but failing to so attracts an additional time the vehicle must wait.

Store-carry-forward mechanism

The store and forward technique is a widely used one (Briesemeister and Hommel, 2000) (Li et al., 2013), employed in situations where the network is sparse. The authors have suggested this method could take a few seconds or a few minutes and this is the time it would take the last vehicle with the information to find another able to carry the information in the right direction. The entire process can be broken down into three scenarios:

If the MDC is one, then vehicles must avoid duplicate transmissions as this means a dense network is present.

If the MDC is set to zero, and ODC is zero, then it means the vehicle is isolated and waits for a hello update, if a hello update from another vehicle is received then the vehicle applies a different algorithm which may mean a vehicle in the opposite direction and it can then forward the packet.

In evaluating the DV-CAST protocol, a circular highway is used testing for efficiency and scalability. The algorithm is said to be reliable and efficient if the intended messages can reach all vehicles within the specified area with satisfactory progress while scalability relates to how the protocol handles duplicated messages within the network. It is generally agreed that the store and carry method is a good way to handle message distribution in a sparse network while pointing out the weakness of the system relates to the accuracy of location information from the GPS data.

2.3.4.7 Urban Vehicular Broadcast (UV-CAST) (Viriyasitavat, Tonguz and Bai, 2011)

UV CAST protocol is another adapted protocol specifically for urban scenarios, involving higher road traffic, intersections, etc. Its functionality covers a range from well-connected networks to sparsely connected ones. In this protocol, a vehicle uses information from beacon messages to verify its position to determine if it is within a sparse network or not. In the case the vehicle is within a dense network, a broadcast limiting scheme is initiated; otherwise, it begins a store and carry forward mode whether or not it is disconnected from the primary network or just happens to be the last in the network. To help in the determination of whether a vehicle is within a connected network, a calculation of an angle theta for all its neighbours is done for which a connected network must have a range of $[-\pi, \pi]$ between the sender of a message (S), a neighbour (N) and the current vehicle itself (A), that is, θ = <S A N. outside of a connected network, the vehicle in a store and carry forward mode does so until it leaves the area of interest, that is, the area where that message is relevant.

In the evaluation of the protocol, though no other protocol was used to compare, the results showed that the protocol handled message dissemination well and the authors used real maps to test the protocol.

2.3.4.8 Two Angles Forwarding (TAF) (Salvo et al., 2012)

In this framework, the authors proposed a Distance Based Forwarding algorithm (DBF) that encourages retransmission of packets only by the node farthest from the sender, and this builds on an older protocol known as Distance Defer Transmission protocol (Sun et al., 2000). This is further separated into three algorithms; Single Angle Forwarding (SAF), Two Angles Forwarding (TAF) and Multi-Two Angles Forwarding (MTAF). In order to do that, a defer timer is employed in which a vehicle waits an amount of time which is inversely proportional to the sender-receiver distance before retransmitting a received message. Another rule in this framework is the inhibition of multiple copies of the same message by keeping track of message IDs. It is intended to avoid the use of beacons by using information from GPS and Road Side Units (RSUs).

In this model, it is conceived that when a vehicle receives messages from more than one source which are its neighbours, then it forms a triangle with them. Each of the Angle forwarding techniques mentioned above has different rules as to when and how these angles are formed and is applied each time a vehicle receives duplicate messages.

During this period a timer is started based on $\eta = T_{forward}\ (1\text{-}d/r)$.

Where $T_{forward}$ is the maximum wait period, d is the distance between the receiver and first sender and r is the transmission range.

For the SAF, if the receiving node is Rx and two transmitting nodes are Tx_1 and Tx_2 respectively, then angles γ, α and β is formed between them respectively. Rx is expected to calculate cos α and forward the received message only if that value is greater than δ_{th} where δ_{th} is the constant threshold. The message is not forwarded is that condition is not met during the timer duration.

In the case of the Two Angle Forwarding, the cosine of the angle β is also computed, and messages are only forwarded by Rx if both cosines are greater than δ_{th} during the timer duration.

Lastly, the Multi-Two Angles Forwarding (MTAF), unlike the previous algorithms, this does not only calculate the angles for one-hop neighbours, but it also calculates the cosines of all possible triangles of all vehicles that the receiving vehicle has received the same message from. It seems evident that by computing a larger scope for retransmission, the MTAF can reach a larger number of vehicles without creating a broadcast storm. However, the MTAF involves more computation, and hence some speed is sacrificed especially in comparison with the TAF algorithm.

Evaluation of the algorithms was conducted in a square grid revolving around an RSU which emits messages periodically. The setting does not entirely model a typical VANET scenario. Also, there is no accounting for changes in the speed of the vehicles as triangles formed may be gone the next broadcast period.

2.3.4.9 Acknowledged Broadcast from Static to highly Mobile (ABSM) (Ros, Ruiz and Stojmenovic, 2012)

ABSM is a broadcast algorithm created to cater for a broad range of vehicular conditions, utilising information extracted from periodic beacon messages, containing acknowledgements of the circulated broadcast messages. It is based on a protocol called Parameter-less Broadcast in Static to Highly Mobile as-hoc network protocol (PBSM) (Khan, Stojmenovic and Zaguia, 2008) which uses a connected dominating set (CDS) and neighbour elimination scheme (NES). Connected Dominating Sets are easy to form at intersections and junctions because more vehicles convene at that point. When a vehicle receives a message, it first checks if other neighbours already cover the area of interest which would make its retransmission redundant. Since the vehicles form a connected set, those who are part of a CDS wait for a shorter period than others because the connected set equates better connectivity. Each vehicle can upon extracting a message create two lists, one for a group of vehicles that also have the same message, R and another group for other vehicles, N. This lists are important because the historic content of the former list provides some level of acknowledgement. The vehicle can then forward the message to every non-empty group of vehicles, N. As long as the message is relevant, if more vehicles join the N group, the message is forwarded to them as well. The process is a form of a store and carry forward technique for message dissemination.

The authors have attempted to use only standard beacon messages without the need to classify network or vehicle speeds. In simulation-based performance evaluation using a straight four km scenario and another with crossroads and varying road traffic density, the algorithm was shown to provide higher reliability and message spread efficiency than other methods for message dissemination in VANETs.

2.3.4.10 Enhanced Street Broadcast Reduction (eSBR) (Martinez et al., 2010)

Enhanced Street Broadcast Reduction scheme (eSBR) is a message dissemination protocol aimed at reducing the broadcast storm problem, increasing accuracy and reducing delays in urban vehicular network scenarios considering that vehicular communications will depend on line of sight paths to be effective. The authors are more concerned with the use of warning messages rather than beacon messages, though both will exist in the network with the former having priority over the latter. While in warning mode, vehicles inform other vehicles about their status by sending warning messages periodically. Normal mode vehicles enable the diffusion of these warning packets and, periodically, they also send beacons with information such as their positions, speed, etc. These periodic messages have lower priority than warning messages and are not propagated by other vehicles.

When a vehicle receives a warning message, it checks its sequence number and is only allowed to broadcast it if it has a new sequence number, older messages are discarded and so on, if the message is to be rebroadcasted to the surrounding vehicles, it does so only when the distance d between sender and receiver is higher than a distance threshold, or the receiver is on a different street than the sender.

The authors evaluated the performance of eSBR scheme in comparison to several protocols which were; distance-based scheme and a location-based scheme, using two different scenarios: A Manhattan grid-style, and a real map. The results showed about 8% better performance of eSBR against the other protocols. While the authors insist that the method eliminate the need for a store and carry mechanism even for sparse networks, it seems it introduces a certain amount of overhead in the network by using regular messages and duplicates to achieve its aim.

2.3.4.11 Real-Time Adaptive Dissemination (RTAD) (Sanguesa et al., 2015)

Real-Time Adaptive Dissemination (RTAD) is a combination of several algorithms and techniques to ensure efficient message dissemination in vehicular ad-hoc networks. It is aimed at being able to automatically adopt the most suitable dissemination scheme in order to fit the warning message delivery policy to each particular situation. It takes into account several parameters such as; the vehicular density and the topological characteristics of the environment where the vehicles are located, in order to decide which dissemination scheme to use.

The RTAD system as previously noted needs to estimate the vehicle density to select the most appropriate broadcast scheme, and this is achieved by using the number of neighbours, rather than the number of beacons received.

There are three main parts of the system; A Real Attenuation and Visibility (RAV) model which operates either when the sender and receiver are within the maximum transmission range, and they are in line-of-sight, for example, if the two vehicles are located in the same street, or if they are located in different streets but there are no buildings blocking the radio signal. The other scenario is if the sender and receiver are not in line-of-sight, but the receiver is close enough to a junction, thereby increasing the probability of successful reception due to the reflection and diffraction of the wireless signal on the nearby buildings.

Also, the streets are broken down into sections called an SJ Ratio defined as the result of dividing the number of streets by the number of junctions. If this value is high, then the topology is regarded as a complex one otherwise it is a simple topology; the simplest topology is a street where two vehicles have a direct line of sight.

Finally, the system maintains a neighbour list that is built by using the beacons exchanged periodically (each second) among the vehicles, avoiding any additional channel overhead. Whenever a new beacon is received, each vehicle checks its neighbour list to determine if the sender is a new neighbour, thereby adding this vehicle to the list.

For evaluation of the system, depending on the values of the factors described above, one of eSBR, eMDR or NJL dissemination scheme is selected as the best fit. This means that the factors above, most especially the SJ Ratio must be pre-calculated offline for each street in other to use the system. By so doing, the system is far responsive and adaptive to different scenarios than the original algorithms on their own. Simulation results demonstrate significant improvements, being able to support more efficient message dissemination in all situations ranging from low densities with complex maps, to high densities in simple scenarios. RTAD notably improves existing approaches in terms of percentage of vehicles informed, while significantly reducing the number of messages sent, thus mitigating broadcast storms.

2.5 Summary and Discussions

Various message dissemination techniques for VANET have been presented in this chapter. The trend found here is that solutions proffered by researchers are seen to be directed towards particular use-case scenario because of the difficulty in obtaining a single solution to fix a variety of problems. There are several paradigms to consider in designing a VANET solution which is, reliability, efficiency and latency with the consensus of most VANET survey revealing improbability of achieving optimum levels on all three. The usual practice, therefore, is to focus on one or two metrics to improve upon.

While safety related applications may require quick message dissemination, the provision of high levels of efficiency and reliability may be difficult at the same time. For example, in cases of emergencies on roads, a quick broadcast or probability based scheme like RTAD have shown to be more appropriate. Whereas delay tolerant applications, for example, infotainment and tolling will benefit more from high efficiency and reliability. Protocols such as AMB and DBA-MAC are examples of techniques that can provide efficiency and reliability by suppressing duplicated messages to ease the burden on the network. Reliability may also be achieved through the use of acknowledgements from the receiver of the message. An example of a protocol that explicitly applies this is the UMB protocol which uses handshakes to provide reliability.

In this research, an effort is made to provide acceptable levels of reliability, efficiency and latency for VANETs in designing the framework. For example, the use of vehicular sensor data that can increase reliability, ensuring a single carrier of messages to avoid unwanted duplications and network partition improves efficiency while algorithms that reduce latency are also introduced to the framework.

With VANET being a shared resource network, road traffic factors such as the number of participants, the speed of travel, etc. play a major role in how messages are disseminated. These factors affect the “goodness” (delivery capability) of the network in various ways and in chapter 4 it is seen that each route or road has a unique response to varying factor levels and this information is vital to the design and implementation of the framework.

Chapter 3: Methods and Tools for Building the Framework for Improved Message Delivery (FIMDEV)

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Chapter Overview

In order to prove any concept in research, it is important to follow a logical process from the start to conclusion while maintaining a high level of integrity. To do this, several approaches can be used. A hypothesis can be formulated and tested using real-life scenario and setup, or these can be simulated using carefully constructed environments. The former while giving stronger validity and the ability to capture real responses like the effects of several factors that may not have been considered in modelling the environment, is an expensive way to prove or disprove the hypothesis. On the other hand, simulation models are highly regarded for problem solving (Sargent, 1991) and consequently the methods and tools for simulation. Generally, researchers follow the Operations Research methodology which consists of formulating the problem, constructing the model, validating and evaluation of the model (Perros, 2009) of which simulation techniques is one of. This research project will follow this methodology closely because several models will be utilised within the proposed framework.

A model is a representation of the structure of a real-life system, and they can be analogue, iconic or symbolic. Simulation models are symbolic models where behaviours and properties of real-life systems are represented by mathematical equations and computer programs (ibid). These behaviour and properties are 'simulated' to interact with each other, these interactions are monitored and then analysed at the end of the experiment. In simulating a system (model or framework), the following are the main features of the process that must be considered; the environment, the interdependence of activities, sub-systems, organisation of components and changes in the state of elements/system over a time limit.

Phase 1: Research Background

An extensive state of the art review of VANET, VANET standards and its applications is carried out. Several proposed message dissemination techniques are also discussed at this stage. It will also involve decisions about what tools to use in the course of this research and methods of achieving the desired objectives.

Phase 2: Determining Important Traffic and Network Factors

Experiments and statistical analysis will be carried out to determine what road traffic factors affect the performance of the network. This is done using a 2^k factorial analysis which is a form of experimental design that provides the smallest number of experimental runs with "k" factors to be studied, where high and low values for each factor is set before the start of each simulation, results are then analysed using a statistical formula or software as described in chapter 4.

Phase 3: Data Gathering from Various Vehicular Sensors and Map Building

Design the new framework to combine information from different sensors, knowledge of current road traffic as well as a "wireless network map" of the area using several algorithms to improve message delivery within the network. The choice of road traffic and network variables will depend on the outcome described in phase 2 above.

Phase 4: Implementation and Evaluation

Validate the performance of the proposed framework using synthetic data and present experiments to show improved performance with respect to improving the efficiency, reliability and time taken to deliver messages within the network.

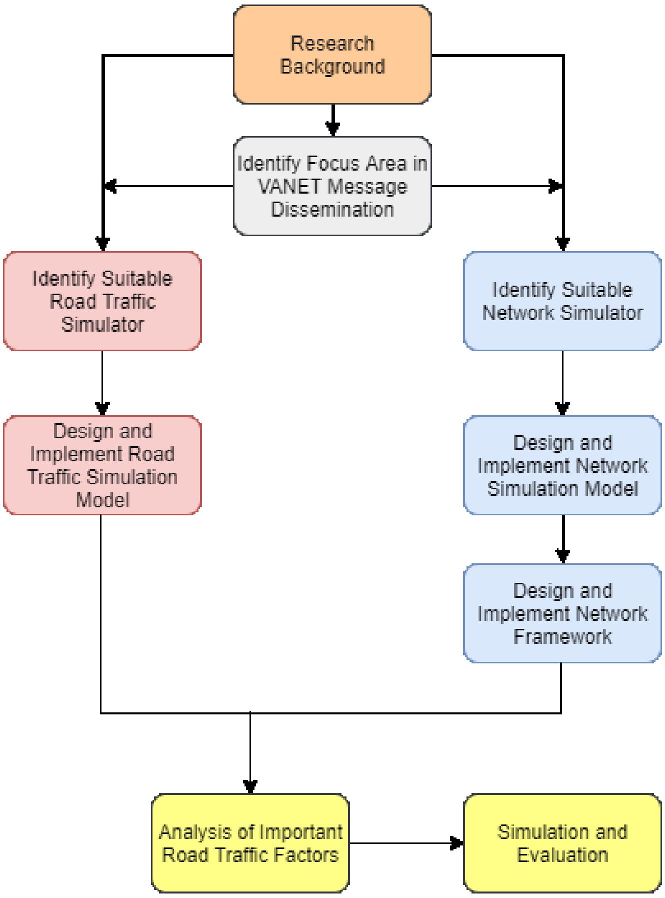


Figure 3.1: Research Method

3.1 Tools for Systems Evaluation

Though important, real-life evaluation of vehicular ad-hoc network paradigms has been hampered in the past by a lack of standardisation, that is, there was no assurance that what was being built would be valid eventually when standards organisations, industry and researchers agree on a single standard. For example, in the past, a test bed might be built using a wireless standard of IEEE 802.11a which would render the test bed invalid today due to the issuance of the IEEE 802.11p standard. This would mean replacing wireless radios in the setup, leading to a loss of time and money.

On the other hand, the importance of simulation in VANETs cannot be over-emphasised as this makes a small job of hundreds of experiments involving nodes (vehicles) with rapid movements in a quick changing topology. It means that to conduct successful experiments in this field, and there is a need for both a vehicle environment simulator or traffic generators and a wireless network simulator.

3.1.1 Vehicular Traffic Simulators

Considering some similarities between Mobile Ad-hoc Networks (MANETs) and VANETs it is no surprise that some tools from the former have been adapted for the latter. However, MANETs do not have the same characteristics as VANETs, for example, vehicles in a vehicular network move along a particular route that is, on the road, streets, etc. Therefore, traditional mobility patterns such as random waypoint model used in MANETs should not typically be used for any practical experiment in VANETs. Also, following traffic flow theory (Gerlough and Huber, 1975), vehicles move along those routes following vehicular traffic flows. Such factors such as inter-vehicle spacing, headspace, etc. must then be considered in a realistic VANET model.

In vehicular networks, mobility simulators are divided into two broad categories which are microscopic and macroscopic with a third group called mesoscopic models which combine features from the former two. Microscopic models give the ability to identify attributes such as speed, inter-vehicle spacing, acceleration, etc. of each vehicle. Macroscopic models, on the other hand, defines the mobility of vehicles on a broader scale by defining a section by section basis and focuses on the flow of the traffic, that is the traffic density, traffic queue of a section of road. Mesoscopic models combine properties from the microscopic and macroscopic models in that, individual vehicles can have attributes, but the movement of the traffic is done at a macroscopic level. Though the distinct advantage of Macroscopic and Mesoscopic models is that they require less computational power compared to microscopic models, they are only suitable for certain cases.

Examples of traffic simulators are given below;

SUMO (Simulation of Urban MObility) (Behrisch et al., 2011) is a very popular open source microscopic vehicular traffic simulator that gives the experimenter a lot of customisable features such as distinguishable vehicle types, multiple lane streets, lane changing ability, explicit rules at junctions and traffic lights and a functional graphic user interface. SUMO also has tools to help experiments in large road networks such as dynamic vehicle routing between two or more points and can import several network formats like VISUM (Crișan and Filip, 2015), XML formats and thus OpenStreetMap. OpenStreetMap being a great source of location/map data allows for exporting road information into SUMO which can be cleaned up and edited using a SUMO tool called NETEDIT. Upon completion of vehicle and traffic descriptions in SUMO, they can be exported as traces into network simulators for experiments.

VanetMobiSim (Fiore et al., 2007) is described as a tool capable of generating realistic vehicular movement traces for telecommunication networks simulators. It provides realistic features for traffic models and can operate at either the macroscopic level or at the microscopic level. Like SUMO it has the ability to import data from several sources, for example, data from maps created by the US Census Bureau topologically integrated geographic encoding and referencing (TIGER) database. This is a useful tool as the TIGER data includes other transportation features, such as railroads in the entire United States. VanetMobiSim also handles multi-lane streets and traffic lights at junctions. It also includes other features such as Intelligent Driving Model with Intersection Management (IDM/IM), Intelligent Driving Model with Lane Changing (IDM/LC) and an overtaking model (MOBIL) to provide a more realistic feel of how vehicles interact on roads. It can also export its traces in different formats.

MOVE (MObility model generator for VEhicular networks) (Karnadi, Mo and Lan, 2007) is a vehicle simulation tool that allows users to rapidly generate realistic mobility models for VANET simulations. MOVE is built on top of SUMO and therefore has properties and features of SUMO, it allows simplification of mobility generation by providing a user interface that eliminates the need to write simulation scripts as is the case in SUMO. Its trace files can be used on several network simulators.

For this research project, SUMO has been chosen as the mobility generator because of all the features listed above, it has decent support in an online community and is being used by the research group hence allowing easier cooperation in research.

3.1.2 Network Simulators

Network simulators are tools that emulate network characteristics allowing researchers to examine network behaviour under different conditions such as a difference in one contributing factor or the other. Like mobility simulators, it is an easier and cheaper alternative to setting up testbeds including all the tools and components in the system. It also helps reduce the time it takes to run dozens of experiments. Network simulators are therefore integral to creating or modifying network protocols in a fact-backed manner.

Some of the currently popular network simulators are discussed below;

GloMoSim (Zeng, Bagrodia and Gerla, 1998) (Martin, J., 2001) is described as a network simulator that effectively utilises parallel execution to reduce the simulation time of detailed high-fidelity models of large communication networks (Bajaj L. et al., 1999). It is a scalable simulation environment for both wireless and wired networks. GloMoSim uses libraries designed in a layered manner quite like the OSI reference model; this allows development of tools for specific layers or parts of the simulation environment.

JiST (Barr, Haas and van Renesse, 2005) is a discrete event simulation engine that runs over a standard Java virtual machine. It works by utilising current virtual machine as a simulation environment, at the code level by way of embedded simulation semantics. It helps to combine standard systems and language based simulator designs and has the ability to function better than other speciality simulation programs in terms of memory and time taken to perform tasks. It is designed as a straightforward implementation to avoid call-backs and unnecessary coding.

Network Simulator 3 (NSNAM, 2012) popularly known as NS-3 is a discrete event network simulator that is a successor to a now legacy network simulator 2 (NS-2). NS-3 though a successor to NS-2, there are major differences in both simulators, for example, the programming language of NS-2 was Object Oriented TCL (OTCL), NS-3, on the other hand, is written in C++, therefore, making it easier to understand and work with as well as making it scalable. This has led to a significant number of contributions to its framework including models and protocols for VANETs. Its popularity means continuous maintenance and exponential development of newer versions. It allows for the creation of ad-hoc networks with realistic attributes such as signal fading, path loss and the implementation of the new 802.11p standard for VANETs.

3.2 Methods

Creating each scenario for the experiments involves quite a few steps which need to be painstakingly followed in order to achieve the desired results. The following represents the major steps taken in this project's simulation methodology.

The first process involves identification of road sections to be considered in the research scenario. Information about what type of road it is, what is the usual average speed and number of vehicles on that road can be gotten from resources such as NottinghamInsight and SCOOT (a system that gathers traffic data such as vehicle speeds and the number of vehicles per unit time from strategic traffic routes in Nottingham).

The identified section is extracted from OpenStreetMap (OSM) and edited using various tools from SUMO, in the process eliminating unusable routes such as pedestrian only routes, bicycle routes and so on. This file is the network file into which intended traffic can be inserted. It is therefore imperative to have this correctly implemented.

The map can be exported once it meets all the requirements in the sense of the needed territory. A file with ".osm" extension will be extracted.

Network file: As stated earlier the network file is the geographical template into which the traffic can be injected. It contains all necessary road infrastructure which will be used, unnecessary infrastructure and/or routes can be removed. This network file is an xml file representing the road infrastructure as a directed graph where the streets and junctions are edges, an example of a section of network file used in this research can be seen in figure 3.2.

Routes file: In order for trips to be made in the network file, routes have to be specified and this can either be done manually by specifying the start and end point for each vehicle or this can be done automatically using some traffic routing tools provided in SUMO. Obviously, for large scale simulations, it would make sense to use one of the automatic route generators from any of the following; OD2TRIPS, DFROUTER, JTRROUTER, and DUAROUTER with each using a different algorithm and providing different features. In this research, DUAROUTER was the selected generator used.

Configuration file: In order to complete the mobility setup in SUMO a config file is needed to inform subsequent simulators about the necessary components of the mobility model.

Examples of added instructions that can be defined are how long the simulation is for, which network file to use.

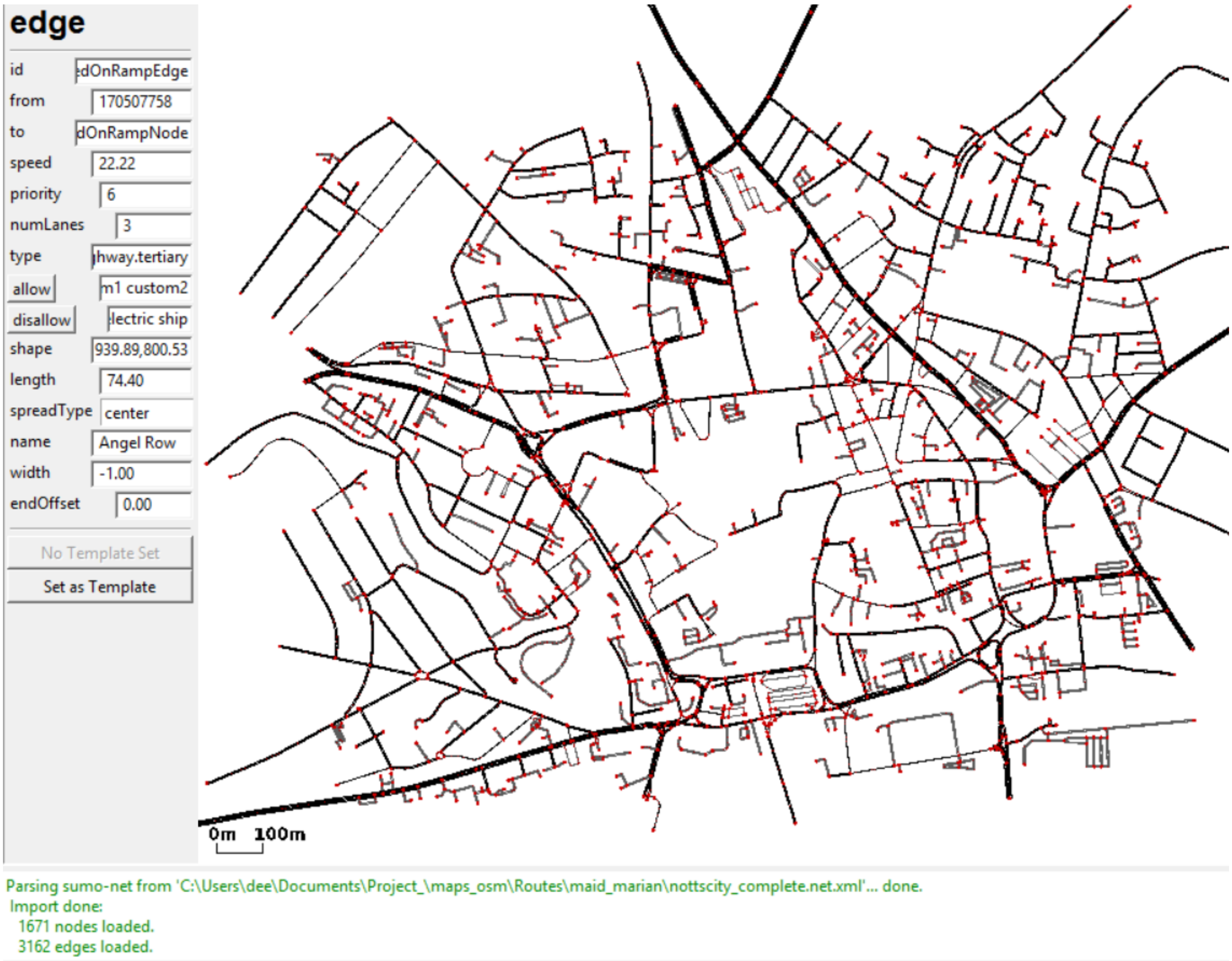


Figure 3.2: Preparing the Geographic Layer of the Map for Traffic Simulation

Trace file: Finally, trace files to be used by the network simulator must be created using the SUMO definition for mobility in the net file. SUMO has an exporter package that can be called to combine all aspects of the road network including traffic patterns added to the model.

This ensures that all attributes in the mobility model are properly exported and ready for conversion into trace.

Network Simulation: To complete the simulation methodology the network aspect is implemented next. As previously discussed NS-3 is the choice for this research as it allows users to prepare code either in C++ or Python bindings which are familiar programming languages. It also supports some important aspects of VANETs such as the implementation of the 802.11p standard.

Helpers: Modules which are necessary for a VANET simulation to run properly are imported into the program at this stage. Many of such modules exist which can be reused; they are called helpers (Fernandes and Ferreira, 2012). Examples of such modules are network module, mobility module etc.

Channel setup: Every wireless network has a channel in which it operates and NS-3 allows users to program channels and model the necessary behaviour for each scenario. Here the IEEE 802.11p channel properties are implemented. Also, the channels must be modelled with other properties such as propagation loss and propagation delay.

Nodes: Here the network setup is informed of the participants in the network. Nodes can be created here, or nodes can be imported from external trace files as previously explained above. Importing external trace files is facilitated by a mobility helper class in NS-3. All nodes are grouped as part of a container to allow easy installation of other modules on each node.

Networking: After creating the nodes, they can then be assigned network addresses using IPv4 or IPv6. In this project IPv4 is used because it is thoroughly understood, a recommendation is to change this at a later stage to IPv6.

Simulation: Simulation can be initiated after all necessary parts, i.e. channel, device, nodes are configured. The length of the simulation can be configured at this point. This point involved several tries in order to get the right amount of time for all nodes to enter and vacate the simulation area. At this point, the simulation can also be visually inspected using the tool network animation. A snapshot of this can be seen in figure 3.3, which shows the wireless network simulation for a section of the city taken from the road network file seen in figure 3.2.

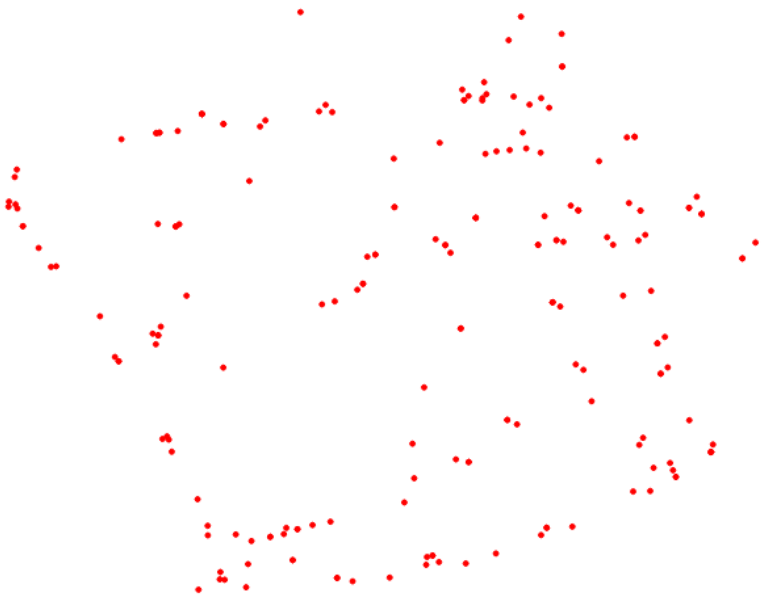


Figure 3.3: NetAnim visualisation of network Simulation.

Statistics: In order to understand what has happened in the network, data must be collected and analysed. There are several ways of collecting data from NS-3 simulations; flow monitor and statistical framework. The flow monitor is the most popular and easier method as it can be implemented and installed on all nodes in the network. As the name implies, the flow monitor monitors the flow of packets in the network during the simulation period. It can gather information such as the number of transmitted data, number of received data, delay and so on for each flow.

Summary

In this chapter, the tools and methods for this research project were presented. It is important to understand the environment in which the research lies, the available tools which will be most suitable for each environment and the method or sequence of objectives to tackle to meet the required aim of the research.

An extensive study into road traffic and network simulators was presented in this chapter; this was necessitated by the need to understand where each contributes in the research's paradigm.

The next three chapters contain experiments and analysis to determine the critical factors to consider when designing the models and framework for message delivery in VANET, followed by the design of the framework and models and an assessment of the proposed solutions in which these tools and steps described here are utilised.

Chapter 4: Identifying Main Factors Affecting Architecture of the Framework for Improved Message Delivery

Chapter 4: Identifying Main Factors Affecting Architecture of the Framework for Improved Message Delivery

Chapter Overview

In chapter two it was seen that there are several ways of transmitting and improving message delivery in an ad-hoc network and that vehicles and their characteristics need to be considered in this process as they are the carriers and actors in VANETs. In this chapter, an investigation into what vehicular traffic factors are foremost with the aim of improving message delivery in the network; that is what factors can be used in an inclusive framework to improve message delivery.

In this chapter, a statistical analysis based on the 2^k factorial methodology to determine the representative factors affecting wireless communication condition in Vehicular ad hoc networks (VANETs) is presented. The purpose is to identify what are the key factors that influence Packet Delivery Ratio and Average Delay in order to concentrate on those parameters, thus reducing the amount of required simulation time when evaluating VANETs as well as understanding what parameters are needed in building a holistic framework.

Simulation is an important part of the research, especially one that deals with complete abstract systems. Simulation models are, therefore, used to study real-life systems which either do not currently exist or may be too difficult or expensive to deploy real scenario. By using the model methodology in this research, it allows the verification of complex systems in a much less complicated manner. In simulating models or systems, the aim is to measure the performance of that model or system for different input factors. For VANET model simulations, there are several factors which may affect the performance of the network and detecting the effects of all factors will involve a lot of experiments, computation, time and careful analysis.

A way of identifying relevant factors to be considered in further experiments and inclusion in the proposed framework is the 2^k factorial analysis (Cano, Manzoni and Sanchez, 2004), where k represents the number of factors under consideration and whose values can only have two states. This method is proven to aid in identifying the most crucial factors that affects a particular output in an experiment. In the case of this research, it will allow a determination of factors that influence or has a bearing on the wireless communication condition of the network which will be represented by the Packet Delivery Ratio (PDR). The PDR is a ratio of network packets sent against network packets received. The use of the factorial design analysis will also identify interactions between factors, regardless of whether those factors are exogenous, that is, one whose value is not affected during the experiment or if it is endogenous, that is, its value is determined by other variables during the simulation.

During the 2^k analysis, all factors considered relevant are varied, hence the ability to identify not only the effect of the factor on the output but also the effect of interacting factors on the output. It, therefore, provides clarity with less time than it would take to run hundreds of experiments to identify the above by observation.

By following the Rational Unified Process (RUP) for experimental research (Hui et al., 2015), software analysis and designs occur in phases with each step having unique characteristics. By determining the key factors in VANET to fully understand those that may play a vital role in the proposed framework and model, knowing the effects of each factor on the overall wireless network quality for each route is crucial in aiding a sending node to identify the best route for a message to be sent to its destination (Figure 4.1).

Figure 4.1: Decision Making Depends on What's Happening on the Road Traffic-Wise

This chapter is organised as follows: Section 4.2 presents some of the most relevant works using 2^k factorial analysis in some research fields. Section 4.3 gives an overview of the 2^k factorial approach. Section 4.4 introduces the different factors that have been studied. In Section 4.5, the 2^k factorial analysis made in this VANET scenario is presented. The results obtained reflect which are the key factors to take into account when simulating VANETs and what values to incorporate into the framework being modelled. Finally, Section 4.6 concludes this chapter.

4.1 Related work

As stated, the 2^k analysis is a useful tool used in researches where factors can be manipulated in order to observe responses of the entire system. A combination of factors is called a treatment, and each factor can take several levels. While there is some amount of certainty that for example, from ordinary simulations, it is observable that the number of vehicles can affect the capacity or quality of the wireless network, it remains unclear as to how the interactions of several factors might affect the network. The 2^k factorial analysis method for detecting such interactive effects is quite popular in other fields especially statistics (Winer, Brown and Michels, 1991) (Comrey and Lee, 2009). Nevertheless, researches describing the use of 2^k analysis can be found in the field of computing (Jain, 1991), some of those works related to communication will now be discussed in the following section.

In Gupta et al., (2007), a performance assessment of networked controlled systems was carried out and various factors affecting performance parameters such as delay, system gain were identified. Network control systems are a network structure and components that can integrate communication and control algorithms to fit real-time applications. Thorough experimental results, tables of detailed characterization and most importantly, the use of 2^k analysis helped in their study and estimation of both the individual and combined effect of those factors on the system performance with security being the main concern.

In the paper titled Improving Multipath Routing Performance in WSNs by Tuning IEEE 802.11 Parameters, Liu et al., (2008) showed that the design of a model works better when the factors that may affect it is known and when those factors can be incorporated into the model's design. The researchers investigated multipath routing as opposed to single path routing in wireless sensor networks. They discovered that the default settings in the IEEE

802.11 wireless standard do not allow for better performance due to high rates of packet collision. Evidently, from the paper, it was shown that the retry limit and the size of the congestion window are key factors which must be adjusted accordingly in order to achieve better multipath routing performance found by using factorial analysis.

Boppana and Mathur (2005) performed several experiments on the effects of factors on Dynamic Source Routing by applying several changes to each iteration. They pointed out that while geographic graphs can give a general overview of the performance changes in DSR, a better method was needed to find out the relative (combinatory effect of factors) impacts of two or more factors on the network. The research was prompted by the need to understand why some proposed optimisations had negative effects on the performance of DSR and conclude that some other factors such as destination response limit and indeed network density needed to be modified in other to increase the performance of DSR's performance.

In Perkins et al., (2002), the authors investigated the effects of different factors on the performance of Mobile Ad-hoc Networks (MANETs) by quantifying the effects of factors such as, node speed, pause-time, network size, number of traffic sources, and type of routing as they relate to throughput, average routing overhead, and power consumption being the performance metrics of the network. Their factorial design showed that for MANETs, the routing, number of devices and speed had the most effect on the network. The authors stated the care taken in choosing factor levels because different factor levels may produce different projected results. While power consumption and control overhead are not main barriers in vehicular networks, their investigation shows the value of having a proper guide to designing future MANET experiments and what factors to focus on when designing routing models.

In Adaptive Fault Tolerant Replication, AFTR (Kumar, 2012) like the name implies, is an adaptive fault tolerant replication routing protocol able to handle delivery of time sensitive messages in mobile ad-hoc networks. Its performance was analysed through some metrics under different influencing factors, in this case, network size, transmission rate, node mobility, pause time and an optimal number of copies of the message while measuring the delivery ratio, routing overhead and throughput. The design of the model was made to be adaptive to changes within the network and the 2^k analysis showed what factors needed to be watched in the network in order to maintain optimal performance by the protocol.

Fogue et al., (2011) presented in their paper, representative factors affecting the spread of warning messages in vehicular ad-hoc networks. The work was focused on how those factors relate to the scenario under test, for example, highways or Manhattan based layouts. The results of their 2^k analysis showed that vehicle density and the type of roadmap used were the most affecting factors which led to the design and selection of mobility scenario for experimental testing of vehicular networks during simulations.

The 2^k analysis in this research is significant and different from others because of the metric measured, that is, the primary response variable being the packet delivery ratio rather than time. Extra factors have also been considered in this research and included in this analysis and care has been taken to ensure measurements cover a variety of simulated real roads within the city rather than on synthetic highways.

Using statistical analysis helps give credence to any research being done and using it meaningfully in the design of experiments (DoE) can not only contribute to reducing wasted time and effort but will lead to more accurate tests and results. It is critical to have only useful details added to the proposed framework of this research, otherwise unnecessary data leads to costly overhead, use of bandwidth and inaccurate behaviour of the model.

4.2 Design of Experiment Using 2^k Factorial Analysis

Across a range of scenarios, there are several factors that may or may not affect the desired level of wireless communication in vehicular ad-hoc networks. Therefore, by running standard analysis across a range of roads, we can find out what exactly can help improve the current performance of the network.

The intent of setting up and carrying out experiments include but not limited to the examining what factors are most influential on the response being considered, investigating how to vary an influential factor such that its effect on the response is small; determining how the factors can be set such that uncontrollable factors' effect on the response is negligible or minimised and investigating what factors to variate such that the response is at the desired range.

In this research, all objectives listed above are important, however, the main focus will be on knowing how each factor can be utilised to get the response (packet delivery ratio) at a desirable range.

Over time scientists have sought ways of investigating best result scenario given a variety of factors. There are various methods that can be used to investigate and carry out experiments to examine the influence that various factors have on the response of the process (Montgomery, 2013). An obvious method would be to select different combination of factors and run the experiments to see what happens. this is simple method primarily built on guess work. It can be beneficial if the experimenter already has deep knowledge of the workings of the process added to vast understanding of the different physical approaches to the experiment. However, if the first result produced is not the desired output then the experiment will be repeated until the result is acceptable. this could lead to quite a number of experiments which correlates to the number of factors present in the experiment. Also, if by chance the experiment produces a good result upon first try then the tendency will be to end the experiment at that point rather than find other combination of factor levels that could produce a better response. In this case there is no guarantee that the results, though good, is the best one for that system.

On the other hand, using Design of Experiment (DoE) and analysis, the experiment can be screened to identify influential factors which can then help identify the extent to which they influence the response (Eriksson, 2000). These screeners are usually not as much as the full range of experiments that can be done in that system. Following the screening experiment, the experimenter can begin to focus on optimising the system with respect to the combination of main factors that will result in the most favourable system response. finally, testing can be done to determine the nature of response to variation of factors in the system. the following sections will describe how factors influencing the PDR have been selected and screened to determine the influential factors and which ones can be combined to produce the optimal response sought after.

In order to perform the steps/methods described above, a 2^k DoE is selected. The method allows for exploration of a large number of factors (k) with each having 2 levels, though the factors may take more levels in a full factorial design, using two levels to represent a minimum and maximum expected level for each factor in each experiment is justifiable as both levels are bound to produce a change if they are significant enough in the experiment. The minimum and maximum levels of each factor are represented by –1 and +1 respectively which can be viewed as labels of sorts since the factors can be quantitative or qualitative in nature.

For example, considering the present experiment, if the factors available for analysis in the VANET scenario are; the number of vehicles, average speed of vehicles, route, etc. as A, B and C respectively, then the packet delivery ratio (PDR) can be considered the main response variable.

To help explain the usage of the factorial analysis, consider the simplest case: 2^k, where k = 2. If the factors represented are x and y, then a notation known as the Yates notation can be determined as follows:

x	y	Notation
-	-	1
+	-	x
-	+	y
+	+	xy

Table 4.1: Yates notation for x and y

Summarily, the above scenario means there are two levels each of two factors, which means $2^k = 4$. This notation is a coded representation of the factors being considered.

The Yates notation helps in explaining the interaction of factors as follows: 1 represents a situation where both factors are at a low level, x is when only factor x is at its high level, y is when only factor y is at is high level and xy is when both factors are at their high levels. Usually, more than one observation is used to determine the final output for each factor level. For this project, the mean of 10 simulation runs is used, that is, the experiments are replicated 2^k analysis.

Though the interactions and effects of factors can be determined using non-linear regression equation:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\ \beta)_{ij} + e_{ijk}$$ *Equation 4.1: Notation for 2 factor treatment design*

Where the measured response Y can be written as the overall mean (μ) plus the treatment effect for both levels (α + β) plus a random error (e) and i = 1, ... , a, | j = 1, ... , b | k is number of levels (psu.edu, 2018).

Minitab software for statistical analysis will be used to determine the effects of factors, because using this software gives much more accurate calculations than manually calculating or designing experiments and shows which of those factors are actually significant enough, thereby allowing more rigorous analysis to be carried out within a short time.

Significance and variance which makes the results of the 2^k analysis viable, are done automatically in Minitab, making it a very powerful tool for this analysis. There is also the opportunity to remove factors not considered significant enough after the first run in order to check the true significance, or variation of the remaining factors. The variance of individual output of the analysis further illuminates the impact of the factor on the response data, it therefore shows which factors affect the response data more than the others and so on. By so doing, it enables proper design steps to be followed giving importance to the strongest factor and in that order.

4.3 Factors to Study in VANETs

There are several factors that may affect the delivery of data in VANETs (measured by the amount of data delivered as compared to the amount of data sent), some have more statistical significance, variance and interaction with others. Hence, the need to determine which factors to be considered when designing a framework or model that involves data delivery in VANETs. In this section, factors identified will be briefly discussed before the analysis to confirm which make the final cut by using the full factorial analysis method.

Several factors have hitherto been used as de facto standards when carrying out simulations in wireless experiments. Research such as (Jerbi, Senouci and Haj, 2007) show that the commonly used factors are: number of nodes, average speed, type of routing scheme, transmission range, MAC type and packet size. Other factors that may indeed affect VANET performance such as environmental factor is beyond the scope of this work but may be considered for future work, however, some work on the effects environmental factors such as rainfall had previously been done by (Neelambike and Chandrika, 2015) (Ramesh, Rajan and Divya, 2014) (Patil, 2012).

4.3.1 Number of Nodes (Vehicles)

Since the vehicles themselves are the key players in a VANET scenario, it is therefore imperative to consider them at first glance. These vehicles will be equipped with devices to enable them to perform wireless communication with other vehicles or with devices by the roadside (also known as road side units) such as toll gates. Vehicles are envisaged to disseminate data when requested by other vehicles; these may include information about the road traffic. The vehicles are also meant to disseminate beacon messages regularly as well as inform other vehicles about potential danger in that area. That is, messages must be disseminated efficiently for both safety and non-safety services. It is, therefore, safe to assume the number of vehicles correlates to the number of messages in the network, as each vehicle transmits and retransmits messages to others.

4.3.2 Average Speed of Nodes (Vehicles)

In VANETs, the nodes or vehicles have faster speeds than those found in other ad-hoc networks and these speeds vary from 0 – 70 miles per hour. In considering the Nottingham city scenario, it is typical to find average speed of up to 40 miles per hour. However, for the sake of experimental analysis, speeds of up to 50mph for inner city scenarios will be considered.

4.3.3 Routing Protocol

Routing protocols are an important aspect of vehicular ad-hoc networks because they enable the vehicles to achieve data delivery between source and destination greater than one or two hops. They are an essential part of VANETs, and any design for a framework must consider this factor.

Several routing protocols have been studied in ad-hoc networking research, particularly in VANETs, some of these routing protocols have been identified to perform better than the rest in terms of data delivery, and others is especially suitable for high mobility because each protocol usually have a specific application targeted, thereby using specific resources at its disposal. For example, a routing protocol can be designed to take advantage of the number of vehicles in the area or make use of buses, etc. Many new protocols have been suggested, however, for the purpose of this research, only the 'traditional' routing protocols such as AODV and DSDV will be examined as they represent reactive and proactive routing protocols respectively. Though the output of experiments comparing routing protocols can show evidence of improvement or lack of improvement of one over the other, it is important to know just how far reaching those effects are on the overall ability of the system or framework as a whole.

4.3.4 Data Size

In network transmission, for example in TCP transmissions, messages are broken down into packets which are then transmitted. These packets join a queue of packets from other devices ready for transmission. The larger a message is, the longer it would take to send it completely from source to destination. Hence, it is expected that bigger messages will contribute to a higher probability of dropped packets, channel contention and delays in the network (Zhang, Li and Liang, 2017).

4.3.5 Message Periodicity

The whole aim of VANETs is for vehicles to be able to exchange messages, whether periodic updates, safety or non-safety related messages. Some routing protocols flood the network with messages in a bid to have full dissemination. However, this causes broadcast storms and collisions. Furthermore, it is anticipated that the periodicity of messages will be proportional to the number of vehicles and hence also be a factor that can be managed.

4.3.6 Transmission Range

The transmission range is a crucial factor in wireless networks. Many a research have shown that a range of distances is suitable for data dissemination than others are. However, wide transmission ranges do not necessarily translate to better dissemination because of issues such as hidden terminal problems and broadcast storms. Several researches use between 200m and 300m as transmission radius, failing to check for the effect of either reducing or increasing that value.

4.4 Factors' Effect Determination Using 2^k Factorial Analysis

Having identified the factors applicable to VANET research, the 2^k factorial analysis will now be used to pinpoint which of these factors affect the wireless network performance in terms of message delivery ratio in order to incorporate them into the proposed framework for improving message delivery in VANETs and to reduce time spent in simulating various scenarios in this project.

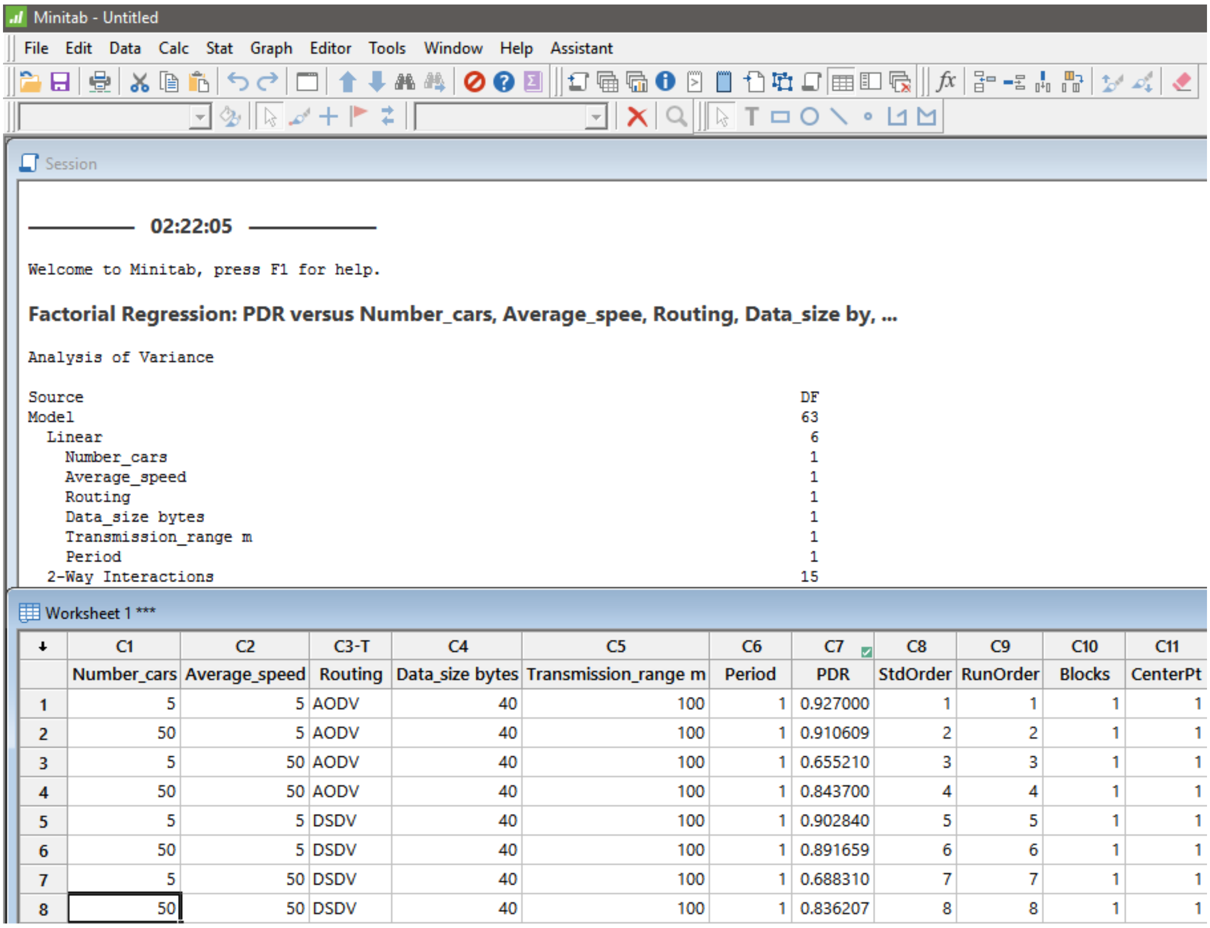
In the previous section, six factors were discussed, and reasons were given for picking them initially. The table below provides the factors including the upper and lower level values that will be used in the experiments. For each level of each factor varied, all other factors will be kept constant while the experiments are run in NS-3. After which the output of those experiments is fed into Minitab for analysis.

Factor	Level -1	Level 1
Number of vehicles	5	50
Average speed of vehicles	5 mi/h	50 mi/h
Routing	AODV	DSDV
Data size	40 bytes	200 bytes
Message periodicity	1 *packet/s*	20 *packets/s*
Route	Angel Row	Angel Row
Transmission range	100*m*	300*m*

Table 4.2: Factors considered and their high and low values for the 2^k Analysis

4.4.1 Minitab Analysis: 2 Level Full Factorial Analysis Design

In a 2-level full factorial design, as briefly stated earlier, the factors being considered will occupy only one of two levels, both representing a high value and a low value. The number of experiments to run in the full factorial mode is 2^k, where k is the number of factors. In this case, the analysis requires 2^6 (64) runs which includes all combinations of these factor levels. A 2-level factorial design and analysis while not being fully exploratory, will provide useful information to a researcher proportional to the number of factors. Basically, 2-level factorial designs can identify correlation, effects of factors etc. that can provide direction on what to focus on in subsequent experiments or in this case factors that should be highly considered in building a framework or model.



↓	C1	C2	C3-T	C4	C5	C6	C7	C8	C9	C10	C11
	Number_cars	Average_speed	Routing	Data_size bytes	Transmission_range m	Period	PDR	StdOrder	RunOrder	Blocks	CenterPt
1	5	5	AODV	40	100	1	0.927000	1	1	1	1
2	50	5	AODV	40	100	1	0.910609	2	2	1	1
3	5	50	AODV	40	100	1	0.655210	3	3	1	1
4	50	50	AODV	40	100	1	0.843700	4	4	1	1
5	5	5	DSDV	40	100	1	0.902840	5	5	1	1
6	50	5	DSDV	40	100	1	0.891659	6	6	1	1
7	5	50	DSDV	40	100	1	0.688310	7	7	1	1
8	50	50	DSDV	40	100	1	0.836207	8	8	1	1

Figure 4.2: Minitab Session

4.4.2 Determining the Major effects

For simplicity, the factors are each represented by a letter of the alphabet, e.g. number of cars is A, routing protocol is C, etc. After the factors and the response variable, in this case, the PDR are put into Minitab, a factorial design can then be selected from the Stat components. Several graphs can be chosen to help explain the outcome of the analysis, such as a Pareto chart and a Normal effects plot.

4.4.2.1 Pareto Chart

A Pareto chart of the factors' effects after analysis is used to determine the significance and weight of an effect. The chart displays the absolute value of the effects and draws a reference line on the chart with effects which go beyond the reference line indicating a strong significance (Minitab, 2016). Where Lenth's pseudo standard error uses the concept of sparse effects assuming the variation in minimal effects is due to random error.

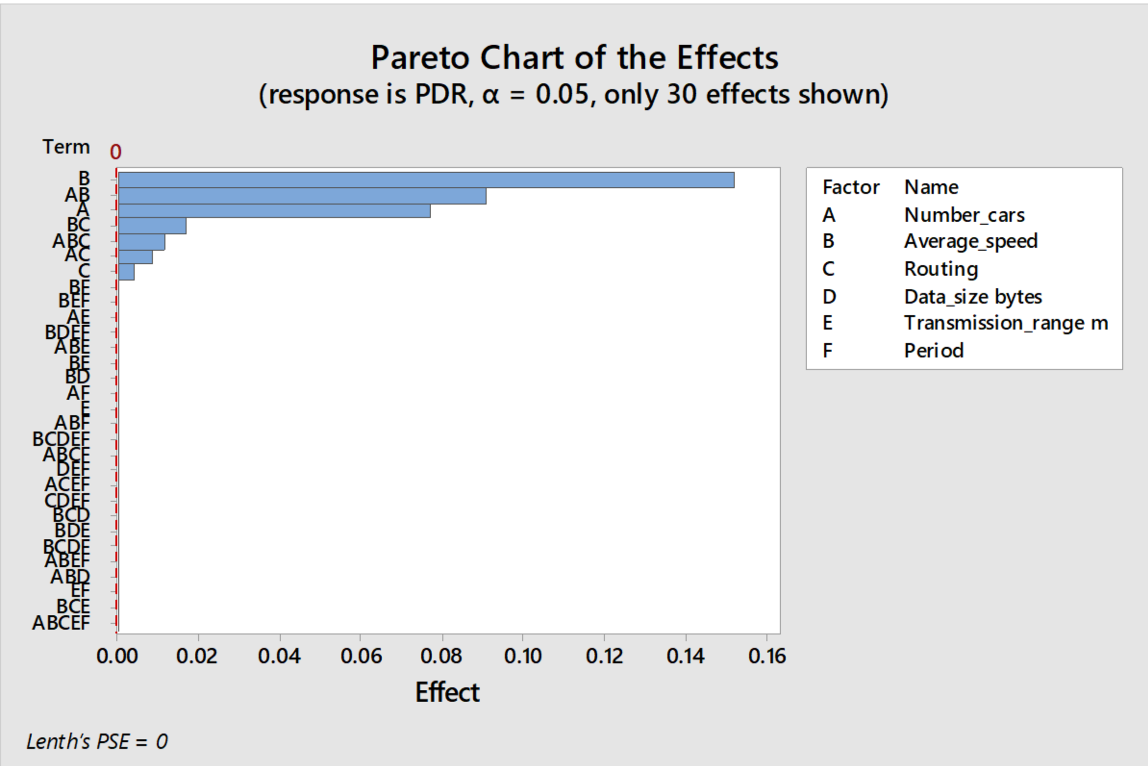


Figure 4.3: Pareto Chart of the Initial 2^k Analysis

It can be seen from figure 4.3 that several factors such as B, AB, A can be considered significant or important (those that go beyond the red reference line at the origin). However, this is not very clear, especially with other factors such as BE, BEF etc. whose values are not quite visible. Pareto charts display value of effects and not the effects which increase or reduce the response. A different graph can be used to identify the more significant factors clearly.

4.4.2.2 Normal Plots

Normal probability plots of the effects compare the magnitude and statistical significance of main and interaction effects from a 2-level factorial design. Like the Pareto plot, there is also a reference line, however, in this case, the line indicates points with insignificant effects, that is, if the effects were zero. Significant effects have a label and fall toward the left or right side of the graph (Minitab, 2016b).

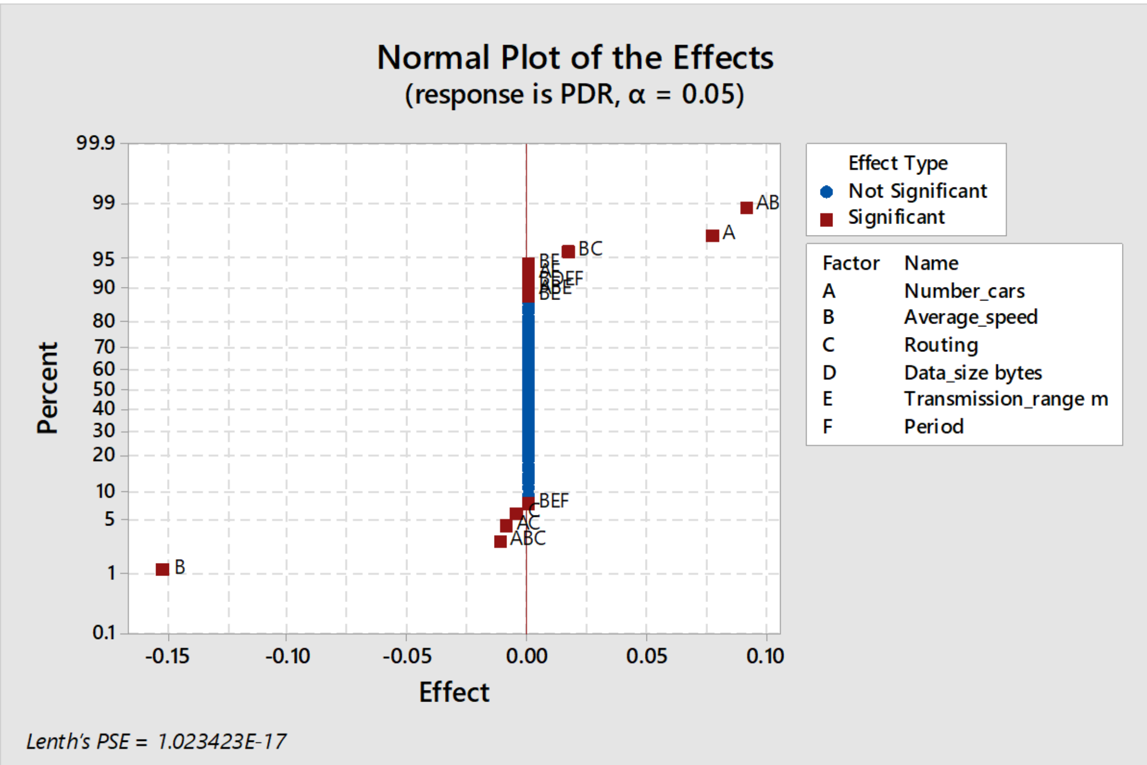


Figure 4.4: Normal Plot for the Initial 2^k Analysis

From the Pareto and particularly the Normal Plot, it is seen that the more significant factors are the number of vehicles, the speed, the interaction between the number of vehicles and speed and to a much lesser degree, the interaction between routing, speed and number of vehicles.

Now, it is possible to reduce the number of factors in the analysis to those identified in the previous paragraph in order to see a clearer picture presented by the factors.

4.4.3 Eliminating Less Important Factors

Having identified some significant factors as seen above, the less significant factors can then be removed from the 2^k analysis to allow a clearer perspective of the effects of the highly significant factors.

4.4.3.1 Pareto Chart

Reducing the factors being considered after the first run gives a clearer view of the effects of the other factors including the interactions between those factors as seen in the chart below.

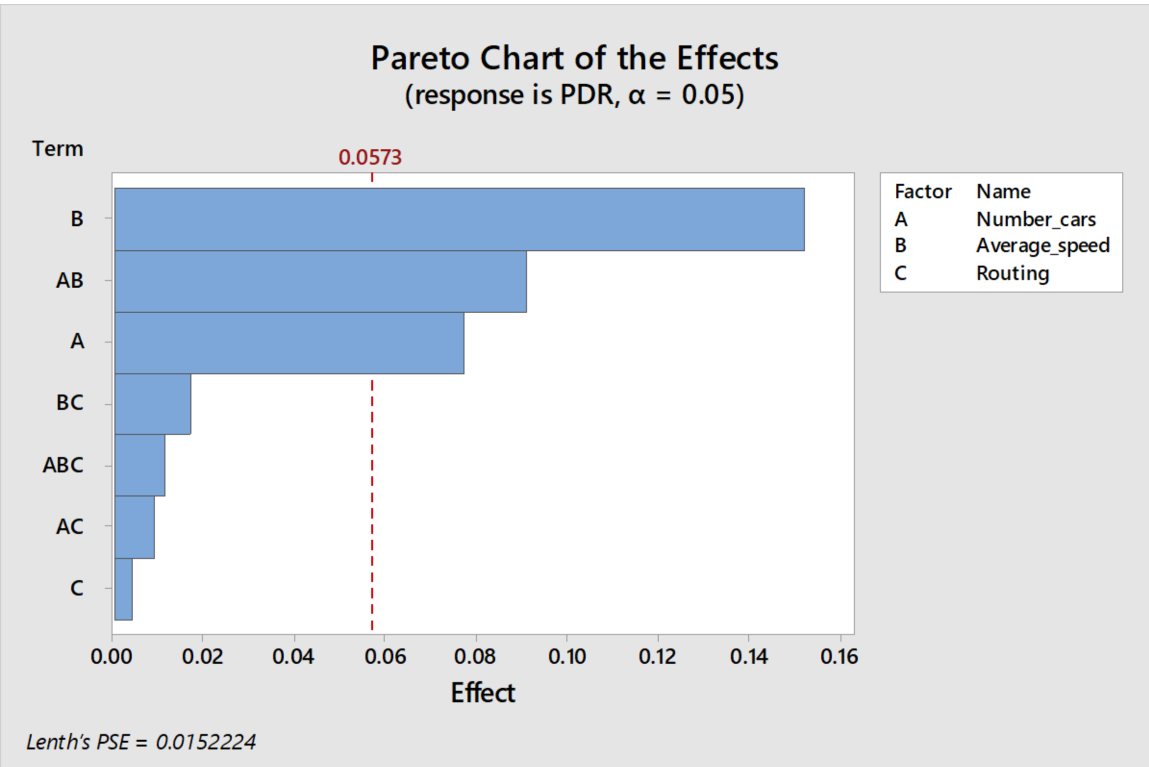


Figure 4.5: Pareto Chart of the Second 2^k Analysis

From the Pareto chart above, it is clear that the major effect is caused by the average speed (B), number of vehicles (A) and the interaction between the speed and number of vehicles (AB). The last factor being considered which is the routing protocol (C) in use has some effect, but at a less significant level, same goes for the various interactions between routing and number of vehicles (AC) and routing and speed of vehicles (AB).

4.4.3.2 Normal Plots

The normal plot merely confirms the discussion in the previous section as seen in the figure below.

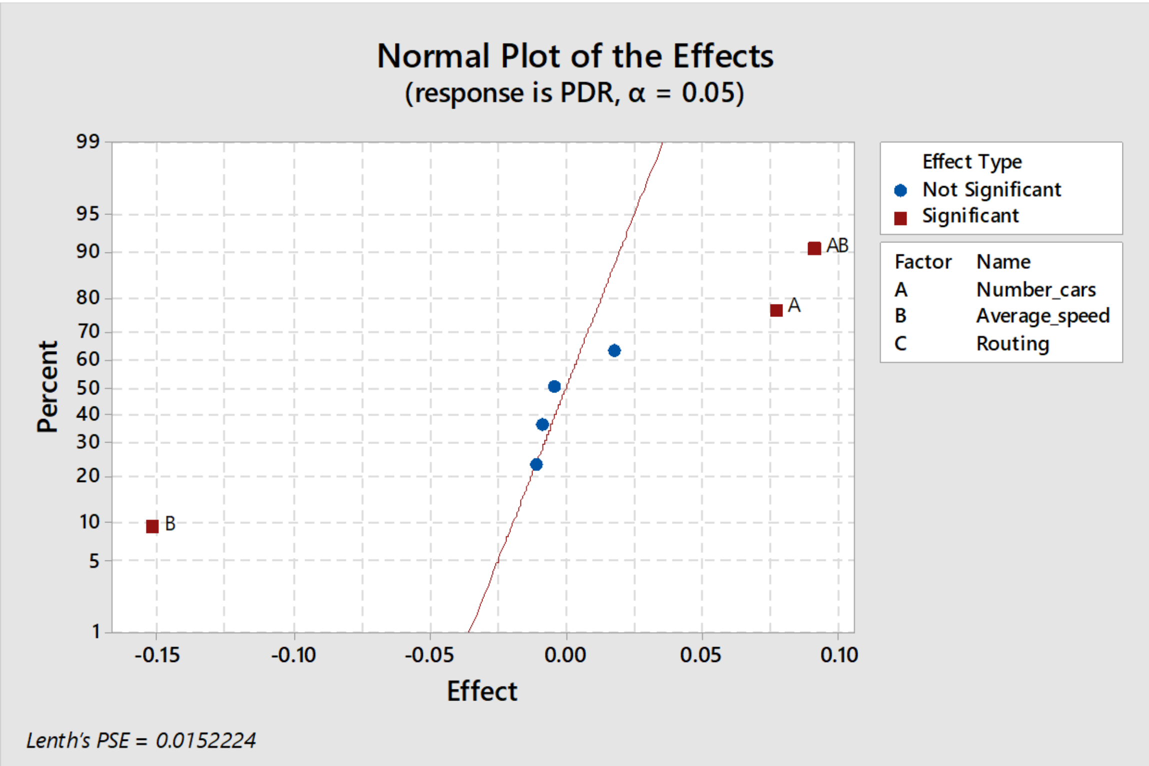


Figure 4.6: Normal Plot for the Initial 2^k Analysis

Based on the obtained results, the factors and their effects can be discussed as it relates to the VANET scenario.

4.4.4 Evaluating the Impact of the Number of Vehicles

The 2^k analysis showed that the number of vehicles in the VANET scenario has a major effect on the packet delivery ratio (PDR) of the ad-hoc network. Two levels of this factor were used to perform this experimental analysis to represent a high and a low level while keeping the other factors unchanged. However, while running this experiment, several other number of vehicles were used - 10, 20, 30 and 40 vehicles were placed in the scenario in separate experiments. As expected, the PDR was affected due to the changes, but interestingly, the PDR did not progressively get (or remain) worse proportionally to the number of vehicles. This can be explained by the way messages contend for channel access, message delivery should work better when there are more players in the scenario, however, these same players contribute to saturating the network at some point (possibly causing collisions). Another reason behind the abnormal behaviour noticed might be the spatial distribution of vehicles in the network, when several vehicles are clustered they may experience better network access.

4.4.5 Evaluating the Impact of Vehicle Speed

The 2^k analysis output in fig. 4.4 shows that vehicle speed is a major factor in the successful delivery of packets in the VANET scenario. A critical look at the point at which the factor lies on the Pareto chart suggests that there will be performance degradation at higher speeds. It is an interesting factor because the IEEE 802.11p MAC layer was designed with the VANET environment in mind. However, this analysis shows that at 50 miles/hour it becomes a serious challenge perhaps due to the short amount of time each vehicle spends within the transmission range of the transmitting vehicle as suggested by the Pareto chart that shows a correlation between vehicle speed, number of vehicles, routing protocol and transmission range. Higher number of vehicles and a large transmission range cancels the negative effect of high speeds on packet delivery ratio because there are more vehicles within range to accept packets transmitted. This effect of speed is made possible by using varying speeds in multiple lanes for the experiment.

4.4.6 Evaluating the Impact of the Routing Protocol Used

A factor expected to play an important role in a VANET scenario is how the messages are transmitted. Some interesting message dissemination schemes were discussed earlier in this thesis, but the main categories of message distribution are flooding, reactive and proactive protocols. Flooding is the easiest to implement, but it creates duplicate messages, broadcast storms and channel contention hence very few researchers include this method in evaluation or design of models for message dissemination. The choice of assessing the impact of routing based on either reactive or proactive protocol covers a wider range of models that may be available to VANETs. Reactive protocols initiate a message distribution process when needed whereas proactive protocols maintain a record of possible routes to deliver messages in a VANET environment.

From the 2^k analysis performed, routing has a slight effect on the ability to deliver packets in the scenario. It also has a combined effect with vehicle speed and number of vehicles. What this means is that changing the number of vehicles and their speed is what affects the performance of the routing protocol; therefore, the impact of the routing protocol can be safely be classed as a less important factor since it is a dependent factor.

4.4.7 Evaluating the Impact of the Transmission Range

The transmission range was shown to have some effect on the PDR as seen in figure 4.4. The result was obtained by changing the transmission range of the vehicles in the network while keeping the other factors unchanged. Generally, the larger transmission range means more vehicles are reached at once. However, this also depends on the number of vehicles in the network. Vehicles close to transmission sources will receive the message and discard duplicates from sources further away, thereby limiting the effect of this factor in the scenario tested.

4.4.8 Evaluating the Impact of the Period

In the Wireless Access for Vehicular Environment (WAVE) standard, vehicles in the wireless network are expected to transmit and receive beacon messages in addition to other messages such as safety messages or application messages. The beacon messages contain information about the broadcasting vehicle's whereabouts, speed, etc. These beacon messages are not expected to be rebroadcast once received and are transmitted at specified intervals. In addition, the beacon messages have a lower priority in the IEEE 802.11p MAC scheme which means it could be ignored upon the reception of higher priority messages such as warning messages.

To carry out the 2^k analysis, beacon and standard packets were transmitted within the simulation scenario. The outcome of the analysis (Fig. 4.3) does not show the periodicity to have a strong significant effect on the packet delivery ratio on its own. However, there is a slight significance (Fig 4.4) in combination with other factors (number of vehicles, average speed and transmission range). This can be explained as thus; as the number of vehicles increases, the number of beacon messages increases which may, in turn, affect the contention and subsequent delivery of messages and as the speed increases, the ability for messages to be successfully delivered within a short time decreases. Finally, as transmission range increases or decreases, messages might be received (in the case of the former) or dropped (in the event of the latter). Hence the effect of periodicity in itself is affected by the number of vehicles and the speed at which they are travelling.

4.5 Summary and Discussions

In this chapter, different road traffic and network factors affecting VANET operations were identified and described. It is seen that the number of factors can be substantial including the interactions of these factors. In other to determine what factors to consider in the design of the new framework, significant factors were identified using a 2^k analysis design of experiments.

From the analysis, the factors identified for consideration in the new framework are the number of vehicles in the network, the speed of the vehicles and to a lesser degree the type of routing protocol in use. These factors and their interactions had significant effects on the metric used as a response(PDR) in the experiment. There are other factors whose effects are present but not significant enough to make a huge impact, such as message periodicity, transmission range, and size of the message being sent.

Having concluded the analysis of affecting factors in VANET, a novel framework to utilise this knowledge is proposed in the next chapter. The speed and number of vehicles on the road will be used in a way that translates to how good a network is expected to perform on that road. Other data from the vehicles are also included to support this framework.

Chapter 5: Framework for Improved Message Delivery in VANETs (FIMDEV)

Chapter 5: Framework for Improved Message Delivery

Chapter Overview

In this chapter, a Framework for Improved Message Delivery in VANETs (FIMDEV) is presented. FIMDEV is an overlay application that seeks to implement a set of rules to help improve the dissemination of messages within a vehicular ad-hoc network. This is accomplished by first determining the corresponding packet delivery ratio and delay for each set of number of vehicles and speed for each road under consideration. These values are stored in tables for future use, such that real time information can be gathered and cross-checked against the stored values of PDR based on number of vehicles and speed to determine what routes are best in delivering messages to a location in the city. This relationship between the number of vehicles and speed has been found to be unique for each pair of values for each road considered. A lot of research identifies ways to improve message delivery without a consideration for the dynamics described above, a few methods suggested in literature depend on a fixed set of data whereas each road is quite unique.

5.1 Message Dissemination Issues

The benefits of vehicular ad-hoc networks have already been stated in previous chapters, notably safety applications and convenience, sales and service applications. While safety applications, for example, a sudden car crash or the need to perform an overtake manoeuvre on a large truck are generally most useful within a local vicinity, other applications, for example, parking information or service stations, extend beyond the local area and hence messages need to be propagated efficiently. The properties and limitations of VANETs such as the capacity of the network and its participants make challenging work the distribution of messages over distances more than the current road or street. In this work, the concern is not particularly about the content of the message but more with the ability to identify the best means to deliver said message to either its destination or to a wider audience.

Lochert, Scheuermann and Mauve (2010) identified the different dimensions of message dissemination in VANETs as;

Obtaining information from individual vehicles in the network, distribution of messages available in VANETs to other interested participants located in other parts of the network, identifying and reducing redundancy of messages and measurements in the network and making sense of the network as a geographical entity seeing that individual participants cannot give a clear picture of the network reality. This project deals with the last three dimensions in VANETs, that is, distribution of messages, reducing duplication and making sense of the network as a geographic entity.

Following the previous chapter in which key components that may influence the design of the overlay framework was identified, another important element of the framework is a database containing information that is not directly linked to safety or service related usage. This network overlay involves the understanding of the network both as a network and as a geographic entity that allows the vehicles perform functions as both network devices and road traffic devices respectively.

In relation to the accumulation of a database, previous work by Gamati et al. (2012) describes algorithms for data aggregation, and processing said data, which is outside the scope of this work, but it is worthy of note that such techniques are indeed possible to achieve. While gathering current data about the vehicles and the current traffic on a particular road can prove useful as seen in other research such as Ibrahim and Weigle (2008), Nadeem et al. (2004), other researchers such as Caliskan et al. (2007), counter with an argument that using only current information is not enough as a basis for building optimal frameworks or models. Therefore, the conclusion made by Caliskan et al. (2007) and Lochert et al. (2010) that the kind of information used, its usage and distribution are all related holds true based on their observations. This implies the need to design models or frameworks which utilise (a) specific kind of information, in a particular way in order to disseminate other messages efficiently.

5.2 Motivation for the Framework

As mentioned in previous chapters, routing in VANETs environments is very challenging issue. Most routing algorithms will need to sustain routes from source to destination even though nodes travel under varying velocity and added to the fact that buildings and road topologies may have impact on radio signals and hence network performance. Routing protocol should cope with different network loads and satisfying various types of application requirements. Other factors that may affect network loads are the number of commuters on the road and this can vary widely depending on the time of the day, the network could be dense at peak-time and sparse in off-peak time. These conditions and factors should be considered in the design of a routing protocol to suit various VANET environments. Due to rapid network topology changes and the factors stated, dissemination methods must be resilient, and should ensure reasonably high message delivery rate.

Applications in the VANET environment need timely message delivery system especially over long distances. Some messages may only need to be distributed to vehicles in close proximity but often application messages will be propagated over several miles in a given time to utilise the usefulness of such messages. For example, while a car crash update message is vital for vehicles in close proximity for the sake of caution, this message will also be necessary for traffic management purposes for vehicles further along the route; the same message might even be useful to paramedics or hospitals closest to the event. Events and messages can also be sent to law enforcement agencies and many more. Information being sent can include images, sounds and other multimedia file from the event in question which may help the receiver better prepared for the situation at hand. Other situations that may require exchange of messages as previously noted are non-safety events such as querying parking spaces, weather conditions, traffic situations. Other messages that may need disseminating in a VANET include organisations who wish to advertise to the VANETs, this is a commercial value that may propel the use of VANETs as a marketing tool. For example, vehicle manufacturers may wish to direct vehicles to the nearest service location if the vehicle diagnostics indicate a need for it.

These messages may need to travel a long distance between vehicles, going through possibly several miles and different vehicular densities. This variation and distance can significantly affect the ability of message delivery and time taken to complete. Such negative effects of vehicular density and road network can be overcome by the design and implementation of a message dissemination protocol that acknowledges these effects.

One-size-fits-all: Researchers have found it difficult to find message dissemination techniques to satisfy the different requirements and or scenarios possible in a VANET. For example, Chaqfeh et al. (2014) identified models to categorise message dissemination in VANETs as the push and pull models. The push model typically used to describe a way of spreading safety messages that may be of interest to other nodes even beyond the scope of the initiating area. Examples of where the push model may be used are, road condition warning, traffic time estimation, etc. On the other hand, the pull model describes a method where message dissemination is only activated based on the request of another node, that is, information request from one node from another node in a different area. Examples of its usage include service discovery (perhaps parking, fuel station, etc.) and other comfort or value-added service application. The pull model is characterised by less overhead and some acceptable delay in the network.

Given the disparity in both models, it is evident to see that designing a single framework offers a significant challenge as one would need to consider certain criteria for example, should non-participating vehicles be involved in message dissemination? At what point does the delay in message delivery adversely affect message dissemination and become too much a negative factor in the system? A good solution would need to consider the vehicles in the vehicular network along with the peculiarities of the road and not focus on the message itself. In doing this, the push and pull models can be safely accommodated in one framework.

5.3 Framework for Improved Message Delivery

Framework for Improved Message Delivery (FIMDEV) is a dynamic framework network overlay that works by identifying wireless network condition through the comparison of current road traffic information against previously measured wireless network values (PDRs) generated by similar road traffic conditions. The issue of how current road traffic information is retrieved is outside of the scope of this work, however, projects such as MODUM (Namoun et al., 2014), SCOOT (Bretherton and Mark Cowling, 2005) and (Gamatti et al. 2011) describe and use various methods to capture road traffic data for analysis. The framework is made up of different modules that play important roles in the system. Figure 5.1 shows the makeup of the overlay framework, the unique part of it being the communication module which houses a database (otherwise called map) of the wireless network communication values (PDR and delay values) for each road. Other modules include the geographical module, positioning module, sensor module and a decision-making layer which uses the information in the above modules to decide how messages should be transferred.

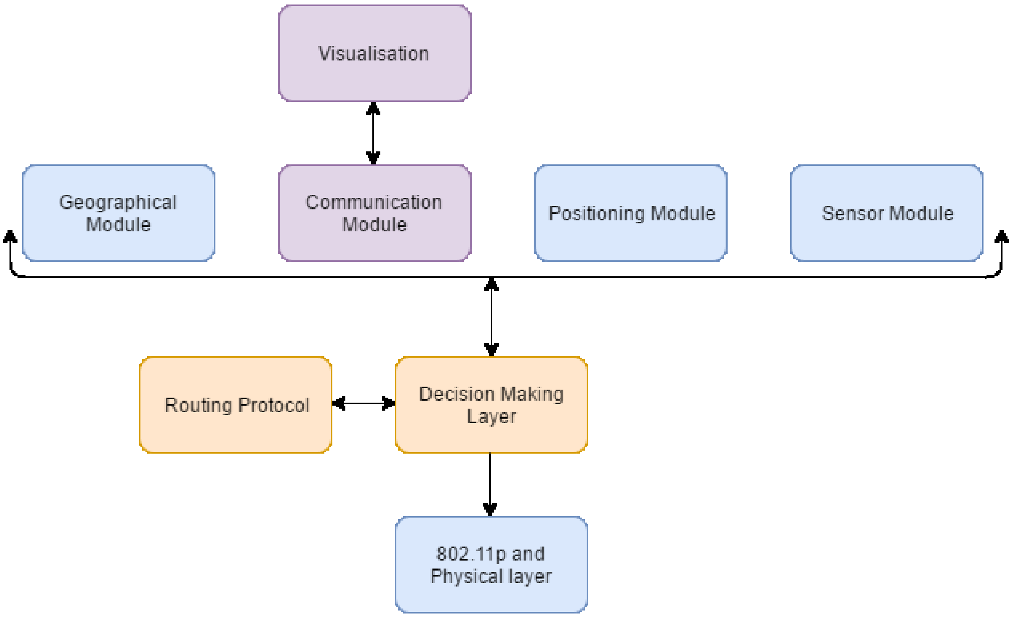


Figure 5.1: the FIMDEV framework

The following sections describe the framework in more detail, including any assumptions made.

5.3.1 Sensor Module

Sensors play a huge role in the determination of traffic or vehicle conditions which in turn can influence other decisions made in the network. In the paper Collaborative Data Dissemination Methods in VANETs (Gamati et al., 2013), the authors rely on vehicle sensor data to develop an algorithm in collaboration with other vehicles' sensor information, to detect road conditions and determine the geographical area where these road conditions exist e.g. an area where there is traffic density, unusual traffic behaviour, a range of weather conditions (e.g. rainfall, etc.). Data from speed sensors, for example, will play a vital role in ensuring the accuracy of information (Tripp-Barba et al., 2014). For this research project, the sensor data is critical in order to maintain validation or corroborate the traffic conditions reported by other vehicles; sensor data at this stage are simulated information such as the speed of the vehicle.

The format of the sensor messages are as follows:

s/n	Field size	Data
1	20 bytes	nodeID:TimeStamp:AverageSpeedData
⋮	⋮	⋮
2	20 bytes	nodeID:TimeStamp:FogLightsOn

Table 5.1: Example of data format for finding best path

The data in table 5.1 for the sensor module is crucial to the operation of the module in section 5.3.3 as explained below. It can also serve in other aspects such as detecting other road conditions within the area (Abufanas and Peytchev 2015).

5.3.2 Positioning Module

The position of the vehicles along the route is a crucial factor as it allows algorithms to differentiate between reachable and unreachable nodes. As will be seen below, if a path is to be determined between two points, those points' locations must be identified in relation to the area under consideration. In (Sun et al., 2000) the authors proposed and implemented a protocol called TRADE which uses the information obtained from Global Positioning System in order to categorise the neighbouring vehicles, by doing this, the protocol can accurately detect the furthest reachable node within the neighbouring list. Though the use of positioning is widely accepted, the use of GPS as the default choice is a bit of a stretch because of the level of accuracy available for use in the public domain. In terms of experimental simulation, pure dependence on a god-like accuracy of positions is faulty, as this will ultimately prove impossible to achieve in real world scenarios. In this research project, the proposal is that the most suitable Global Navigation Satellite System to use will be the Galileo system that offers higher accuracy to within a meter (Steigenberger, 2017).

For this module, knowledge of the current position as well as recent past positions will add much-needed accuracy to further operations and also help determine any possible trend to be incorporated in future.

s/n	Field size	Data
1	20 bytes	nodeID:TimeStamp:PositionNow
⋮	⋮	⋮
2	20 bytes	nodeID:TimeStamp: PositionNow

Table 5.2: Example of data format for finding best path

5.3.3 Communication Module

This module contains information about the wireless network condition of the area in question; it is a wireless network condition map of the area as visualised in Figure 5.2. It is a collection of data obtained by running experiments offline under various conditions, it shows the effect of the number of vehicles and their speed on the wireless network in the form of PDR and delivery delay. In order to achieve the aim of this research, it is crucial to determine the wireless communication condition of the network of each road with various combinations of traffic elements. That is, capturing the level of wireless network condition when the state of vehicles in this scenario is altered by changing the number of participants and their average speeds. These factors have been chosen after careful study of the factors that have a considerable effect on the potential outcome of any VANET communication. The various factors and their determination are discussed in the preceding chapter.

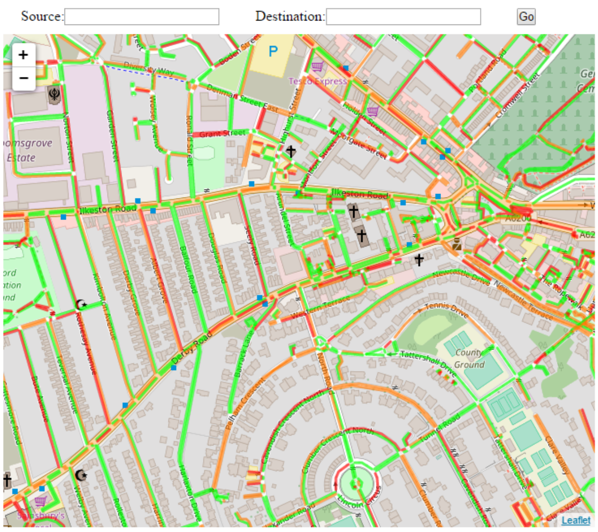


Figure 5.2: Visual representation of the communication map

The experiments conducted consists of a series of simulations on each of the City's roads under consideration, the metrics considered as outcomes include the packet delivery ratio and average end to end delay. This method of analysing and storing values is inspired by application of similar methods used in SatNavs where each road and landmark is digitised for future use. If each road's wireless network situation is known beforehand, then it allows for some adjustment to how messages are moved about those roads.

Packet delivery ratio is the ratio of the number of packets received by the destination to the number of packets sent from the source node, and it is a uniquely important factor as it represents how efficient a wireless network is; high values indicate a good network (Shobana and Karthik, 2013). On the other hand, the average delay in the network is a value for which lower means better. It is defined as the time taken from sender to destination; the obvious issue here is whether there is foreknowledge of available or possible routes or the time required to discover said routes. The End-to-End delay is, therefore, a measure of how well a routing protocol adapts to the various constraints in the network and points to the reliability of the routing protocol.

$$Packet\ Delivery\ Ratio = \frac{\text{total number of packet recevied}}{\text{total number of packet sent}} * 100\%$$

Equation 5.1: Packet Delivery Ratio

Experiments show that the effect of number of vehicles and average speed is unique to each road being tested, this is probably due to the unique spatial design or arrangement of each road; more work on this is currently under consideration. Hence, there is indeed a need to experiment variations and record the output of metrics used for each road to be included in the design.

In order to classify each road as good average or bad, we varied number of vehicles and speeds for each road simulated and recorded the results of those experiments. Next the results are identified as:

Algorithm 1: Stratifying Communication Network Value

Require: Identified road segment [rsID]
Require: Data for rsID in database
Ensure: Compare current sensor data from vehicle against data in database

```
if AvgSpeed[rsID] and numNodes[rsID] range found then
  get PDR value for rsID
  if PDR[nodeID] ≥ 0.75 ≤1 then
     cnv[rsID] = GOOD
  else if PDR[nodeID] ≥ 0.5 ≤ 0.74 then
     cnv[rsID] = AVERAGE
  else if PDR[nodeID] ≥ 0 ≤ 0.49 then
     cnv[rsID] = POOR
  end if
else
  location not covered
end if
```

Figure 5.3: Algorithm for condition identification

Together these values are called communication network values (cnv) which are then stored for each road against its corresponding number of vehicles and speed in a database. The algorithm will seek close values even when exact matches are not found to avoid inconclusive searches.

5.3.4 Geographical Module

Several types of research have shown that digital geographic map of an area to be useful tools in implementing vehicular network designs. The map of a zone can provide road information critical in directing messages along the right path or used in performing conditional routing at junctions etc. For example, the authors in (Xiang et al., 2013) proposed a map-based protocol called GeoSVR aimed at solving local maximum and sparse connectivity problems in VANETs thereby increasing packet delivery ratio. It works by locating the nodes on a digital map and calculating the optimum path by using a shortest path greedy algorithm.

Similarly, for FIMDEV to function, sections of the area under consideration will be represented as a weighted graph, with junctions, intersections and roundabouts represented as vertices (nodes) in the graph while the roads represent the edges of the graph. These edges will all have weights which represent the current wireless communication condition values of each road; therefore, a greedy path finding algorithm can be applied to find paths between two points. By using the wireless communication network value, the best path found thus represents the best route for a message to transverse which may not necessarily be the shortest road based on distance but the least congested one.

If all sources and destinations are listed as numeric IDs, these, along with the communication network value can be imported into a readable format as such;

s/n	Source	Destination	Cost
a	1	2	1
b	2	3	1
c	3	4	3
d	4	5	2

Table 5.3: Example of data format for finding best path

Where the cnvs good, average and poor have been replaced by numeric values 1, 2 and 3 respectively to represent the network cost of traversing the wireless network.

The algorithm for analysing the path between source and destination is the modified Dijkstra Algorithm (Grossmann and Flitter, 2016) for single source path finding, where each edge and node are as described above.

Algorithm 2 Communication Path Finder Using Dijkstra

Require: Weighted Graph G, roads = edges, junctions etc = vertexes (v)
Require: Source node s
Ensure: Path between two points in G satisfying the wireless network value constraint

```
for all v ∈ V[G] do
    cnv[v] ← +∞
    previous path[v] ← undefined
end for
cnv[s] ← 0
S ← empty set
Q ← V[G]
loop
    Q is not an empty set
    u ← Extract_Min(Q)
    S ← S ∪ {u}
    for all edge (u, v) outgoing from u do
        if cnv[u] + w(u, v) < cnv[v] then
            cnv[v] ← cnv[u] + w(u, v)
            previous[v] := u
        end if
    end for
end loop
```

Figure 5.4: Algorithm for Path Identification

The procedure is given below:

1. All nodes are initially set to infinity apart from the starting position which is given a value of zero. That is, the communication network values between the starting point and every other point is regarded as infinity.
2. All nodes are regarded as temporary apart from the starting node, in order to indicate what nodes have been "visited".
3. The starting node begins the process by being marked as active.
4. Calculation of the ability to reach all neighbour nodes from the active node by summing up its value with the weights of the edges.
5. If such a calculated path of a node is smaller than the current one, update the value and set the current node as the previous node.
6. Next the node with the minimal temporary value is marked as active.
7. Steps 4 to 7 are repeated till all nodes examined.

At the end of the algorithm, a path that has the best communication network ability between the source and intended destination is found and this information is forwarded to the decision layer in order to forward the intended message.

5.3.5 Decision Layer

A Decision Forwarding layer where decision-making is done will be fed data from the upper information modules where some intelligence for the next step in the propagation of messages in the network is applied. This module applies a modified direction based forwarding technique, taking into account the current network conditions retrieved from the communication module and the actual road from source to destination retrieved from both the geographical module and the position of the vehicle from the GNSS module.

The decision-making forwarding scheme is one similar to the trajectory forwarding algorithm proposed by Niculescu and Nath (2003), which is a method that directs messages closer to its destination by selecting a node in a specific direction. It is a forwarding strategy based on iterations of the algorithm for each node while considering each node as the source node while in possession of a message due for delivery, until the message arrives its destination. In the case of this research project, the algorithm not only selects a node in a forward specific direction but considers other factors such as the speed of the vehicles, angles between the vehicles and distance between the vehicles. This is done to ensure that messages are indeed sent along the paths identified in section 4.4.3 above. As long as messages are ensured to travel along the identified path, then message duplication can be avoided.

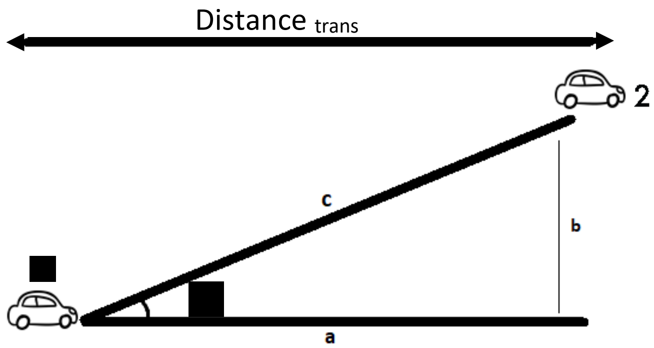


Figure 5.5: Scenario description for directed forwarding of messages

In trajectory-based forwarding, messages follow a trajectory established at the source, but each successive node takes a greedy decision to infer the next hop based on local position information from a Global Navigation Satellite System such as GPS or the Galileo. If the trajectory is expressed as a coordinate $X_{1(t)}$, $X_{2(t)}$, $Y_{1(t)}$, $Y_{2(t)}$ then some forwarding decision for the next vehicle can be described using trigonometry to find the angle between both vehicles and the distance. That is;

$$\alpha = \text{Tan}\left(\frac{b}{a}\right) \quad \text{equation 5.2}$$

$$c = \sqrt{(b^2 + a^2)} \quad \text{equation 5.3}$$

Transmission between two vehicles can be viewed as if in a straight line or at an angle which forms part of a right-angle triangle as shown in the Figure 5.5. The positions of both vehicles S_1 and S_2 can be obtained from the GNSS in use.

While transmission in a straight line in most cases can be considered straight forward and transmission at an angle a bit more complicated, both modes involve several factors as described below.

Speed: To ensure successful transmission between two vehicles, both vehicles should have similar speeds or have acceleration not greater than Acc_{trans} which allows both vehicles to remain in a private cluster. This means that for the sake of calculations, both vehicles may be viewed as being stationary. An analogy of this situation is a satellite in space being in a geosynchronous orbit.

Angle: Considering the scenario in figure 5.5 and remembering the angle α formed by the positions of two vehicles S_1 and S_2 relative to the road can be used to eliminate vehicles to which messages are not intended. In this research, angles greater than 60 degrees eliminates vehicles from being considered as the next possible source node as this would imply that S_2 is not sufficiently ahead of S_1 unless it is the only vehicle within the permitted distance discussed below. Finally, a minimum angle of 5 degrees is defined as an angle equal or below which the vehicles can be assumed to be in a straight line.

Distance: The distance between both vehicles must not exceed the threshold distance defined as the maximum of the sending vehicle's transmission range. In the event of an absence of a second forwarding vehicle within the specified distance, S_1 must carry the message until this criterion is fulfilled.

$$\text{Maximum Distance} = |transmission\ range\ S1| \qquad \textit{Equation 5.3 Max Distance}$$

Whenever a vehicle receives a message, it first checks if an identical message has been received within a specified time period T_{rec} (time message received) by checking the timestamp and nodeID contained in the message. This is done to help reduce redundant retransmissions. In the absence of repeated messages, the node applies the algorithms 5.1 and algorithm 5.2 by comparing its current road segment information (rsID info) against that in the database. It can, therefore, extrapolate information on how the ability of the roads between it and the destination of the message can support the transmission of said message. The overall cost of each path is computed using Dijkstra's algorithm as described by substituting the cost of each link with the cnv accordingly. The main concern here is the amount of data to be searched considering space and time complexity. This concern can be mitigated by having the data stored in a sorted array, thereby reducing the space and time complexity of both the search and Dijkstra's algorithm.

5.4 Summary and Discussions

VANETS being a highly mobile and complex system requires a network architecture that is collaborative, self-organising and mostly free from infrastructure dependency in order to be successfully deployed. This means all aspects of the network's framework must be seen to play an important role; for example, in the previous chapter, an investigation into the effects of road traffic factors revealed the need to include the most effective road traffic factors in building a holistic framework for VANETs because they significantly influence how well the wireless network behaves.

The proposed framework (FIMDEV) in this chapter seeks to use vehicle sensor data and road traffic data in a novel way. Firstly, vehicles sensor data improves how efficient the message dissemination process is by providing information such as the position of the vehicle relative to message sources and destinations. Secondly, road traffic data will be transcribed as an indication of how well the wireless network is expected to perform on a particular road. Researches commonly ignore these data in the design of message dissemination solutions for VANETs, whereas these data are rich sources of information which when correctly used can improve the distribution of messages in a reliable, fair and efficient process in a VANET scenario.

Chapter 6: Framework Evaluation and Discussions

Chapter 6: Framework Evaluation and Discussions

Chapter Overview

As discussed in chapter 3, to evaluate the framework proposed in the previous chapter, simulations were identified as a suitable method for evaluation and prove of concept. Using actual test beds provides validation on real world scenario, but it is expensive and time consuming to implement especially in situations where hundreds of experiments are to be conducted. On the other hand, simulation tools allow researchers to replicate these real-world scenarios with some degree of accuracy, and it allows making crucial changes to the experiments easier. Therefore, simulation, coupled with real data is the closest to validation many network research processes rely on. This chapter is set as follows; section 6.1 discusses the simulation architecture and decisions, including experimental scenarios used. Section 6.2 discusses the experiments to evaluate FIMDEV and section 6.3 discusses the results of those experiments.

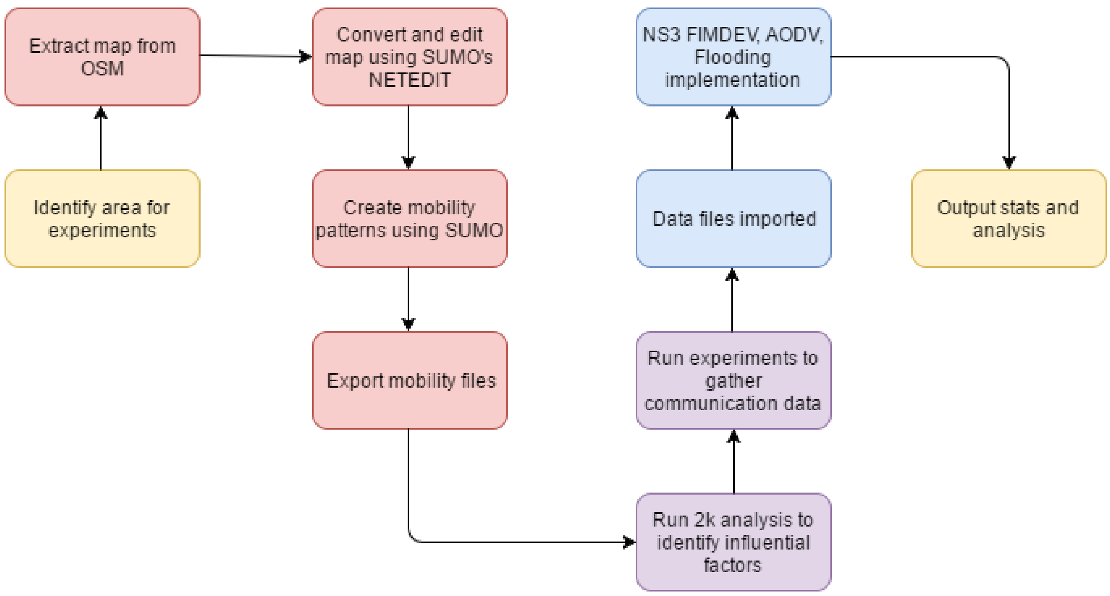


Figure 6.1: simulation process

6.1 Simulation Architecture and Decisions

Valid simulation must as much as possible, be based on reality, such as following driving speed limits, road laws and layout, directions and collision avoidance. Therefore, in testing and evaluating this framework utmost care has been taken to ensure that the data closely matches what might be obtainable in real life. Hence, the outcome of the experiments should have practical significance on whether or not the results are significant enough.

Stated previously, Nottingham city centre has been selected for this evaluation and has been modelled to mimic real city traffic scenario normally witnessed in the city. Each run of experiment allows for multiple choices for routing to occur, that is, there may exist several possible routes a message may take towards its final destination from the source. The mobility pattern has been generated using a random traffic flow on all roads within the city and will be utilised following the prevailing 802.11p standard parameters. The investigation contained in this chapter revolves around identifying the effectiveness of FIMDEV in assisting the routing protocol in selecting the best route for a message being sent; it also involves an evaluation of the practicability and scalability of the framework.

To ensure that the driving parameters indeed follow the actual traffic situation, the mobility model allows for a maximum speed of up to 30 mi/h which is normal for UK city centres. All vehicles do not travel at this speed but follow traffic rules such as traffic lights and obstacles (other vehicles). At the same time to differentiate the effect of traffic conditions, we can place a cap on the maximum allowable speed within the scenario. While this is the case, it is worth noting that most vehicles in the scenario may not reach the maximum speed allowed and we estimate about 15% of the vehicles do reach this speed as witnessed in SUMO simulations.

In this project, Nottingham City was chosen as a basis for experiments and evaluation, the Nottinghamshire Insight Mapping website (GIS, 2013) (Figure 6.2) provided a very good platform to start with, aiding with identification of specific trafficable routes and providing accompanying data to make the initial choices. In order to add accuracy and validity to the work, further data was collected from the Nottingham SCOOT system (Robertson and Bretherton, 1991) (Valsecchi, Claramunt and Peytchev, 1999), these data helped in setting the initial boundaries for the experiments such as the high and lower limits of the number of vehicles on roads within the city as well as the average speeds normally expected on each road.

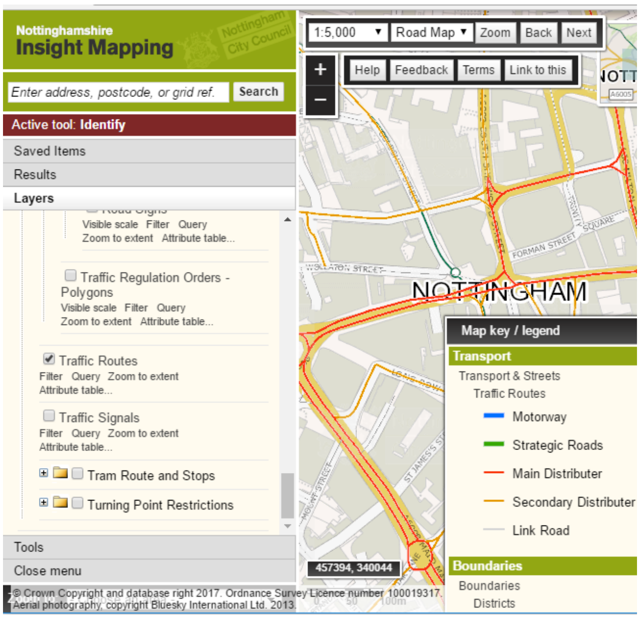


Figure 6.2: Nottingham Insight

In this project, we assume that traffic data is gathered from Nottingham Traffic Centre on Nottingham roads through the SCOOT system which records this data and is processed both in the traffic centre and at Nottingham Trent University and stored in a shared memory at Nottingham Trent University. This process is shown in Figure 6.3.

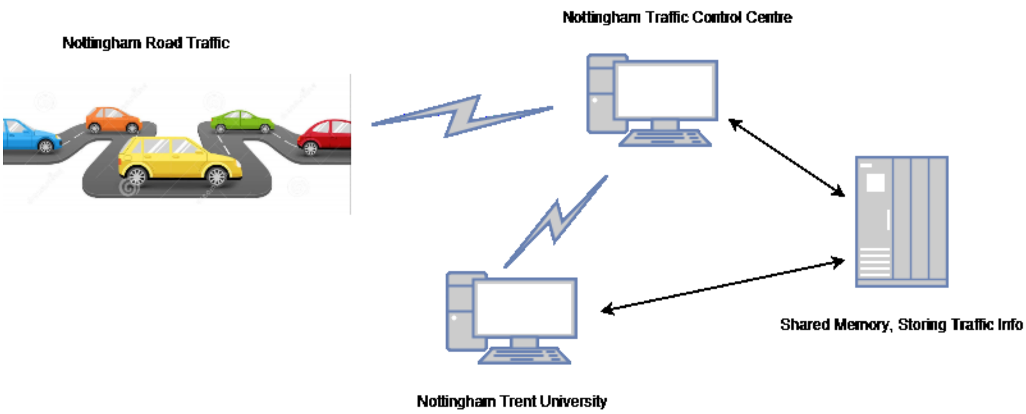


Figure 6.3: Flow and Processing of Nottingham City Traffic Information

This system proved effective when Helsinki University of Technology used the traffic data to perform traffic analysis in real-time (Argile A. et al., 1996). The assumption covers the ability of vehicles in Nottingham city being able to obtain this information from various previously installed hotspots along several roads.

6.1.1 Assumptions

Some assumptions were made in the course of this evaluation, as much as we tried to remain close to reality and model actual data obtained from the city transportation facility, it would be important to note the following:

1. Vehicles in the scenario are mobile and are equipped with a global navigation satellite system that provides certain information such as position, speed and direction.
2. The messages being sent may contain just the needed information or other control information such as those described in section 5.3.
3. Each vehicle has the framework embedded, and has a system powerful enough to store data, process data and utilise results.
4. The vehicles communicate with others using VANET communications IEE 802.11p.

SUMO provides vehicle ID, position, direction and speed for each node, and also includes the coordinates for each road section. Therefore all necessary information can be obtained from all data produced by SUMO before use in the network simulator.

6.1.2 Scenario Pattern

Map of the city of Nottingham was exported from openstreetmap (OpenStreetMap, 2015) and then converted to simulation usable file called a network shape using SUMO's netconvert tool. Some SUMO built-in parameters were used to check the downloaded map for errors and correct them while other netconvert parameters ensured the inclusion of street and road names in order to aid accuracy when injecting traffic onto specific traffic routes before exporting the file as an eXtensible Markup Language (xml) file. After this is done, the newly created xml file can be edited with any text editor, to identify traffic routes needed and create vehicles for each route to serve as a basis for communication network experimentation as described in chapter 3 of this thesis.

The scenario for the experiment described in section 6.2 comprises of a series of interlinked city roads, the same scenario has been used for all experiments in this work to ensure consistency in the process. For each road, a set of traffic parameters was selected, that is, number of vehicles and average speed in order to run the initial experiments. The experiments was performed 10 times each for each set of parameters, the output of this experiment which includes overhead, packets sent, packets received, delay and the packet delivery ratio.

Scenario: City centre, Nottingham (UK) sees relatively simple traffic flows with different number of vehicles. As mentioned previously, for this experiment a map of Nottingham city centre is extracted from OSM and converted then some mobility pattern is injected into this. this has been detailed in chapter 3. Figure 6.4 shows what the city looks like from a top view and what the traffic route looks like. Hence the mobility of vehicles in this experiment is for every navigable route in the map and for each set of experiments for example, 50 or 200 vehicles are injected at random and navigate around the city.

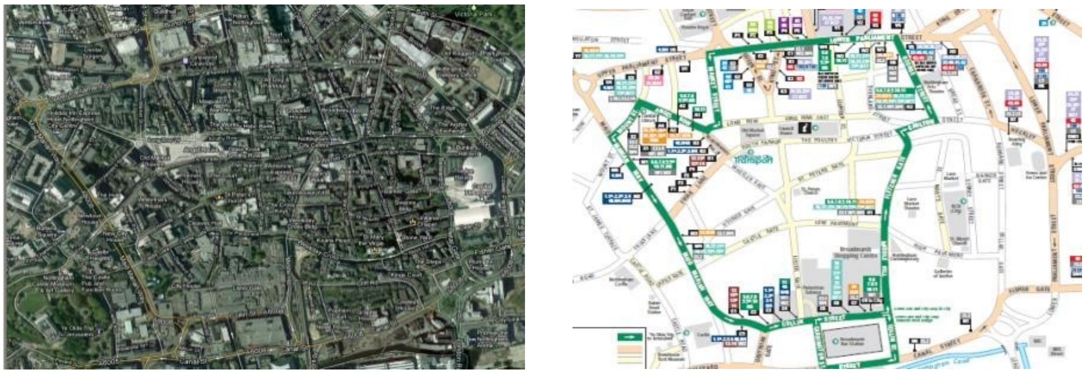


Figure 6.4: Nottingham (UK) City Centre.

A realistic mobility pattern should contain vehicular parameters such as traffic following, acceleration, deceleration, movement towards a destination following road rules. Two sets of experiments are done with maximum speeds set at 20 mi/h and 30 mi/h respectively. Vehicles in following traffic rules may converge at certain points such as at an intersection while other vehicles on other routes may experience congestion free traffic. This creates an interesting perspective on how routing actually performs as many research fail to capture the constantly changing topology of the traffic.

6.2 Evaluation and Analysis

In order to achieve the aim of this research, it is crucial to determine the wireless communication condition of the network with various combination of traffic elements. That is, the state of vehicles as the primary players in this scenario are altered by changing the number of participants and their average speeds. These factors were chosen after careful consideration of the factors that have considerable effect on the potential outcome of any VANET communication; the various factors and their determination were discussed in chapter 4 of this thesis. The experiments conducted consists of a series of simulations on each of the City's routes where vehicles can use.

A point of interest arising from this set of experiments was identifying when the wireless communication on a route is behaving abnormally. It is seen that specific number of vehicles and speed gives rise to specific communication patterns and values. Thus, building this map can also help identify when some unusual activity such as a Denial of Service (DoS) attack occurs in the vehicular wireless network.

6.2.1 Simulation parameters

Table 6.1 shows the parameters and values used in the preparation, experiment and evaluation of the framework.

Parameter	Value
Simulation area	City wide
Simulator	SUMO, ns-3.23
Number of vehicles	50, 100, 150, 200, 250, 300
Vehicle's speed	0- 30 mph (0- 48 km/h)
Mobility Model	SUMO defined
Nodes Distribution	Random injection
Movement Pattern	Random
Simulation Time	21600 (Seconds)

Sink of nodes	varied
Channel	Wireless
Network Interface	WirelessPhy
Propagation	TwoRayGround
Mac Type	802.11p
Protocol	AODV, DSDV
Transmit power	7.5dBm
Packet size (bytes)	128

Table 6.1: Simulation parameter configuration

To Evaluate the advantage of including the proposed framework FIMDEV to traditional data routing, consider some scenario where there are several options to route a message between two points, such as in the figure below; where the green pin marker (top right corner) represents the starting position for message transmission and the red pin marker represents the destination.

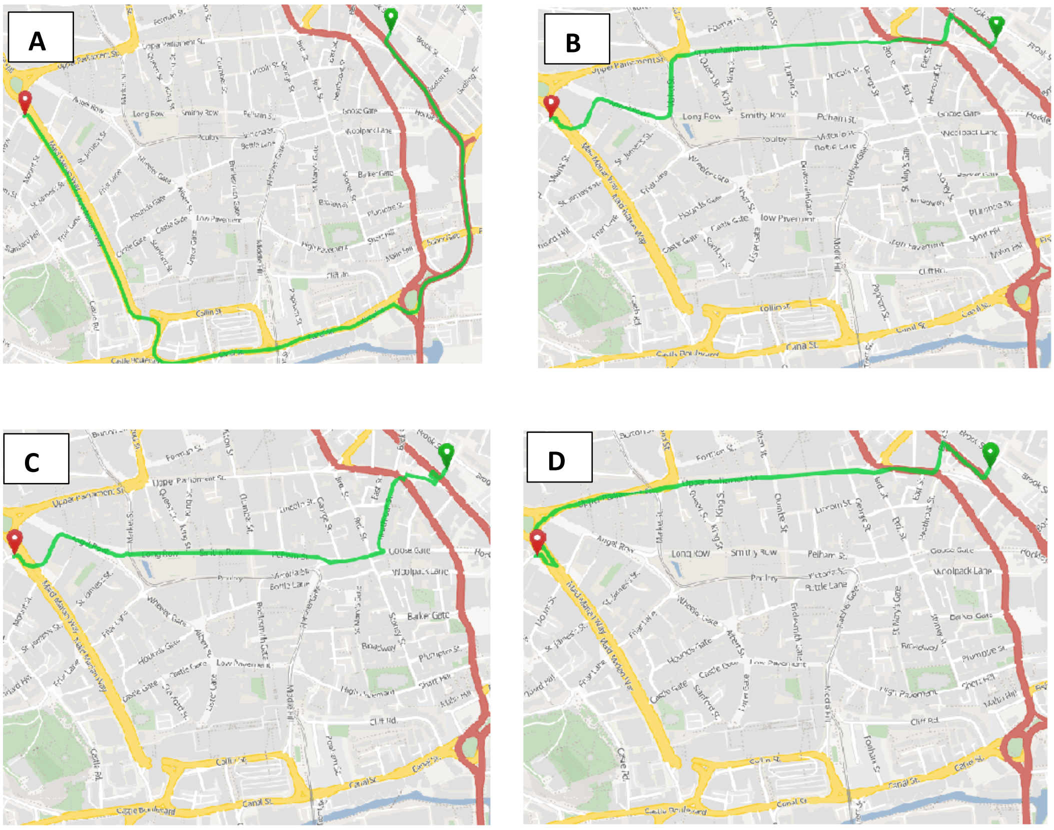


Figure 6.5: Possible Routes Between Brook Street and Central Police Maid Marian, Nottingham

Traditional routing protocols and most other common VANET routing protocols as discussed in chapter 2 of this thesis, would normally find the shortest path as the geographical distances between source and destination points as cost of performance. In such situations, the obvious choice would be to route messages through the road indicated in figure 6.5D. However, this is a blind choice as option D may very well represent a route with network difficulty or poor network performance at that moment due to lack of vehicles or too many vehicles respectively. FIMDEV on the other hand helps to determine the quality of the route based on the current road traffic and how that information translates into the quality of the wireless network.

To evaluate FIMDEV, geographical position and road traffic data was prepared as per the scenario. Road information containing street name, street ID as well as GPS coordinates was extracted from Open Street Map, example seen in the figure below.


```
{ "type" : "Feature", "geometry" : { "type": "LineString", "coordinates" : [[-1.16403511509,52.9566491216],
    [-1.16423741449,52.9565408517], [-1.16431647606,52.9565512436], [-1.1643748846,52.9565712064]] }, "prop
    "streetName" : "Moorgate Street" }},
{ "type" : "Feature", "geometry" : { "type": "LineString", "coordinates" : [[-1.14126074149,52.9537159557],
    "properties": { "id": "6976280#0", "streetName" : "Cranbrook Street" }},
```


Figure 6.6: Data from OSM

The data above is formatted in a new table to allow for path determination based on the condition of the route communication-wise. Each route is identified both by name and numeric ID, therefore a table of edges is populated as follows;

	A	B	C	D	E	F	G
1	3138 edges loaded.						
2	1662 nodes loaded.						
3	EdgeID1	EdgeID2	Current Cost	E1Point	E2Point	Name	ID
4	994780641	28789882	3	[-1.14270225327,52.9560642344]	[-1.14276481026,52.9558898918]	Beck Street	29159304
5	206188649	352832745	2	[-1.1413813789,52.9552733399]	[-1.14149997463,52.9551809714]	Nile Street	31527839
6	352832745	28789882	1	[-1.1416314282,52.955183333]	[-1.141383,52.954984]	Huntingdon Street	29189083
7	28789882	36428416	2	[-1.141142,52.954788]	[-1.141771,52.954340]	Lennox Street	6947739
8	28789882	343136646	1	[-1.141417,52.954963]	[-1.144717,52.955397]	Lower Parliament Street West	4607613
9	28789882	36416697	3	[-1.141417,52.954963]	[-1.140192,52.950200]	Lower Parliament Street East	5205711
10	36428416	330158147	3	[-1.14221954904,52.9546274224]	[-1.14247893757,52.954869374]	Cranbrook Street	36976280#4
11	330158147	2147623010	2	[-1.14252180902,52.9541852156]	[-1.1422320994,52.9545812262]	Brightmoor Street	17187122#2

Figure 6.7: Edge Weighted Table for FIMDEV implementation

Chapter 5, section 5.3.5 describes the process and algorithm used to determine the best route. Upon completion of that process, the route advice (containing the geo coordinates) is available to the node currently with the message to be delivered which will then allow it to process the directed forwarding (section 5.3.5) in the direction of the best route(s) indicated.

6.2.3 Protocols for Comparison

Following the analysis for message delivery methods in VANETs as reviewed in chapter 2, the proposed framework will be compared thus; when used with commonly known active and reactive routing protocols (AODV, DSDV) and when those protocols are used alone in finding the best path between a sending node and receiving node. For this comparison, the varying controls in the experiment are the number of vehicles in the network and the speed at which they are traveling at.

6.2.4 Performance metrics

The measurements of this project focus on communication performance metrics with respect to efficiency and reliability of communications. The performance indicators used to investigate the effectiveness of FIMDEV in message delivery for VANETs are end-to-end delay, packet delivery ratio, overhead and number of hops .

End-to-End Delay: This metric is used to measure the time delay taken in transmitting messages from the source node to the destination node which typically includes the time taken to process the data during the retransmission and buffering operations. This can be affected by transmission rate and size of message. For this research, typical values for these factors were used throughout the experiments.

Packet Delivery Ratio: This metric is used to measure the number of transmitted messages against the number of received messages from all source nodes to all destination nodes. The PDR is a ratio of packets sent against packets received in the network.

Overhead: This metric is used to measure the effectiveness of a protocol in utilising the network properly and it is measured by obtaining a ratio of control messages to other messages being broadcast in the wireless network.

Number of Hops: This metric is used to measure the number of nodes a message would need to pass through while on its journey from source to destination in the wireless network.

6.3 Results

This section describes the outcome of the experiments conducted and how the proposed framework fares in assisting selected routing protocols under several conditions such as varying speed to show the effect of routing and message dissemination in a realistic city scenario.

6.3.1 Push Scenario

In this scenario a vehicle (node) has some information to disseminate, in VANET terms this would typically be safety messages, warning messages or messages to engage clusters. The push scenario has been touted as the primary function of VANETs and must therefore be as efficient as possible. For this scenario, we have chosen to position the disseminating node and the destination node at opposite locations within the city centre; doing this increases the robustness of the experiment and at the same time increases the route options available in sending the message and ensuring its success. The experiment is set up such that each node outputs a message when it receives a non-control packet, this enables us to track the data and identify when it is received by the final sink node. The scenario will be replicated for a maximum speed of 30 mi/h and a maximum speed of 20 mi/h.

6.3.1.1 Results at 30 mi/h

In section 6.1.2 we discussed the need to mimic road traffic conditions as closely as possible and in chapter 4 we identified the road traffic factors with the most effect on message dissemination as number of nodes and the speed the vehicles travel at, another important factor is the route but this is a fixed factor. For this set of experiments we set a maximum allowable speed of 30 mi/h and replicate this for varying number of vehicles: 50 – 300.

Packet Delivery Ratio

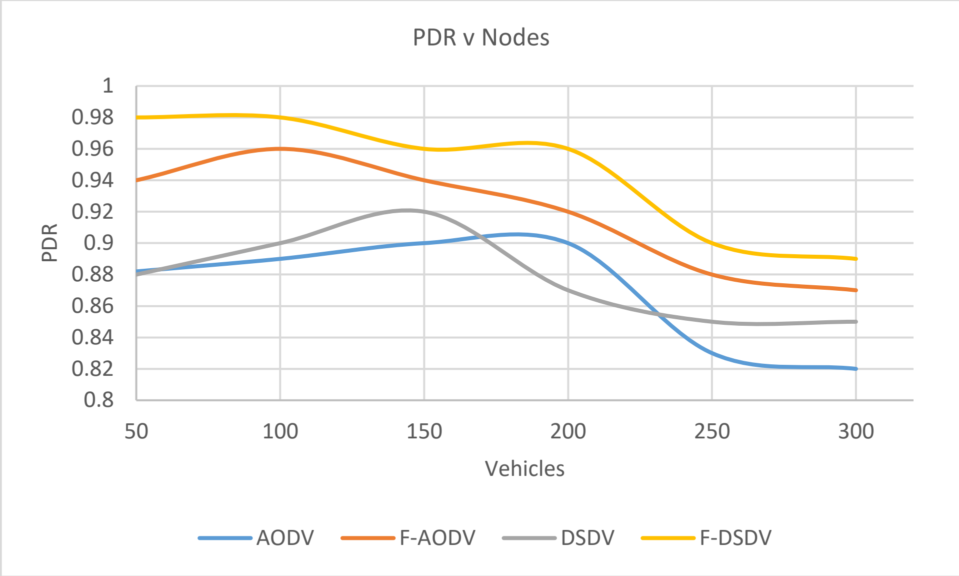


Figure 6.8: Packet delivery performance, max speed 30 mi/h

In this experiment 50, 100, 150 up to 300 nodes were used and simulation ended when the tagged message reaches its intended target. AODV and DSDV routing protocols were used to determine the efficacy of FIMDEV on both a reactive and proactive protocol. From figure 6.8 both protocols show decent packet delivery percentages of above 85% with this value increasing to 94% and above when FIMDEV is used to assist message dissemination. AODV on its own sends a lot of packets to discover routes and some of this packets are lost thereby leading to a hit on the PDR, when AODV is used with FIMDEV there are less route discovery packet being sent because FIMDEV uses directed broadcasts, that is, once a route is discovered and confirmed to be of good quality, there is less risk of packets being dropped along that route. AODV on its own may or may not select the best route, the protocol is mostly concerned with if there is an available vehicle in the next hop and so on. DSDV uses routing tables to complete message dissemination, as long as those tables are accurate at the time of broadcast it is likely to be more successful than AODV. FIMDEV is able to piggyback off of these tables to identify possible routes and whether those possible routes are viable thereby reducing chances of dropped packets.

Delay

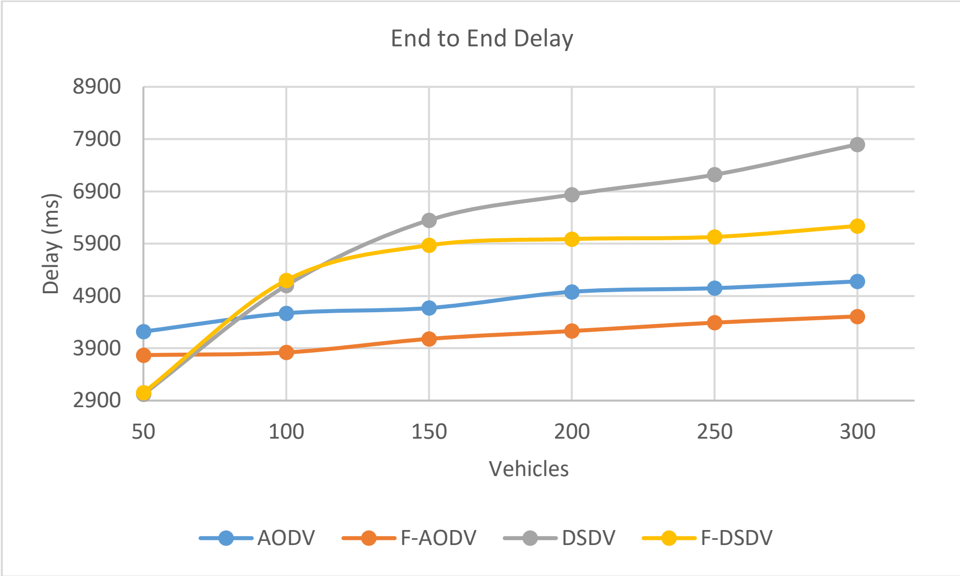


Figure 6.9: Delay, max speed 30 mi/h

Delay is a major issue in message dissemination, with VANET having a fast changing topology it is important to reduce delays where possible. On one hand FIMDEV adds extra computation to the routing mechanism, however it is also able to compensate because it is mostly able to eliminate delays due to dropped packets and lost routes. At the start of the experiment in figure 6.9 involving 50 nodes, we see AODV having more delay than DSDV; this can be caused by the need to transmit several request and response packets which accumulates and contributes to the overall delay. However as the number of nodes increases, there is a sharp rise in DSDV's delay due to its struggle to achieve scalability in the network, that is, acquiring and updating its routing table. In both cases where FIMDEV was used to assist message delivery, the framework was able to maintain a stable level of delay yet this increased as the number of nodes increased meaning that it was also affected by DSDV's need to acquire routing tables; however FIMDEV was able to limit delay by eliminating routing decisions that end in dead links.

Overhead

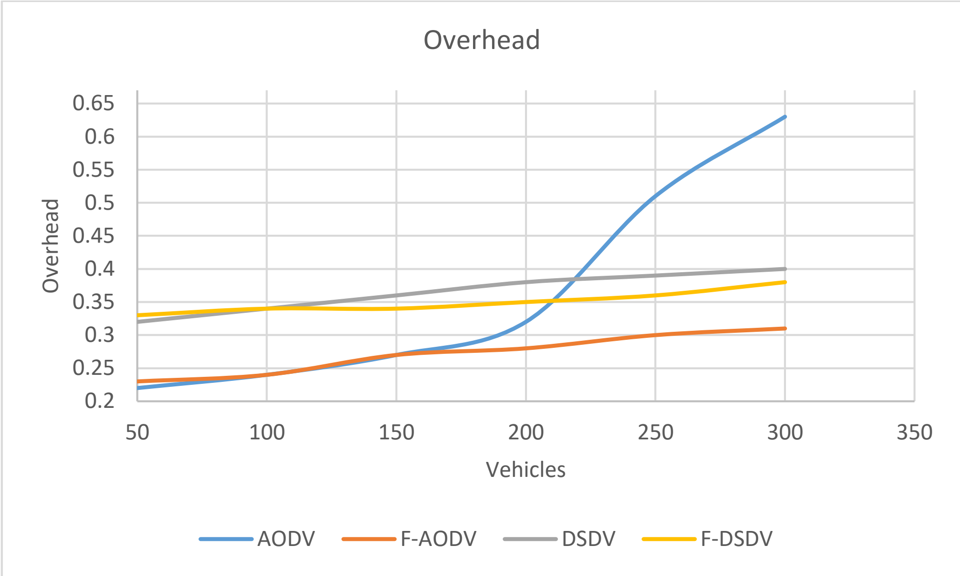


Figure 6.10: Overhead, max speed 30 mi/h

To make the experiment robust and examine its practicability in the real world, each node broadcasts both safety updates and non-safety messages in line with the WAVE protocol for VANETs. Hence, the overhead measured is a ratio of control messages to other messages being broadcast. As seen in figure 6.10, as the number of nodes increases the amount of overhead increases as well. This may or may not be the case all the time because it depends largely on the amount of control messages needed, for example, lost routes and dropped packets results in more packets being needed to rectify the situation. AODV sees a huge rise in overhead as the number of nodes increased, this is a situation expected when the routing protocol encounters a problem in identifying the best route towards its destination. DSDV on the other hand can have relatively low overhead if its routing table is not out-dated by the time broadcast happens. Using FIMDEV in both situations also sees a rise in overhead but not by much as the framework suppresses retransmissions and implements a furthest-away scheme of broadcast.

Number of Hops

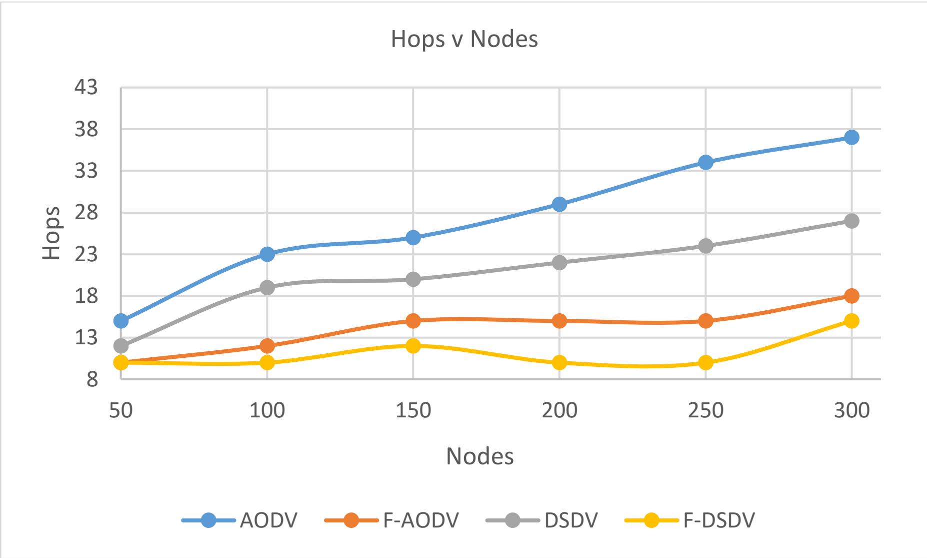


Figure 6.11: Number of Hops, max speed 30 mi/h

There are several factors that may affect the number of hops recorded, one would be path selection, and another would be availability of neighbouring nodes in the sender's transmission range. Depending on the route strategy, it is possible to still have multiple hops within a vehicle's transmission range on a stretch of road. Therefore one would expect to see more hops as the size of the scenario increases and the number of nodes increases. Figure 6.11 shows the number of hops taken from source node to destination node, logically, more nodes presents the opportunity for more hops and this has been the case with AODV, DSDV has lower affinity for hops because it can make use of its routing table to determine the next best hop to forward a message too. In the same vein, F-DSDV can further reduce this hop count found in DSDV by ensuring that the next hop is the furthest in the direction wanted.

6.3.1.2 Results at 20 mi/h

Maintaining the various number of nodes while reducing the maximum allowable speed will give an insight into the possible effect of slower nodes on the network. Logically we would expect either of two things to happen; either a very good network due to the fact that vehicles are slow to leave the transmission area of the broadcasting node or it could also end up as the opposite where nodes are clustered in the same area thereby leading to congestions. The following experiments examines the effect on the parameters as done previously.

Packet Delivery Ratio

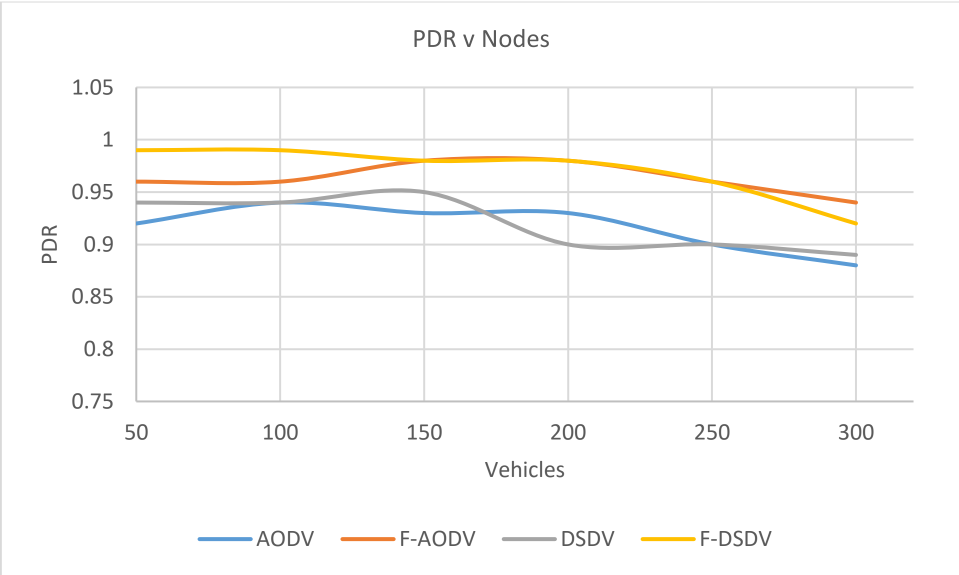


Figure 6.12: Packet delivery performance, max speed 20 mi/h

In this subsection we examine the outcome of the experiment in terms of packet delivery ratio for various number of nodes. We see that all protocols record better PDR at 20 mi/h than at 30 mi/h. As seen in figure 6.12 both AODV and DSDV experience erratic packet delivery, rising between 100 and 150 nodes before a drop below the 90% mark. On the other hand, when assisted by FIMDEV both maintain at least a packet delivery of 95% up on till 250 nodes before dropping slightly. This shows that FIMDEV is even more scalable at lower speeds as this would improve the chances of the success of the directed broadcasting strategy used.

Delay

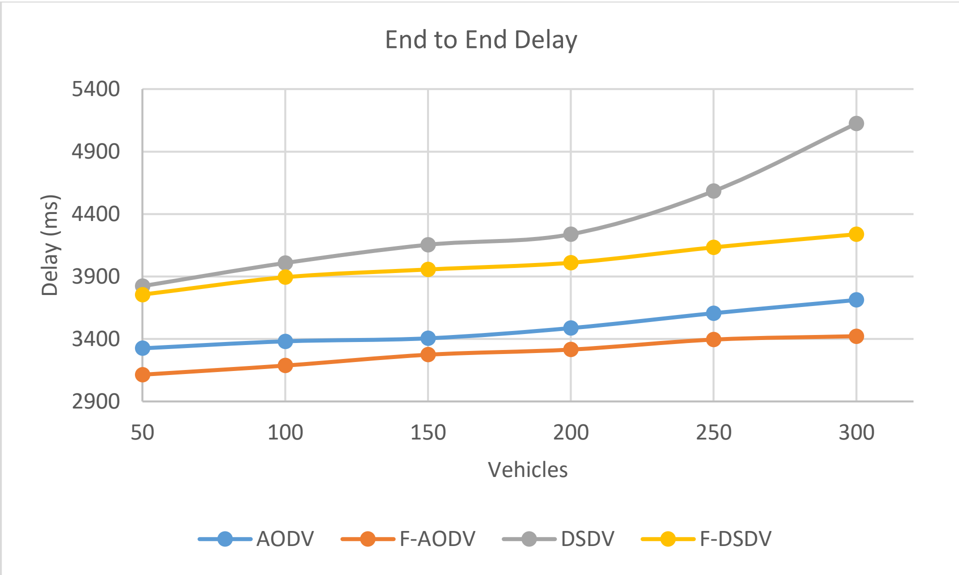


Figure 6.13: Delay, max speed 20 mi/h

In this section we see the effect of a lower speed on FIMDEV and the routing protocols, again all perform better than at maximum allowable speed of 30 mi/h as seen in figure 6.13. Both protocols when used with FIMDEV show a gradual but minimal rise in the delay values as the number of nodes rises. Although not identical, the rise with respect to number of nodes is similar to that obtained in the 30 mi/h scenario. At slower speeds FIMDEV is able to compute its next hop more accurately than at faster speeds therefore leading to less packet loss and the associated delays that come with that process. Overall using FIMDEV ensures the least amount of delay in the dissemination of messages.

Overhead

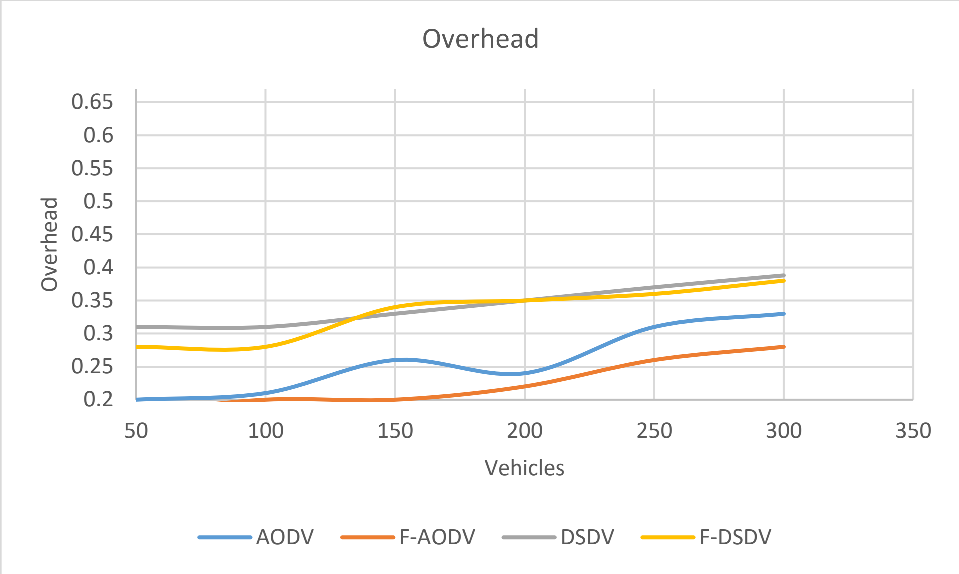


Figure 6.14: Overhead, max speed 20 mi/h

Figure 6.14 shows as expected, the overhead in this scenario for all methods used is lower than when the nodes have a maximum allowable speed of 30 mi/h. At this rate FIMDEV made little difference when used with DSDV, this might be because both times the same route was selected and possibly longer live routes which means less need to send control messages to build the routing tables. Therefore it is safe to conclude that at lower speeds and delay is not an issue, using DSDV on its own is sufficient. FIMDEV should still be used with AODV as the advantages of this outweighs the effects of not using it, there is significantly less overhead in accomplishing the message dissemination.

6.3.2 Pull Scenario

In this scenario a node rather than having some information to disseminate would be requesting some kind of information. The application of this scenario would be when a vehicle needs to know if there are available parking spaces in a lot, or if there exists a service station in a particular area, that is, the message type is not of utmost importance and this pull request actually runs a risk of not being completed because according to the WAVE standard all safety messages take precedence over other message types, hence a pull message will be halted to complete all push requests after which the already discovered route may have expired. Again as with the push scenario the points of interest are placed on opposite sides of the city centre to increase the options available to the routing protocols as well as increase the robustness of the experiment. All nodes in the scenario receive and broadcast control messages in addition to forwarding the pull message. The experiment is replicated for maximum vehicular speeds of 20 mi/h and 30 mi/h.

6.3.1.3 Results at 30 mi/h

The results for the pull scenario based experiments ought to present an interesting find because there are many influences on the network this time. For example, the longer the simulation goes on, the higher the chances of traffic congestion building up in the scenario and bringing with it poor routes and possible broadcast storms. As with the push scenario, the number of nodes are varied and this first instance allows for a maximum vehicular speed of 30 mi/h, all other traffic rules remain.

Packet Delivery Ratio

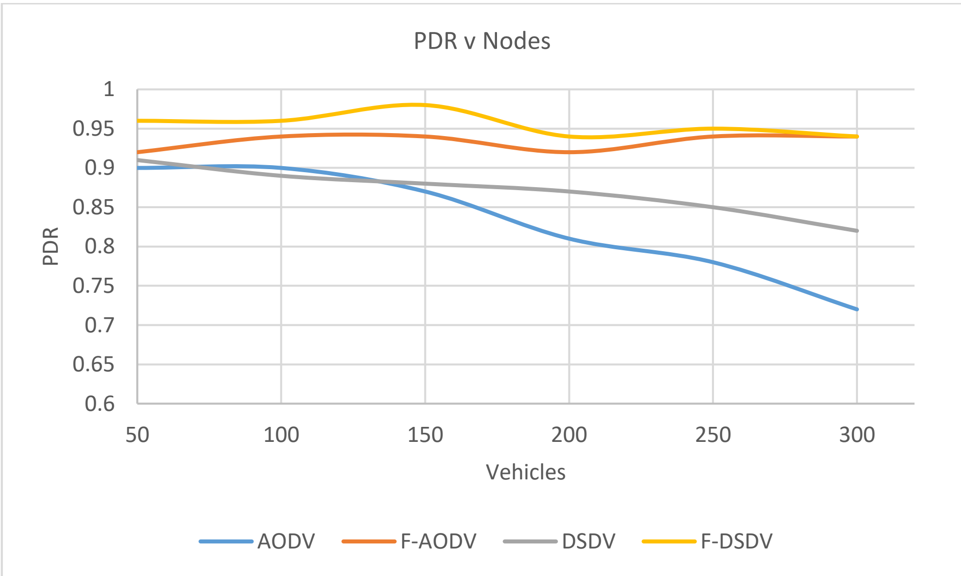


Figure 6.15: Packet delivery performance, max speed 30 mi/h

In this subsection we see in figure 6.15 that the packet delivery ratio of the four message dissemination methods with regards to varying number of nodes. While all four presented high PDR for 50 nodes, both AODV and DSDV witness a degradation in PDR as the number of nodes increased. This may be due to their inability to cope with the number of nodes (scalability), in this scenario the protocols had to deal with requests for a longer time period than previously witnessed. More queries are made of the protocols to determine the desired node and this results in communication with nodes that otherwise have no bearing on the overall goal. It can also mean poor choices have been made by both AODV and DSDV in route selection, with the simulation lasting longer the effect of road traffic build-up can deteriorate the effectiveness of the network. Meanwhile, with FIMDEV assisting both routing protocols, the PDR is seen to be much more stable and quite high at about 95%.

Delay

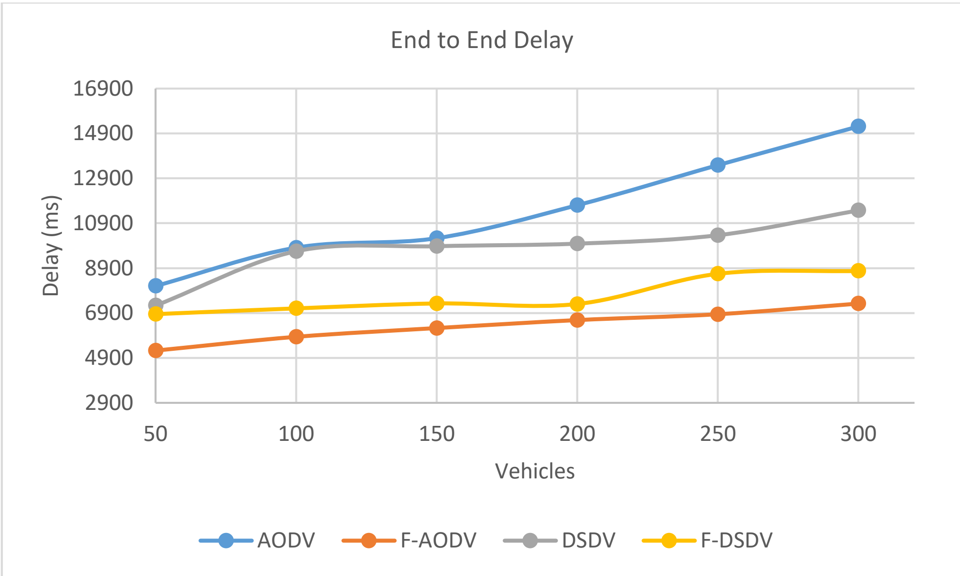


Figure 6.16: Delay, max speed 30 mi/h

This section describes the outcome of the experiment with respect to network delay, FIMDEV assisted protocols outperform the others as shown in figure 6.16 because route selection is based on how good the route is due to the number of vehicles and speed at which they are traveling. With the other protocols applying other greedy routing strategies, there exists the possibility of forwarding a message towards congested routes in the case of AODV or towards dead links in the case of DSDV. Similar to the push model, there is a marked increase in delay when tested with increased number of nodes, however, FIMDEV is able to offer dissemination solutions that does not add tremendously to the network delay.

Overhead

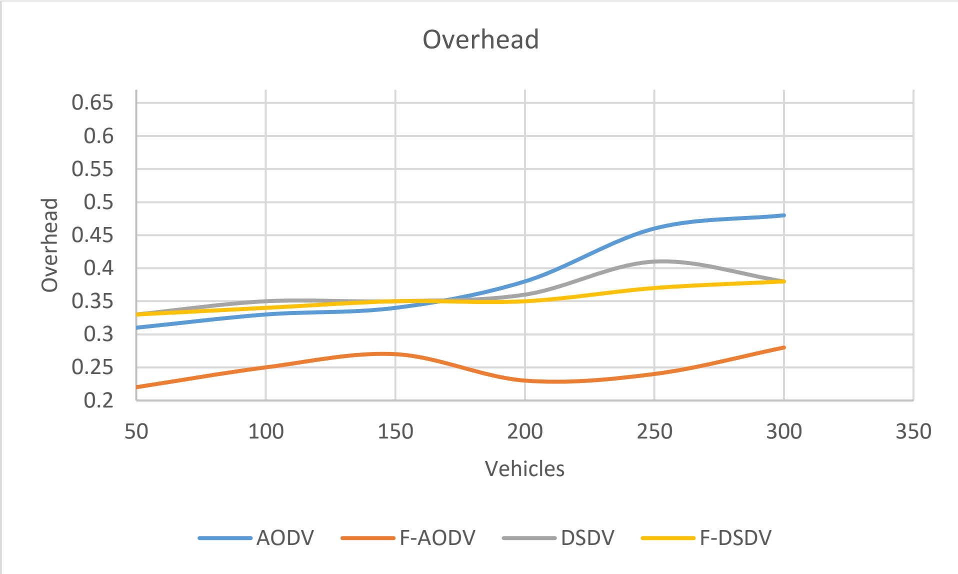


Figure 6.17: Overhead, max speed 30 mi/h

Figure 6.17 shows the output of the experiment with regards to overhead and presents the idea that AODV, DSDV and F-DSDV produced similar overhead up until the nodes where 200 in the simulation. It is unclear at this point the reason for this phenomenon, perhaps no better route than the ones identified by both AODV and DSDV were identified in those runs. If that were the case, FIMDEV simply defaults to the original routing strategy and intermittently check for updates on changes on vehicular traffic on the route. On the other hand, F-AODV sees much lower overhead than the other methods tested; this could be due to a difference in choice of route selection, for example a clear route used in sending messages could function as a path for receiving a response and therefore reducing the amount of messages needed to identify new routes.

Number of Hops

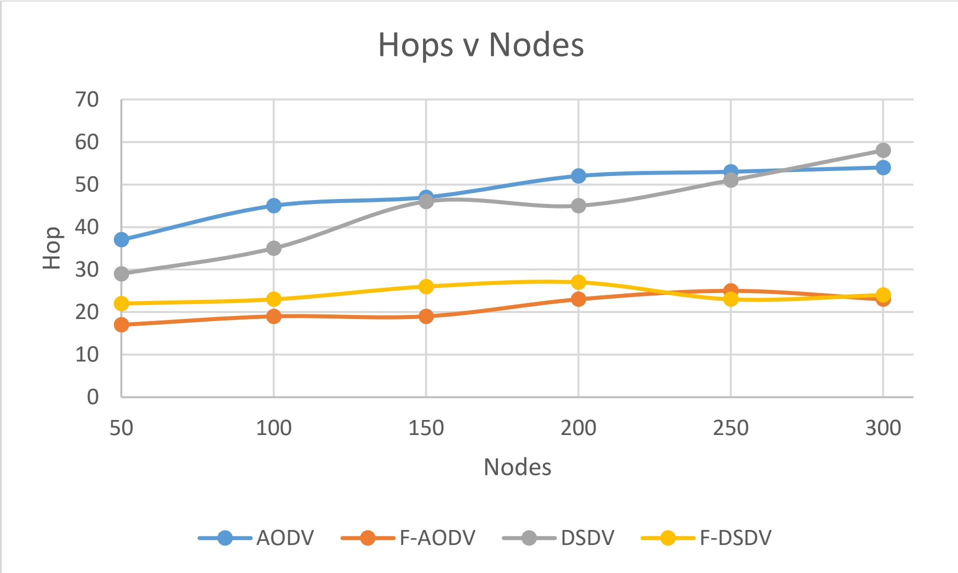


Figure 6.18: Overhead, max speed 30 mi/h

The number of hops seen in figure 6.18 is large under this scenario and this is explained as follows: with the pull requests, the nodes keep propagating the request by the original sending node till the desired response is obtained and sent back to the node. Also, the path or route taken by each routing method and number of nodes on each of those paths contribute to the number of hops witnessed. Therefore a simple pull request can be propagated through a longer route that gives rise to a bigger number of hops. This is evident in FIMDEV's operation as explained in section 6.3.1.1, the ability to identify not only the best route but the furthest node along that path ensures that the hop count is kept as low as possible. Obviously, this is not without dangers, for example, the furthest node may move away from its initial position fast enough for the message to miss its target, however, there may also exits a different node far enough away to continue the dissemination of the message.

6.3.1.4 Results at 20 mi/h

Like the 20 mi/h push scenario, it is imperative that we know how FIMDEV handles pull requests under different road traffic conditions. Lower road traffic speeds can enable nodes to have more reachability within their transmission range, at the same time, too many nodes within each other's transmission range can be problematic and increase delay due to channel contention as well as increase overhead arising from contention and dropped packets.

Packet Delivery Ratio

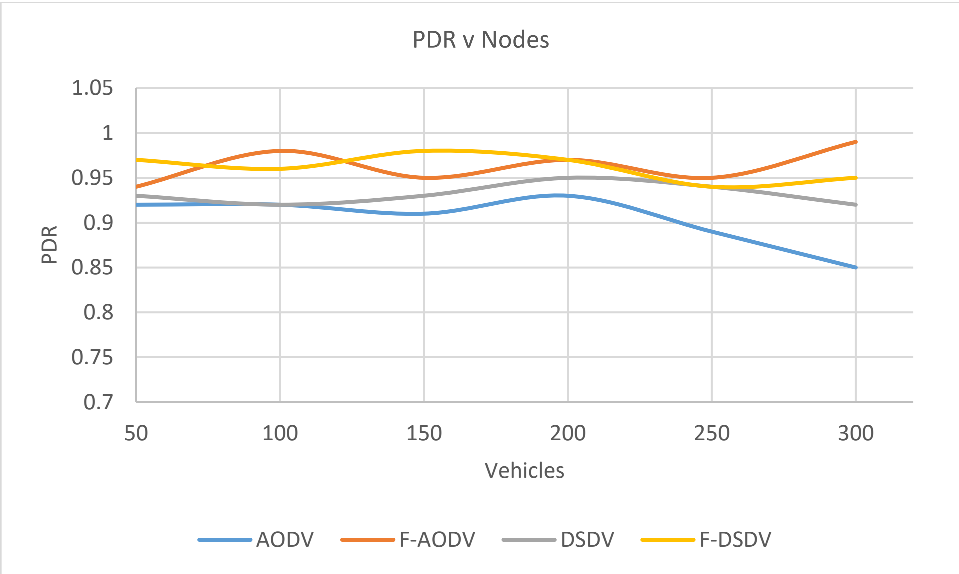


Figure 6.19: Packet delivery performance, max speed 20 mi/h

FIMDEV outperforms the other protocols with respect to the packet delivery ratio from the experiments conducted as seen in figure 6.19. It underlines the importance of road traffic awareness, achieved by acquiring the location of the vehicles and cross-checking the number of vehicles on each route against the expected wireless network condition. Having a knowledge of the available routes between the source node and destination node along with how the wireless condition is for those routes gives FIMDEV the upper hand in selecting the best route to disseminate the message through the best paths. This means that the packet delivery ratio for FIMDEV is an average of the packet delivery ratio of the best paths found, leading to a very stable delivery method. On the other hand, the other protocols such as AODV does not concern itself with the traffic or how that translates to good or poor wireless network conditions but rather selects paths based on how close the next hop is in the direction of the destination. This “blind” approach to message delivery means AODV is likely to select hops that are within wireless congestions or broadcast storms.

Another loophole FIMDEV avoids is hidden nodes by selecting next hops based on the forwarding strategy explained in chapter 5 of this thesis. After the main route to the destination is selected, hops are selected towards that destination by choosing both the farthest node within the transmission range of the sender and receiver as well as direction of the receiving hop. Using FIMDEV’s rules in addition to other protocols can significantly improve the delivery ratio of the network and help in balancing the network by avoiding areas of poor delivery due to wireless network congestions

Delay

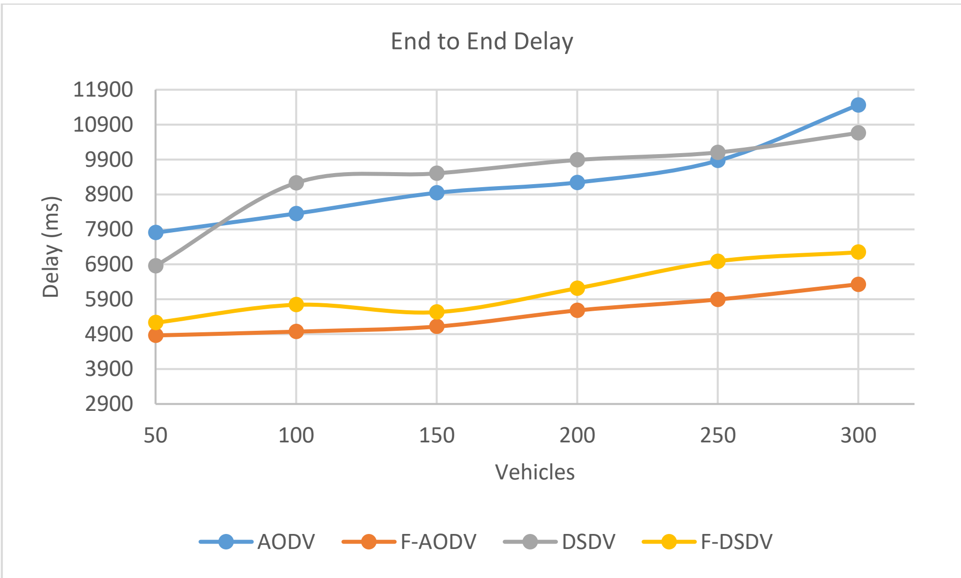


Figure 6.20: Delay, max speed 20 mi/h

The end – end delay has a proportional relationship with the number of participants in the wireless network and subsequent number of steps a message needs to take to its destination. Therefore, the route selection technique and the route itself play important roles as contributory factors in the amount of delay in the wireless network; both should be of optimal quality to reduce unnecessary delays.

Under the scenario in these experiments with outcome shown in figure 6.20, FIMDEV has significantly less end-end delay because only the best paths are selected before the messages are disseminated. Selecting the best path prior to dissemination reduces chances of retransmission of failed messages and also reduces extensive contention for network bandwidth which adds to the delay incurred normally by AODV. At higher speeds, there may be a reduction in the advantage initially provided by FIMDEV if the number of vehicles are such that not enough vehicles are within transmission range, however, an increase in the number of vehicles means there is a probability for at least one vehicle to be within transmission range to accept and forward messages received

Overhead

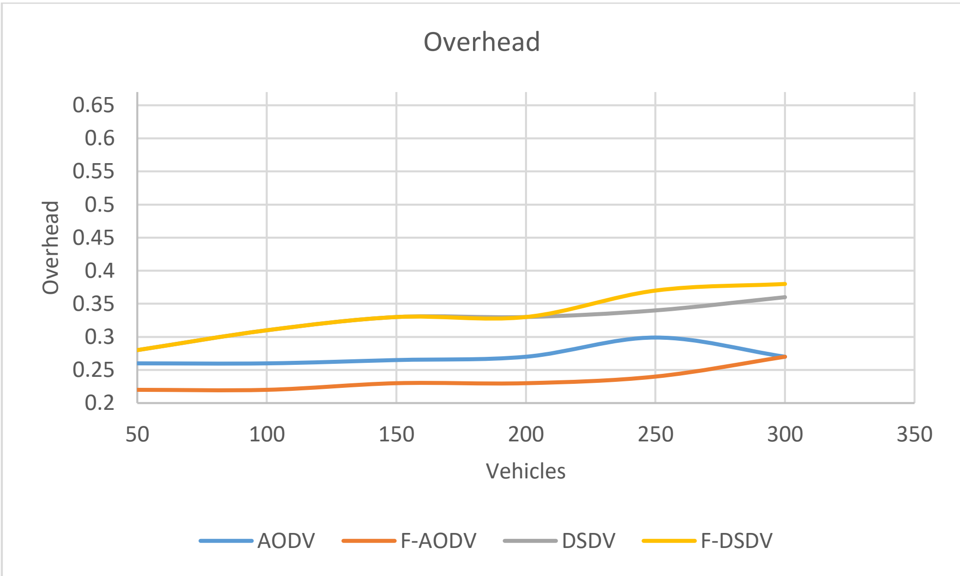


Figure 6.21: Overhead, max speed 20 mi/h

The overhead seen in figure 6.21 shows the overhead of the network under the stated parameters. In this case when DSDV was implemented with FIMDEV, they appeared to have similar overhead right until the 200 node mark which saw the assisted method deviate with more overhead than its counterpart. As the aim of FIMDEV is to improve message delivery while maintaining costs within reasonable range, it is an abnormal result which might mean an event such as traffic congestion due to traffic lights may have occurred soon after a route was selected but the chances of this happening twice (both 250 nodes and 300 nodes) should be considered a rarity.

6.3.3 Conclusion

The framework was implemented under various scenarios and when current road traffic was considered, it aided in the determination of the current wireless network condition of each possible route as recorded in the wireless network map. The route selected in the above experiment using the proposed framework was independent of the geographical distance between the source and destination points and instead is more poised to determine the best route based on what was happening on each road at the time. FIMDEV showed an improved performance in message delivery for VANETs. With marked improvements in delay reduction as the level of contention is minimised, improvement on the packet delivery ratio was also evident.

6.4 Summary

The proposed framework FIMDEV was implemented and tested alongside standard protocols, AODV and DSDV, representing reactive and proactive protocols respectively. From the experiments conducted, using FIMDEV provided better network utilisation by improving the delivery ratio of packets and reducing the average delay in delivering those messages. As previously discussed, it was noted that certain combination of number of vehicles traveling at certain speeds gives rise to what can be considered best network conditions. The rate of transmission in these so-called best network conditions is seen to be good in comparison with other combination of speed and number of vehicle. Furthermore, these conditions are unique to each road and do not follow any recognisable pattern. Hence the need to map out the wireless network condition for each road within an area to produce a network map which a routing protocol can utilise to effectively transmit and forward data.

By using knowledge of the current road traffic (speed and number of vehicles) for each road, FIMDEV compares the current values against the prebuilt map in order to discover which routes have the best chance for message delivery (sweet spots). Upon this discovery, the framework ensure that messages are routed through the discovered paths between source and destination using a series of algorithms. FIMDEV, therefore, avoids network congested routes where possible, hence, ultimately improving the delivery of messages and reducing delay in transmission. While the evaluations conducted at lower speeds are generally good in the experiments for both AODV and DSDV, it can be seen that FIMDEV provides better solutions and it is more stable than AODV and DSDV. At higher speeds, there is a general reduction in the ability of the network to deliver messages because vehicles may move away from the transmission range of a sender before receiving messages, however, FIMDEV maintains its superiority by using the best routes.

Chapter 7: Conclusion and Future Work

Chapter 7: Conclusion and Future Work

Chapter Overview

A recent whitepaper by Juniper Research (Juniper Research, 2017) indicates an upward trend in the adoption of VANET technologies, with the research showing that as many as half of newly manufactured vehicles will be VANET ready by 2022. It underscores the importance of VANET both as a consumable and commercially viable technology, therefore research such as contained in this thesis strives to provide improvements to the VANET concept to support efficient use of the network and vehicles as information carriers. The proposed framework is dynamic and uses current road traffic information to improve message delivery thereby making efficient use of data that has largely been ignored while helping to promote balance in the VANET.

This chapter presents a summary of the work done in this thesis, highlighting the major contributions of the research project. It will also present conclusions resulting from this work and some discussion on the direction for future research on this research theme.

7.1 Utilising Road Traffic Data for Network Wireless Mapping

In this research, road traffic data was used in a unique way to indicate how well a wireless network performs in an area. Several experiments were run for each road within the target scenario, and the delivery ratio for each route under certain road traffic conditions was logged. This is translated into how well the network is expected to perform under similar conditions on that particular road. The feasibility of this process is aided by the ability to obtain this road traffic data in several major cities as a product of traffic-related measurements, traffic management processes, etc. For example, road traffic data for the target scenario in Nottingham was obtained from both the SCOOT data and an EU project MODUM carried out in Nottingham. This research, therefore, shows a novel way of thinking about road traffic data which may otherwise serve no further purpose, in a way analogous to modern GPS techniques where the goodness of each road traffic wise is indicated on a map based on the number of vehicular participants and their speeds. Similarly, the network communication map is proposed to be downloaded Over-The-Air (OTA) where available as a vehicle enters a new area.

By implementing the proposed framework in a simulated realistic scenario based on Nottingham city road traffic data and geographical mapping information using SUMO and NS-3, traditional routing protocols such as AODV and DSDV were evaluated for network performance in routing messages between selected points. The outcome was that though messages can be transmitted between the chosen points, the lack of intelligence in the choice of routes based on current road traffic data can severely affect the efficiency, reliability and speed of message dissemination in VANETs due to unnecessary retransmissions, broadcast storms and hidden node issues. These issues have been mitigated in the proposed framework by applying algorithms for the decision making layer.

7.2 Message Delivery Efficiency

Packet delivery ratio and average end-to-end delay were employed as metrics of the proposed framework’s efficiency. Packet delivery ratio was a significant metric because it shows the success rate of messages being disseminated. In the evaluated scenario, FIMDEV showed better capability when compared against AODV and DSDV regardless of the number and speed of the nodes; it fared favourably under the same conditions. As expected, under certain environments such as an increased in the number of nodes and fast moving nodes, all protocols evaluated produced lower packet delivery ratios due to the network behaviour (dropped packets, disconnections and congestions), however, FIMDEV maintained its advantage over the other protocols by using a priori knowledge of what the current road traffic is and how that information translates to either a useable or poor wireless network performance. Hence, while in FIMDEV routes with a poor wireless condition can be avoided provided there are alternate routes exist, whereas other protocols with no intelligent decision-making algorithms may transmit into already congested areas.

Average end-to-end delay saw improvements in FIMDEV, the reason being that there was less contention for resources and unnecessary rebroadcasts that clog the wireless network was also limited. However, some delay was added to the system due to the need to transverse several algorithms and processes. Some discussion on direction of research to mitigate some added latency is found in the “Future Work” section below.

7.3 Summary of Work

7.3.1 Chapter 4 **Summary**

In this chapter, different road traffic and network factors affecting VANET operations were identified and described. It is seen that the number of factors can be substantial including the interactions of these factors. In other to determine what factors to consider in the design of the new framework, significant factors were identified using a 2^k analysis design of experiments.

From the analysis, the factors identified for consideration in the new framework are the number of vehicles in the network and the speed of the vehicles. These factors and their interactions had significant effects on the metric used as a response in the experiment (PDR). There are other factors whose effects are present but not significant enough to make a huge impact, such as message periodicity, transmission range, and size of the message being sent.

7.3.2 Chapter 5 Summary

In this chapter, a new holistic framework was proposed. The proposed framework (FIMDEV) sought to use vehicle sensor data and road traffic data in a unique way. Firstly, information from vehicles’ sensor data improves how efficient the message dissemination process is by providing the position of the vehicle relative to message sources and destinations. Secondly, road traffic data was discussed as an indication of how well the wireless network is expected to perform on a particular road by comparing the current road traffic data against pre-computed data which forms a wireless network map. These data are rich sources of information which when correctly used can improve the distribution of messages in a reliable, fair and efficient process in a VANET scenario

7.3.3 Chapter 6 Summary

The proposed framework FIMDEV was implemented and tested alongside standard protocols, AODV and DSDV, representing reactive and proactive protocols respectively. From the experiments conducted, using FIMDEV provided better network utilisation by improving the delivery ratio of packets and reducing the average delay in delivering those messages.

By using knowledge of the current road traffic (speed and number of vehicles) for each road, FIMDEV compares the current values against the prebuilt map in order to discover which routes have the best chance for message delivery (sweet spots). Upon this discovery, the framework ensure that messages are routed through the discovered paths between source and destination using a series of algorithms. FIMDEV, therefore, avoids network congested routes where possible, hence, ultimately improving the delivery of messages and reducing delay in transmission. While the evaluations conducted at 10 mph are generally good in the experiments for both AODV and DSDV, it can be seen that FIMDEV provides better solutions and it is more stable than AODV and DSDV. At 50 mph, there is a general reduction in the ability of the network to deliver messages because vehicles may move away from the transmission range of a sender before receiving messages, however, FIMDEV maintains its superiority by using the best routes

7.3 Future Work

Work proposed in this thesis indicates that message dissemination in VANETs can be improved upon and be afforded some reliability in destination delivery by implementing the FIMDEV scheme in an urban environment. As noted earlier, VANET is currently edged on by manufacturers and researchers and has several real-world applications. Though the implementation of research ideas in the real world is some way off, many of the tools and techniques described in this thesis are suggested in such a way as to limit the need for brand new infrastructure or methodology. For example, the vehicles themselves act as both the generators, consumer and transporter of (road traffic) data, the network is mostly envisaged to be self-organised and scalable. Vehicles can avail themselves of the proposed wireless network map indicated in this thesis through the use of Over the Air (OTA) downloads via the internet as currently provided through SIM cards in the vehicle. While this thesis shows that the proposed framework provides better performance, future research and investigation on to extend the work done in this thesis are:

- Extending factors not included in this thesis can be explored. An example of such a factor is obstacles and line of sight influences on message dissemination. This is an interesting factor to consider as propagation effects such as reflection can have both positive and negative effects on the message delivery. For example, a large SUV may very well reflect a weak signal towards a desirable destination and on the other hand, such a vehicle might block off important signals from arriving their destination.

- Extending the scenario covered by FIMDEV. To improve the overall reliability and capability of the framework, experiments to include data for highways might be included to cater for that type of scenario. Also, other transport participants such as (motor) cyclists with mobile devices might be integrated into the framework to increase chances of message dissemination especially in areas where some routes are only navigable by cyclists and pedestrians.

- Another research for future consideration is the ability to use data directly from sources such as Open Street Map and SCOOT through a dedicated platform. In this research, Open Street Map data used was first downloaded and processed for usage. By eliminating that step, it ensures that all vehicles with access to the internet will have up to date records necessary for proper processing. It can also be a stepping stone towards real world implementation through test beds.

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