Sudan University of Science and Technology

College of Graduate Studies

A simplified Cluster – Based Gateway Selection Scheme for Multi-hop Vehicular Networks

إختيار مشروع مبسط مبني على بوابة العنقود لشبكات المركبات عديدة المحطات

A Thesis

Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

in

Electronics Engineering

By

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Supervisor

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College of Graduate Studies

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إقرار

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إختيار مشروع مبسط مبني على بوابة العنقود لشبكات المركبات عديدة المحطات.

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اسم الدارس: أمل احمد الطاهر الفضل.

توقيع الدارس: أمل **التاريخ:** 3/4/2017.

قال تعالى:

سَبِّحِ {اسْمَ رَبِّكَ الأَعْلَى (١) الَّذِي خَلَقَ فَسَوَّى (٢) وَالَّذِي قَدَّرَ فَهَدَى (٣) وَالَّذِي أَخْرَجَ الْمَرْعَى (٤) فَجَعَلَهُ
غُثَاءً أَحْوَى (٥) سَنُقْرِئُكَ فَلاَ تَنسَى (٦) إِلاَّ مَا شَاءَ اللَّهُ إِنَّهُ يَعْلَمُ الْجَهْرَ وَمَا يَخْفَى (٧) وَنُيَسِّرُكَ لِلْيُسْرَى (٨)
فَذَكِّرْ إِن نَّفَعَتِ الذِّكْرَى (٩) سَيَذَّكَّرُ مَن يَخْشَى (١٠) وَيَتَجَنَّبُهَا الأَشْقَى (١١) الَّذِي يَصْلَى النَّارَ الْكُبْرَى (١٢) ثُمَّ
لاَ يَمُوتُ فِيهَا وَلاَ يَحْيَى (١٣) قَدْ أَفْلَحَ مَن تَزَكَّى (١٤) وَذَكَرَ اسْمَ رَبِّهِ فَصَلَّى (١٥) بَلْ تُؤْثِرُونَ الْحَيَاةَ الدُّنْيَا
وَالآخِرَةُ خَيْرٌ وَأَبْقَى (١٦) إِنَّ هَذَا لَفِي الصُّحُفِ الأُولَى (١٧) صُحُفِ إِبْرَاهِيمَ وَمُوسَى (١٨)} سورة
الأعلى.

Dedication

To my parents,

My sisters and my brothers.

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I sincerely thank **Dr. Rashid Abdelhaleem Saeed** for his valuable support during this work, his continuous guidance and all the fruitful discussion that laid the foundation of the research presented in this thesis.

Finally, a special thank goes to my family for supporting me throughout the thesis work.

ABSTRACT

An integration of Vehicular Ad-hoc Network (VANET) and cellular network, e.g. LTE is a promising architecture for future machine-to-machine applications. This integration helps vehicles to have steady internet connection through cellular network and at same time can communicate with each other. However, dead spot areas and unsuccessful handover processes, due to vehicles high speed, can disturb the implementation of this kind of architecture. In this thesis, a Simplified Cluster – Based Gateway Selection (SCGS) Scheme for Multi-hop Vehicular networks is proposed. The main aim of this research is to enhance the integration between VANET and cellular network and to extend coverage in areas where there is no coverage. An enhanced version of Hybrid Wireless Mesh Protocol (E-HWMP) is proposed where it is a combination of IEEE802.11p and IEEE802.11s for multi-hop vehicular networks. E-HWMP provide a tradeoff between reactive and proactive gateway discovery solutions " consists of adjusting the scope for the gateway advertisement". The basic idea behind hybrid routing protocol is to use proactive routing mechanism inside the coverage zone at a certain time while utilizing a reactive routing mechanism on demand. An integrated simulation environment combined of VanetMobiSim and NS2 is used to simulate and evaluate the proposed scheme. An analytical model is also derived which is implemented by Matlab to optimize the proposed scheme. Simulation results show that, E-HWMP protocol performed better than Ad-hoc on demand Distance Vector (AODV) routing protocol and Hybrid Wireless Mesh Protocol (HWMP) routing protocol. Furthermore, SCGS through E-HWMP is compared with other cluster-based gateway selection algorithms i.e. CMGM and SGS that used in other related works; the result shows that SCGS scheme through E-HWMP protocol outperform the other cluster- based gateway selection schemes in terms of connection delay, control packet overhead, packet delivery ratio and overall throughput. Finally, results from analytical model are compared to simulation results to validate the approach of this thesis. Both analytical and simulation results agreed that: connectivity probability increases as average vehicle density increases and increased average vehicle speed degrades connectivity.

المستخلص

التكامل بين العمارة المخصص لشبكة (VANET) والشبكة الخلوية، على سبيل المثال، LTE هي بنية واعدة لتطبيقات المركبات آلة إلى آلة في المستقبل. هذا التكامل يساعد المركبات على ان يكون لديها اتصال ثابت بالإنترنت من خلال الشبكة الخلوية، وفي الوقت نفسه يمكن التواصل مع غيرها من المركبات. ومع ذلك، فإن مناطق البقعة الميتة و فشل عمليات التحول نظراً لسرعة المركبات العالية يمكن أن يعرقل تنفيذ هذا النوع من الهندسة المعمارية. في هذه الأطروحة، يقترح خطة جديدة مبسطة لاختيار البوابة (SCGS) لمخطط ترحيل multi-hop في شبكة التكامل VANET-LTE. الهدف الرئيسي من هذا البحث هو تعزيز التكامل بين VANET والشبكة الخلوية، وتوسيع التغطية في المناطق التي لا توجد فيها تغطية، والحد من كمية من النفقات العامة، والحد من التأخير، ويزيد من نسبة تسليم الحزمة والرسائل. يقترح نسخة محسنة من HWMP هو مزيج من IEEE802.11p وIEEE802.11s للاتصالات بين المركبات (E-HWMP) ، يوفر E-HWMP المقايضة بين الحلول رد الفعل واستباقية اكتشاف البوابة ويتجاوز سلبيات بروتوكولات الهجين السابقة، والذي يتألف من تعديل النطاق للإعلان عن البوابة. الفكرة الأساسية وراء بروتوكولات التوجيه الهجينة هي استخدام آليات التوجيه استباقية في داخل منطقة التغطية في أوقات معينة و اليات وتوجيه رد الفعل عند الطلب. يستخدم بيئة محاكاة متكاملة جنبا إلى جنب من VanetMobiSim وNS2 لمحاكاة وتقييم الخطة المقترحة. ويستمد نموذجا تحليليا أيضا نُفذ بواسطة ال matlab لمصادقة الخطة المقترحة. وأظهرت النتائج أن المحاكاة، لبروتوكول E-HWMP أداء أفضل من المخصص على الطلب بروتوكول توجيه متجه المسافات (AODV). وعلاوة على ذلك، تم مقارنة E-HWMP مع خوارزمية اختيار بوابة القائم على نظام المجموعة الأخرى مثل , CMGM, SGS التي استخدمت فى الدراسات السابقة ذات الصلة؛ اظهرت نتائج المحاكاة ان بروتوكول E-HWMP يتفوق على مخططات اختيار بوابة أخرى من حيث تأخير الاتصال والتحكم حزمة النفقات العامة، نسبة تسليم الحزمة والإنتاجية الشاملة. وأخيرا، مقارنة نتائج المحاكاة و النموذج التحليلى أدى الى التحقق من صحة منهج هذه الأطروحة. على حد سواء اتفقت نتائج التحليل والمحاكاة أن: زيادة احتمال استمرار الاتصال بين المركبات مع تزايد متوسط كثافة المركبات وزيادة متوسط سرعة المركبات يحط الاتصال.

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LIST OF ABBREVIATIONS

2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project2
AGF	Advanced Greedy Forwarding
AODV	Ad hoc On-Demand Distance Vector
APs	Access Points
A-STAR	Anchor- based street and Traffic Aware Routing Protocol
AVC	Available Route Capacity
BST	Base Station Transceiver
C2C	Car-to-Car
CAR	Context-Aware Routing
CEDAR	Core Extraction Distributed Ad hoc Routing
CH	Cluster Head
CMGM	Multi-metric adaptive mobile Gateway Management mechanism
DO	Destination Only
DREAM	Distance Routing Effect Algorithm for Mobility
DSDV	Destination-Sequenced Distance Vector Routing Protocol
DSR	Dynamic source routing protocol
DSR	Destination Vehicle
DTN	Delay Tolerant Network
DV	Ad hoc On-Demand Distance Vector
E-HWMP	Enhanced Hybrid Wireless Mesh Protocol
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FMHR	Fastest Multi Hop Routing Scheme
GANN	Gateway Announcement
GPS	Global Position System
GPSR	Greedy Perimeter Stateless Routing Protocol
GREP	Gate Replay
GREQ	Gateway Requests
GSM	Global System of Mobile
GSR	Geographic source routing
GVs	Gateway Vehicles
GW	Gateway
GWC	Gateway Candidates
GyTAR	Greedy Traffic Aware Routing Protocol
HWMP	Hybrid Wireless Mesh Protocol
IV	Initial Vehicle
IVD's	Inter –Vehicles Distances
LAR	Location Aided Routing
LET	Link Expiration Time
LLT	Longer Link Lifetime
LS	LINK STABILITY

LTE	Long Term Evolution
MAC	Medium Access Control
MANET	Mobile adhoc Network
MERR	Message Error
MFR	Most Forward with r
MMMR	Multi-metric, Map-aware Routing Protocol
MOVE	Mobility Model Generator for Vehicular Network
MP	Mesh Point
MPR	Multipoint Relay
NAM	Network Animator
NFP	Nearest with forward progress
NHV	Next Hop Vehicle
NS2	Network Simulators Version 2
OLSR	Optimized Link State Routing Protocol
PBR	Prediction Based Routing Protocol
PGB	Preferred Group Broadcasting
P-GW	Packet Data Network Gateway
QoS	Quality-of-Service (QoS)
RANN	Rout Announcement
RErr	Route Error
RET	Route Expiration Time
RLC	Reactive location Service
RRep	Route Reply
RReq	Route Request Message
RSS	Received Signal Strength
RSU	Road Side Units
SAW	Simple Additive Weighting Techniques
SGS	Simplified gateway selection
S-GW	Serving Gateway
SUMO	Simulation of Urban Mobility
TTL	Time-to-Live
UMTS	Universal Mobile Telecommunications System
V2I	Vehicle – to – Infrastructure
V2V	Vehicle – to – Vehicle
V2VR	Vehicle to Vehicle Relay scheme
VANET	Vehicular Ad-hoc Network
WAVE	Wireless Access for Vehicular Environment
ZRP	Zone Routing Protocol

CHAPTER ONE

Introduction

1.1 Introduction

Along with the ongoing advances in dedicated short-range communication and wireless technologies, inter-vehicular communication and road–vehicle communication have become possible, giving birth to a new network-type called Vehicular Ad-hoc Network (VANET). The VANETs aim to improve road safety and transportation efficiency, as well as to reduce the impact of transportation on environment. Vehicle communication networks are formed by connecting devices inside public and private vehicles with each other (vehicle–to–vehicle communications) and with fixed communication infrastructure (vehicle–to–infrastructure communication). Providing internet access to devices (end users) in vehicles enables various applications in safety and emergency warning, traffic management and entertainment. The key role that VANETs can play in the realization of intelligent transport systems has attracted the attention of major car manufacturers. Heterogeneous wireless network is the one of the hot research topics in wireless domain. Recent research in wireless networking has been focusing upon the heterogeneous integration of IEEE 802.11-based wireless ad hoc networks with 3GPP cellular networks [124]. The 3GPP cellular networks such as Universal Mobile Telecommunications System (UMTS), are predominantly used for wide-area wireless data and voice services via access to a Base Station Transceiver (BST), also referred to as UMTS Node B. On the other hand, VANETs are used for short range, high-speed communication among nearby vehicles, and between vehicles and roadside infrastructure units. Vehicle to- Vehicle (V2V) communication supports services such as car collision avoidance and road safety by exchanging warning messages across vehicles.

The major weakness of IEEE 802.11 radio is its very limited transmission range which is typically 200-300 meters [1, 132]. In order to cover the wide area, a large number of access point is needed which results in high deployment cost. From this it is understood that the better solution is to use a small number of access points (Aps) along the roadside and form an ad-hoc network among vehicles and apply a relay mechanism to forward the packets for vehicles outside of the AP range or to integrate VANET to the network that can provide high coverage range (i.e. cellular network) in order to reduce the number of access points and the switching process from one access point to another.

The unique characteristics of VANET are the high mobility and rapidly changing network topology caused by the high travelling speed of the nodes; the constrained pattern due to the restricted roads; limitations of bandwidth due to the absence of a central coordinator that controls and manages communications between nodes; disconnection problems owing to the frequent fragmentation in the networks and signal fading caused by objects that form obstacles between the communicating nodes.

Consequently, the main challenges facing VANET are to decide upon the routing protocol that should be used to control the process of forwarding packets through nodes on the network; determining how to select the next-hop node to use to forward packets to their final destination, particularly in a sparse environment, depending on the presence of the unique characteristics of VANET. Therefore, providing a robust routing protocol is considered to be the most crucial solution in VANET [5]. This involves using new parameters to take the decisions regarding selecting the next-hop node to enhance the efficiency of the routing process and increase performance. As a result it is anticipated that designing an efficient routing protocol will aid in accomplishing the task of delivering packets to their destinations in VANET via a more realistic method, which promises to apply road safety efficiently.

VANET is a specific circumstance of MANET. Many routing techniques have been designed in MANET to tackle the limitations with transmission packet delivery delay, involving packets being dropped, wasting bandwidth, mobility and security. These techniques could not be appended to VANET owing to its particular characteristics, such as the restricted mobility pattern.

It is observed that frequencies network disruption is one of the main problems in VANET network. Many researchers in this area have proposed some solutions in order to eradicate this problem. However, since VANET involves vehicles moving in a very high speed with limited coverage area of IEEE 802.11, lack of high technology makes it difficult for such kind of network to have stable connection especially in the rural area where by the network coverage is quite low.

1.2 Related Works

Integration of VANET to cellular network is one of the current issues which attracts the attention of many researchers. Some researchers [2], [3], [4], [7] proposed architecture of integrating ad hoc network to the internet. In [4] author designs scheme which can enable mobile ad hoc network (MANET) to connect to UMTS network, while in [3] and [7] authors integrate the vehicular ad hoc network to the UMTS network. In [7] a prediction-based routing (PBR) protocol is proposed specifically for mobile gateway. This protocol takes the advantage of the predictable mobility pattern of the vehicles on highways. The protocol allows the vehicles which have both WLAN and WWAN interfaces to act as mobile gateway and the normal vehicles contained only WLAN interface to use that mobile gateway to connect to Internet. In [3] a Cluster-based Multi-metric, adaptive mobile Gateway Management mechanism (CMGM) was presented. The cluster scheme utilized to cluster GWc was based on the direction of movement, UMTS-RSS and IEEE 802.11p transmission ranges. If the GWc were closest to the middle of the cluster then CH was elected in a cluster. However, the suggested mechanism in [3] was complex in terms of preserving the clusters for the fast-moving environment such as in VANET. In addition, the process of selecting the CH depends mainly on the geographical location of the vehicle. The result showed that the CH did not have the basic criteria for managing the cluster and enabling them to connect to the cellular network. In addition, the process of forming a cluster and the selection of the CH consumed more time compared with data exchange time. The proposed mechanism stated in [2], Simplified Gateway Selection (SGS) Scheme enabled vehicles to connect to Internet and other mobile services continuously, it described two types of vehicles: vehicles within the coverage area had a dual interface and communicated directly to the UMTS base station transceiver. Through UTRAN and vehicles that move along the road looking for an associate to be used to connect to the UMTS base station transceiver had a single interface. Vehicles received different signals from the base station transceiver. This mechanism showed lower reliability in terms of availability. In addition, the researcher did not take into account the propagation delay between the relay request message and the relay response message.

All these works take the advantage of coverage area offered by UMTS and high data rate obtained from IEEE 802.11 technology and combined together to form a heterogeneous powerful network where a stable and high data rate network is guaranteed. However, all these works involve a lot of control packet overhead and it is limited by the speed of the mobile node.

Thus, the deficient which exists in this technology makes the entire features have many open issues that need further investigation in order to enhance this technology.

1.3 Problem Statement

It cannot be denied that the current integration of VANET and cellular network is the one of the most interesting research topics. This is due to the limitation of the IEEE 802.11 technology in terms of the covered area. Integrating the advantage of high data rate offered by IEEE 802.11 with the wide coverage area of 4G network i.e. LTE, makes it promising architecture in the future of vehicular communication. VANET-LTE integration enables travellers on the road to enjoy games, multimedia streaming and other internet applications with limited connection disruption. Additionally, many different types of data need to be transmitted, and messages will be subject to both delay-intolerant and delay-tolerant. For example, safety messages demand high reliability and low delay, whereas non vital road and weather information will be tolerant to longer delays. These different data types tailored specific vehicular network architecture, which can be achieved by a clustered network.

Many clusters mechanisms have been proposed for vehicular ad hoc network [2], [3], [7], in an attempt to select a few number of vehicles to act as mobile gateway to connect with UMTS network. However, it was noted that this solution is not feasible in terms of cost and availability. In addition, due to dynamic nature of VANET network, it is difficult to maintain connections to mobile gateway. Formation and maintenance of clusters bring extra overhead and involve many control packets which causes consumption of bandwidth to sustain the connection of the vehicle to UMTS network.

Stable and effective cluster mechanism may add more stable connection on VANET. However, lack of stable clustering " in previous work" means that a lot of vehicles will not benefit from internet applications,

The main focus in this research will be at the boarder of the cellular network where the network quality starts to degrade. At the boarder of cellular network much interest will be given on providing an end to end solution by using gateway mechanism to assist other vehicles which are out of coverage and to connect to the cellular network in multi hop manner. This can be done by Simplified Cluster–Based Gateway Selection (SCGS) Scheme.

1.4 Proposed Solution

Therefore, it is an acceptable fact that there is a need for enhance the existing solutions by enabling a relay (mobile gateway) mechanism to take place at certain point at the boarder of cellular network coverage. This work is proposed to create a Simplified Cluster – Based Gateway Selection (SCGS) Scheme for Multi-hop Vehicular Communications. The clusters are formulated only at LTE cell edges which possesses excellent cluster stability, because it done by using received signal strength (RSS) threshold as a cluster formation indicator. The strong part of the SCGS scheme it allows the vehicle to form cluster only at the boarder of LTE cell when the GW observed its LTE-RSS near to fall below specific threshold, at this time a cluster formulated and anew gateway elected according to the proposed algorithm of selecting the best gateway. The scheme is achieved by utilizing a new routing protocol called An Enhanced Hybrid Wireless Mesh Protocol (E-HWMP). This enhancement can be utilized to reduce the overhead inside the 3GPP coverage zone, to extend the network coverage outside the 3GPP coverage area and to reduce delay metrics. This can be done by Simplified Cluster – Based Gateway Selection (SCGS) Scheme that uses proactive routing mechanism in intra-cluster at a certain time while utilizing reactive routing for enter the cluster.

1.5 Aim and Objectives

The main aim of this research is to enhance integration of VANET and cellular network in a way that extends the coverage in dead spot areas, reduces the amount of overhead cost, reduces delay metrics and increases the packet delivery ratio.

The specific objectives of this research are:

1. To design "end to end" multi-hop scheme to extend the coverage of VANET network.

2. To develop a new cluster-based gateway (cluster head) selection algorithm for VANET-LTE communication.

3. To design an Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) Protocol for cluster-based multi-hop Vehicular Communications.

4. To develop a mathematical model with iterative method.

5. To evaluate the proposed scheme under multi-metric design parameters for overall throughput.

1.6 Methodology

This thesis adopts the following research methodology, in order to achieve the predetermined objectives.

The First Phase involves a study through the literature on vehicular ad hoc network architecture, protocol being used and the existing algorithm used to connect vehicular ad hoc network to the infrastructure network. Generally, this phase involves the essence of building the basic knowledge of the VANET network together with narrowing down the research scope.

The Second Phase of this research is based on designing and developing the scheme which can be used to extend the coverage area in VANET to infrastructure network. This scheme was based on multi-hop communication and used a mobile gateway to help other vehicles to connect to the infrastructure network.

In the Third Phase, the most popular and efficient network simulation tool, namely NS2.35, was selected. Vehicular mobility generator VanetMobiSim, was to simulate VANET scenario and the proposed scheme will be implemented and tested in these tools in order to study its performance. Results obtained from the simulation will be compared with the existing scheme and the mathematical model with iterative method will be compared with the simulation.

1.7Thesis Outlines

The Thesis deals with an Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) Protocol for Multi-hop Vehicular Communications. It comprises seven chapters. Chapter 1 gives a brief introduction to the research. Chapter 2 includes VANET overview, provides an overview of routing protocol in VANET, presents a classification of routing protocol in VANET and presents the related works. Chapter 3 presents and describes the main aspects of the proposed “end to end” multi-hop mechanism, presents and describes the main aspects of the proposed E-HWMP mechanism. Chapter 4 describes the simulation system, the simulation tools, scenarios and simulation setup. Chapter 5 describes system model and analyzes the network connectivity. Chapter 6 presents, analyzes and discusses the simulation results and the analytical results. Finally, Chapter 7 concludes the research with some recommendations for future work.

CHAPTER TWO

Literature Review

2.1 Introduction

This section discusses in brief the basic parts of vehicular ad hoc networks (VANET). In recent years, the number of vehicles increases rapidly and continuously on roads, resulting in road saturation and lack of attention by drivers. It is hard to keep safe distance and restrict speed between vehicles, which has led to increasing challenges and dangers faced by drivers. The efforts of automobile manufacturers with national government agencies have been gathered to develop solutions aimed at assisting in enhancing driver behavior on the roads by predicting accidents or avoiding bad traffic areas. This combined effort has resulted in the employment of a novel type of wireless access called Wireless Access for Vehicular Environment (WAVE), which was dedicated to vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communications. Figure 2.1 shows difference scenarios of vehicle to infrastructure communication(V2I) which are responsible for connecting vehicles to the outside world (Internet) and V2V communication used for exchanging information among vehicles [8, 9, 125].

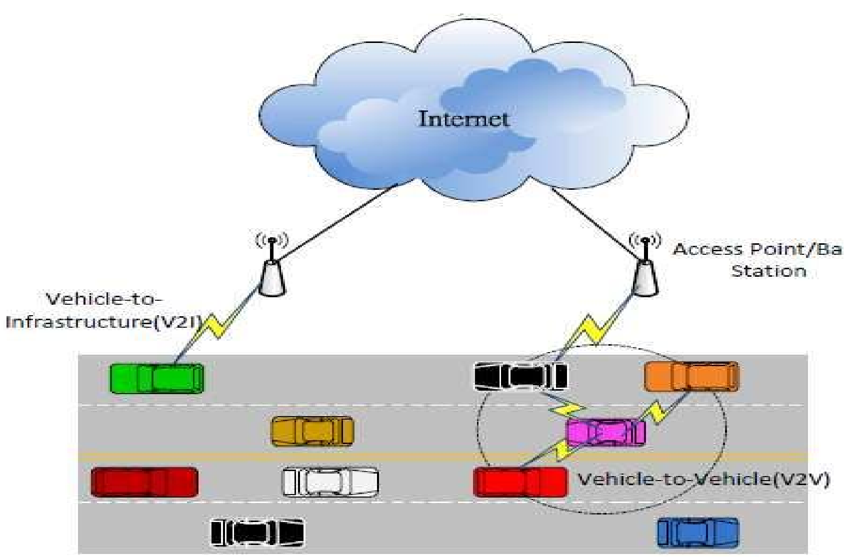

Figure 2.1: IVC and RVC in VANET scenario [8]

While the main goal has clearly been to improve vehicular traffic safety issues, it has introduced traffic management solutions in addition to the on-board entertainment and information applications, such as internet access and gaming [10, 127, 135].

A VANET enables vehicles to create a self-organized wireless network among them on an as-needed basis. However, to establish a successful communication, an efficient path must be initiated to deliver the packet to its destination. This can be accomplished by designing an efficient routing protocol. To contribute in a VANET, transceivers and computerized control modules need to exist in the vehicles that provide them with the ability to communicate as network nodes. The range of each vehicle's wireless network may not exceed more than a few hundred meters; thus satisfying "end-to-end" communication over many miles needs messages to trip through several intermediate nodes. It is not vital to have a network infrastructure to create a VANET, although Road Side Units (RSU) may need to use a fixed network. These roadside units extend the use of many services for vehicular networks. Mobility is the main characteristic of most nodes in VANET.

Vehicle movement is generally restricted to a plan of roadways , because of the constrained mobility pattern,; they have a distinct controlled mobility pattern that is subject to vehicular traffic regulations. In urban areas, high buildings and other obstacles between roads act as gaps to radio communication. Therefore it is necessary to communication over roads. In general, the speed of vehicles is higher than that in other MANET nodes. Vehicles moving in the same direction and generally having the same speed can maintain a fixed gap between them. For that reason they keep contact with one another for much longer periods of time than with vehicles moving in different directions [11].

It is an acceptable fact that VANET is a new emerging field of research where many industries and academies spent significant amounts of time and resources to invest in, study, deploy, and test the technology. There are several ongoing research activities, projects and consortia that are currently working on deploying the said technology. Concerning with, VANET network most of the projects and researches are conducted in USA, Japan, and Europe.

2.1.1 VANET Characteristics

It can be observed that, VANET is subclass of MANET in which nodes in MANET are acting like vehicles or road side unit in VANET. However, it is noted that VANET possesses some unique characteristics which differentiate itself from MANET. Besides, node mobility is the main parameter that differentiates VANET from MANET. In VANET [8] and [9], vehicle mobility is governed by driver behavior, road restriction and the number of vehicles in the road (congestion time lower speed). In addition, this uniqueness of VANET forces the researchers to use different ways of thinking when they design and make decision on this kind of network. Some of the characteristics of VANET include:

- Rapid Changes of VANET Network Topology

Vehicles speed is the main factor which influences the network topology. In VANET, vehicles are moving in a very high speed which results a high dynamic network topology which is very difficult to manage. In addition, network topology could be affected by the response of the driver after receiving messages (i.e. congestion, accident alert etc.). This means that the content of messages can change the network topology.

- Frequent Network Disconnection

VANET network is subject to frequency of network disconnection which making it unreliable due to high packet loss caused by rapidly movement of vehicles.

- Power is not a Problem in VANET

In VANET, the power of the device is not a significant constraint to deploy the network. However, in MANET, sensor and other mobile devices have limited battery life which confines the efficient implementation of MANET network.

- The Network Density is Variable in VANET

This variation is due to the fact that the network density is subjected to vehicular density during the rush hours especially at the major cities where once the vehicular density is higher, the network density will also be higher. Conversely, it can be lower in the area of low traffic highway environments.

2.1.2 VANET Applications

The VANET application can be classified into three categories: 1) safety application, Figure 2.2 shows propagation of accident occurrence and alert other vehicles to slow down or change their lanes. 2) Traffic control application, Figure 2.3 shows congestion avoidance in VANET. 3) Infotainment application. However, the main aim of VANET is to provide safety for the vehicles on the road and controls traffic by providing on-time critical information for both vehicle and driver. In addition, VANET network can also make travel be comfortable and enjoyable by allowing the passengers on board to continue communicate to the outside world (Internet) or to communicate with other passengers in other vehicles. In this section, existing potential VANET applications are discussed and briefly examined.

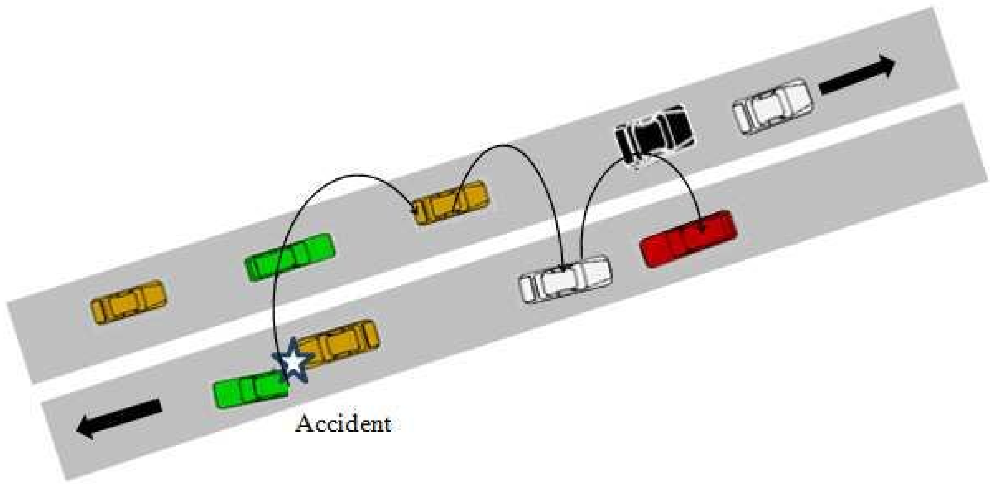

Figure 2.2: Propagation of Accident Occurrence and Alert other Vehicles to Slow down or Change their Lanes [9]

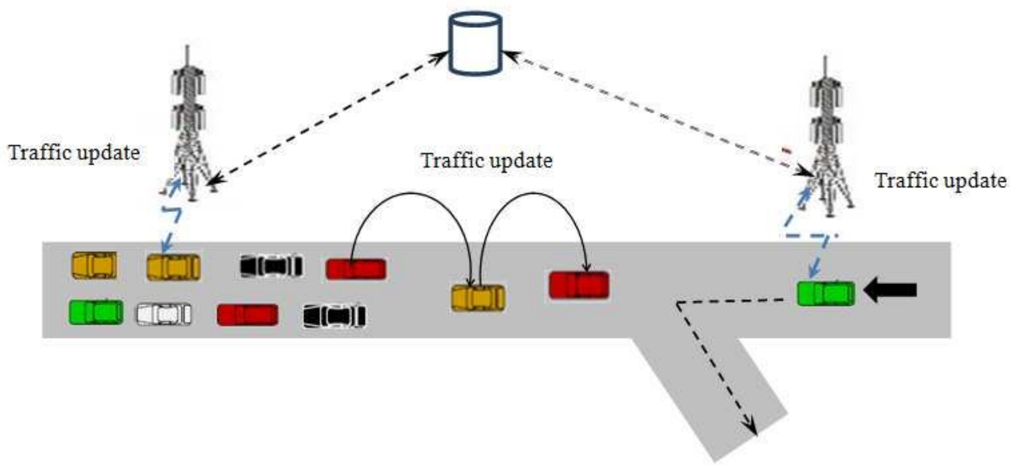

Figure 2.3: Congestion Avoidance in VANET [9]

2.1.3 VANET Routing Challenges

Analyses of traditional routing protocols for MANETs demonstrated that their performance is poor in VANETs [12]. The main problem with these protocols (e.g.,

[13]) in VANETs environments is their route instability, which leads to packets drops, increased overhead from route repairs, low delivery ratios and high transmission delays. An alternative routing approach is offered by geographical routing protocols (e.g., GPSR [14]), which decouple forwarding from the nodes identity. They do not establish routes, but use the position of the destination and the position of the neighbor nodes to forward data. Any node ensuring progress toward the destination can be used for forwarding. Yet, it runs the risk of packets being dropped at dead end streets because no consideration is given to the roads layouts.

2.1.4 Difference between MANET and VANET

The Mobile ad hoc network (MANET) technology consists of a set of self-organized wireless mobile devices which are capable to communication with each other, in the absence of base stations. Vehicular ad hoc network (VANET) is a subgroup of MANET in which all devices are vehicles including cars, buses, trucks or motorcycles. The main characteristic of both MANET and VANET are self-organization and movement. On the other hand, they differ in some ways. These are [15]:

- There are not any movement patterns for nodes in MANET, but the movement in VANET is limited by road elements, for example road design, traffic policy etc.
- The major advantage of limited movement in VANET is that it can be supported by some fixed station. These stations can provide some services for vehicles, for example access to the Internet, and real-time traffic information .
- Although VANET is a subgroup of MANET, the routing protocols which developed in MANET are not feasible with VANET .

2.1.5 MANET Routing Protocols are not Suitable for VANET Scenarios

Here, this section shows how the routing protocols in MANET is not suitable to be applied in VANET, owing to the difference that exists between the two types. The reasons for that can be summarized as follows [16]:

- Scalability: a limited number of nodes (1-2 hundred) can be served by the routing protocols designed for MANET. These protocols compute the path used by a mechanism, which is considered to be very costly for a widely distributed network like VANET. It is not feasible to store routes to other nodes in the network, as in reactive and proactive routing protocols.
- Full Connectivity: in VANET, when the sending node transmits the packet to its destination, a chance of delay is possible with the Delay Tolerant Network (DTN), owing to the changing of vehicle position (high mobility). In other words, the path to the destination is not specified.
- Mobility Pattern: in VANET, the sending node has an idea about the mobility pattern which is represented by the restricted vehicle's movement by the road topology, speed limit and traffic signals. This consideration does not exist in MANET; instead it assumes an arbitrary pattern which is not efficient for mobility patterns as in VANET.
- Disconnected Path: in VANET, the link breakage can be avoided with the aid of the mobility pattern knowledge for neighboring nodes. In contrast, this information is not available for the MANET routing protocols; instead, MANET uses either the periodic messages or path creation periodically to conduct the problem of path breakages.
- Flooding Operation: the flooding operation is considered to be the basis operation in MANET, as in reactive routing protocols where the route to the destination is specified by using the flooding operation. However, in proactive routing protocols, messages are sent periodically. As a result of using the flooding operation, bandwidth is greatly wasted in this operation and reduces the network performance, especially in large networks with a huge number of nodes, as in VANET.
- Non-local Function: the distributed nature of MANET requires that all nodes participate in the operation of routing path establishment and maintenances, to create a routing table in proactive routing protocols and contribute in performing the primary flooding needs. In contrast, VANET requires the localization routing solution to collect information from their neighbor nodes to deal with overheads and scalability, and to gain flexibility regarding the network conditions.

- Using Supported Knowledge: on-board units have the ability to provide vehicles with useful information that improves the performance of the routing protocols, such as the predicted path, velocity, direction, and road topology in digital maps. However, routing protocols in MANET are not supported with this information.

2.1.6 Routing Protocols in VANET

Routing protocols in VANET can be classified into two major categories: topology-based routing protocols and geographic-based routing protocols, as shown in Figure 2.4 [19]. In topology-based routing, packets are forwarded using available knowledge about links that connect nodes in the network. However, geographic routing utilizes the location information of its neighbor's nodes to complete the process of packet forwarding.

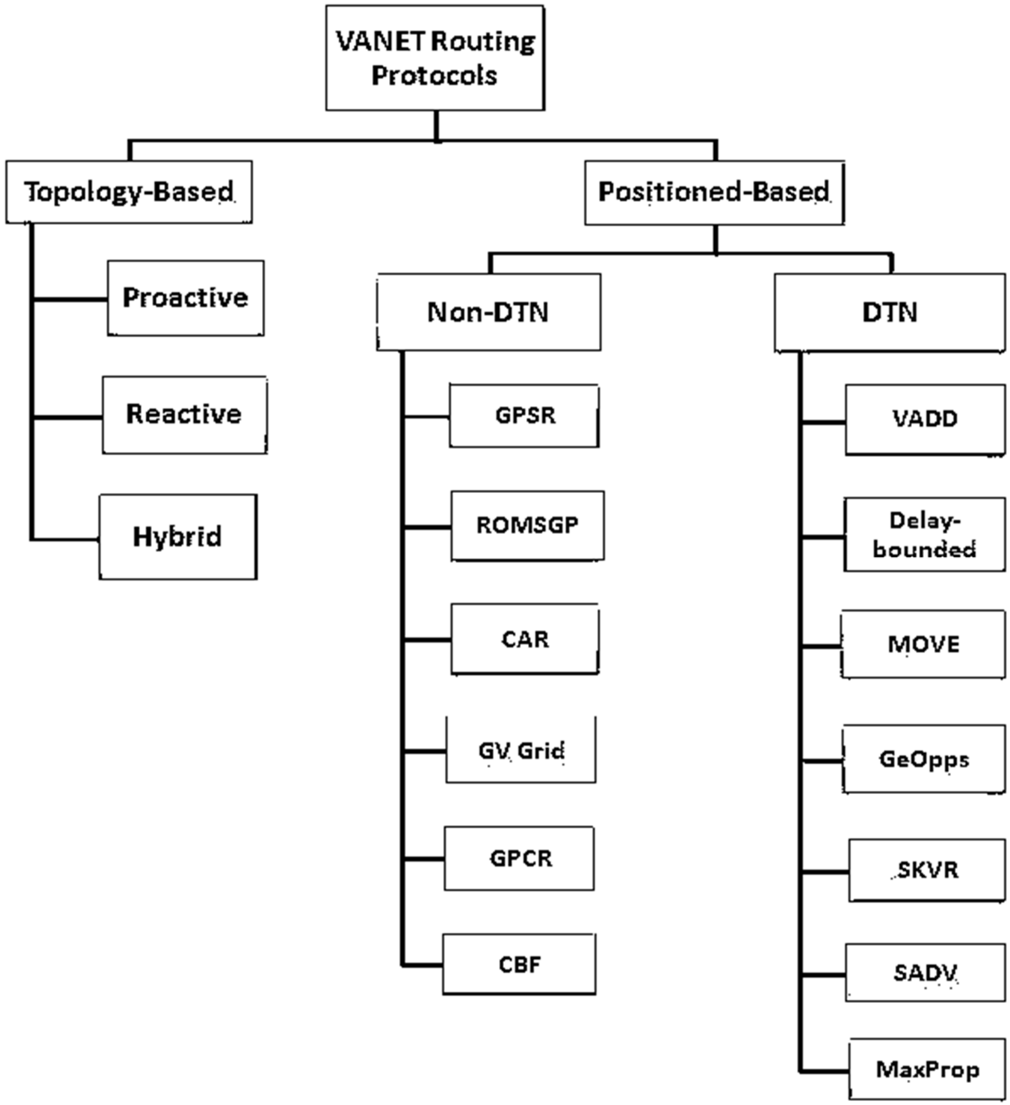

Figure 2.4: Classification of Various Routing Protocol in VANET [19]

2.1.6.1 Topology-based Routing Protocols

This type of routing protocol is considered to be a conventional routing protocol. The link's information is the basis on the process of taking the decision to forward the packet. It can be generally classified into different three categories based on routing strategy: proactive routing protocols (periodic), reactive (on-demand) and hybrid [17], [18] and [19].

A. Proactive Routing Protocols

As stated earlier, proactive routing protocols maintain routes to all destinations, regardless of whether or not these routes are needed. In order to maintain correct route information, a node must periodically send control messages. Therefore, proactive routing protocols may waste bandwidth since control messages are sent out unnecessarily when there is no data traffic. The main advantage of this category of protocols is that hosts can quickly obtain route information and quickly establish a session. Several proactive routing protocols have been implemented depending on the kind of route information stored on node's tables as well as the used updating method. The most representative are Destination-Sequenced Distance Vector (DSDV) [20] and Adaptive Distance Vector (ADV) [21].

B. Reactive Routing Protocols (On-Demand)

This category of routing protocols is also called on-demand routing protocols. Dynamic topology is considered to be the major feature of mobile ad hoc networks, especially for vehicle ad hoc networks. Therefore, regular updates of the global topology information are essential at each node in order to chase the topology changes. This, however, consumes extensive bandwidth. To complicate matters further, the expiration of the updated received routing information before this information is sometimes necessary. In this situation, waste in a bandwidth may occur. The concept of reactive or on-demand routing protocol has been proposed by Johnson [22] in order to reduce the unnecessary routing information updates and the amount of bandwidth consumed.

Unlike proactive routing protocols, as a replacement for keeping the network topology information and route to each destination of the network, On-demand routing protocols [23] establish the necessary routes when required (on demand) by the source, by using the process of route discovery. Generally, when source S needs a route, a Route Request (RREQ) packet is triggered and floods it into the network to build a route to the required destination, D. A Route Reply (RREP) packet is then sent back by D to S, when D receives the RREQ. If the route request has travelled through bi-directional links, RREP is sent using link reversal, or by piggybacking the route in a route reply packet via flooding. The main functions of a routing algorithm in on-demand routing protocols are route discovery and route maintenance.

Reactive routing protocols involve high delay for route establishment during the route discovery phase. Depending on how the routing method is implemented, reactive routing protocols can be divided into source routing protocols and hop-by-hop or point-to-point protocols.

- **Source Routing Protocols**

In source routing protocols every data packet carries the whole path information in its header. Before a source node sends data packets, it must know the total path to the destination, that is, all addresses of nodes which compose the path from source to destination. There is no need that intermediate nodes update their routing tables, since they forward only data packets according to the header information. However, it entails scalability problems since as the number of hops increases, the path information every data packet must carry become major and it may waste bandwidth. Moreover, the path is established from the source node so that a bad adaptation to quickly topology changes will be performed.

The most representative source routing protocol is DSR (Dynamic Source Routing) [24].

- **Hop-by-Hop Routing Protocols**

Hop-by-hop routing protocols try to improve performance by keeping the routing information in each node. Every data packet does not include the whole path information any more. On the contrary they only include the address of the following node where data packet must be forwarded to get the destination as well as the destination address. Every intermediate node must look up its own routing table to forward the data packets to its destination, so that the route is calculated hop by hop. Hop-by-hop routing protocols save bandwidth and performs well in a large network since a data packet does not carry the whole path information. However, intermediate nodes must update their routing tables.

The most representative hop-by-hop routing protocol is Ad hoc On-demand Distance Vector (AODV) [25].

Ad hoc On-Demand Distance Vector (AODV) : AODV is a reactive routing protocol for mobile ad hoc network and other wireless ad hoc network [13]. It is reactive in nature which means it establishes a route to the destination only when a node needs a route for sending packets to a destination. AODV uses route requests (RREQ), route replies (RREP) and route error (RERR) messages for route discovery and maintenance. RREQ contains source and destination address to identify the nodes demand to communicate. It also contained source and destination sequence numbers which are used to make sure that the routes are updated. In addition, RREQ contains broadcast ID and counter which count how many times RREQ has been generated from specific node. Moreover, AODV ensures loop-free routes by counting the sequence numbers [6] that is determining route freshness. This mechanism and the other important mechanisms, which help us to better understand AODV, are described in the coming sections. Figure 2.7 shows Example of AODV Protocol Routing Table**.**

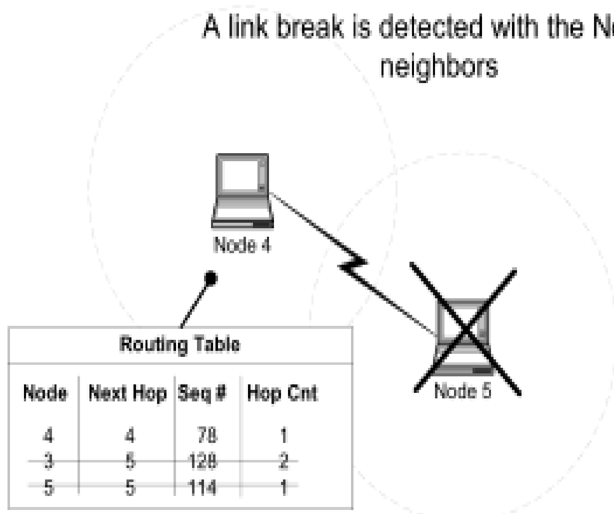

Figure 2.5 Example of AODV Protocol Routing Table [6]

- **Routing Discovery Procedure :** When an originating node requests a route to a destination not being selected before and there is no existing route to that destination, the originating node will broadcast an RREQ message to its neighbors. After receiving an RREQ message, if the RREQ has a greater sequence number or has the same sequence number with fewer hops compared to the destination, then the neighbor nodes will update their information. Moreover, the neighbor nodes will establish a reveres route entry for the originating node in their routing table. If the RREQ message does not have either a bigger sequence number or the same sequence number with the fewer hopes, then it will be discarded [70]. Afterwards, an RREP will be sent if one of these conditions will be satisfied: the neighbor is the destination or it has a fresher (unexpired) route to the destination [71]. Otherwise, an intermediate node will broadcast the RREQ message.

- **Route Maintenance:** Whenever a link of an active route breaks, all routes that are using this broken link will be invalidated by the node upstream of the break. The node will broadcast an RERR message to all of its neighbors. Each RERR massage maintains the unreachable IP addresses of destinations. After receiving an RRER, each node monitors its routing table in order to find out if there are route(s) to these unreachable destinations. If yes, it will be invalidated and afterwards a new route error (RERR) will be disseminated [71]. At the end of this process, the originating node will get an RRER message and it will invalidate the unreachable route(s), and if it is needed a new RREQ message will be initiated. Figure 2.8 shows AODV Protocol Messages

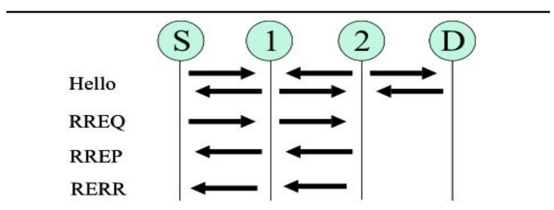

Figure 2.6 AODV Protocol Messages [71]

C. Hybrid

The hybrid routing protocols are a class that uses a combination of both reactive and proactive routing protocols. In this type of protocol, the network scalability is increased by forming a near zone by the close nodes which work together to reduce the route discovery overheads by proactively maintaining routes to nearby nodes, and using a reactive strategy to determine routes to far away nodes. Most hybrid protocols proposed to date are zone-based, which means that the network is partitioned or seen as a number of zones by each node. In protocols belonging to this category, each given node partitions the area of the network into two distinct regions.

The nodes in near distance from the node, or inside a particular geographical region, form the routing zone of the given node. In the routing zone, a proactive (table driven) approach is used. An on-demand routing approach is used for nodes located in the area beyond the routing zone. The most typical hybrid routing protocols are Zone Routing Protocol (ZRP) [26] and Core Extraction Distributed Ad hoc Routing (CEDAR) algorithm [27]. The latter selects a minimum set of nodes as a core to perform QoS route computations.

2.1.6.2 Position- based Routing Protocol

Position-based routing protocol seems to be a promising solution of routing in VANET [28]. Firstly, no routing tables are stored in nodes. The node only uses the position information of nodes to deliver the packet to the destination. Nowadays the Global Positioning System (GPS) is widely used. Therefore, the vehicles will use GPS to know its location and direction which can solve the problem of location awareness that is required by position-based protocols. Secondly, position-based routing does not involve many control packets that are mostly used in reactive and proactive routing. This implies that, the protocol overhead is lower compared to topology-based routing protocols (reactive and proactive ones).

2.1.6.3 Cross-layer-based Routing Protocols

Cross-layer approach is an ‘escape’ from the Open Systems Interconnection (OSI) model, which applies virtually strict boundaries between the layers, data are kept within a given layer. Protocol architectures follow strict layering principles, which ensure interoperability, fast deployment, and efficient implementations. However, lack of coordination between layers limits the performance of such architectures due to the specific challenges posed by wireless nature of the transmission links. Cross-layer solutions remove such strict boundaries to allow communication between layers. Its core idea is not to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers [130].

There have been a large number of proposals for cross-layer design in wireless networks. However, the definition of cross-layer is often ambiguous and inconsistent due to many interpretations. At a high-level, the cross-layer design refers to a protocol design that exploits the dependency between protocol layers to achieve desirable performance gains. The designs can be classified based on how the information is exchanged between layers. In [29], authors showed that cross-layer optimization can be done via four different approaches. The pictorial demonstration of these approaches is shown in Figure 2.5, and their details are briefly presented below.

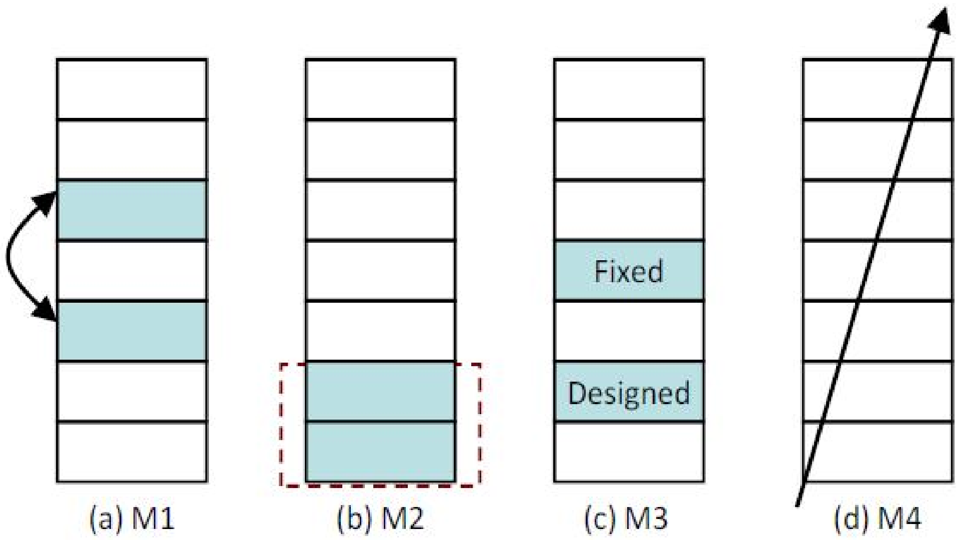

Figure 2.7: Cross-layer Design Approaches [29]

- M1: Information flow with new interfaces: In a traditional layered structure, protocols in each layer operate in a modular fashion to optimize their own set of variables. In contrast, this class of cross-layer designs promotes the information flow between layers via specialized interfaces.
- M2: Merging of adjacent layers: According to this strategy, the service and functionalities of adjacent layers are combined to form a single layer called super layer. Since the layers are combined, joint optimization can be done directly on the super layer as if people are building a single large uniform protocol.
- M3: Design coupling without new interfaces: In this strategy, multiple layers are designed in a collaborative manner. Scientists design one layer by looking at the functionality in another layer, thereby creating a dependency even at the time of designing. The referenced layer is called fixed layer (FL)

and the other layer is called designed layer (DL). Since DL is built based on FL, there is no need for an explicit interface between them.

- M4: Vertical calibration across layers: This strategy refers to adjusting parameters that span multiple layers in the stack. Since the performance seen at the level of application depends on the parameter settings of all downstream layers, it is often desirable to jointly optimize the parameters from all downstream layers

This section summarizes the research that has been done so far in designing cross-layer solutions for VANETs. Existing works are categorized into different sections based on the type of interactions that the protocols demand.

A. Cross-layer Design for PHY-MAC Layers

Physical layer (PHY) links several vehicles within the transmission range through the wireless channel. Wireless communication at PHY layer in VANETs is severely affected by time and space varying channel properties due to the vehicle movement and environmental obstacles. Thus, many cross-layer solutions provide ability for PHY layer to observe the channel condition and to opportunistically transmit messages when current channel condition is good. The channel condition not only affects the transmitting ability but it is also affects the receiving ability of vehicles. Thus there is a number of existing solutions that are based on signal strength measuring at the receivers [30, 31,32]. VFHS is an example of PHY-MAC protocol that can help in reducing delay of handover process and RPB-MACn can be used for collision-free multi-hop communication.

B. Cross-layer Design of PHY-MAC-Network Layers

Due to high mobility of VANETs, the wireless link between two vehicles is short-lived. The channel quality information from physical layer helps the sender in predicting the link connection time, subsequently the sender can find a new receiver before the current link is disconnected. Thus cross-layer interaction between physical layers and higher layers is desirable to maintain link connectivity and improve system performance. Signal Strength Assessment Based Route Selection for OLSR (SBRS-OLSR) [33] is an example of PHY-MAC-Network protocol based on existing OLSR.

C. Cross-layer Design of Network-MAC Layers

One of the foremost challenges in vehicular networks is to design protocols that can handle the high mobility of vehicles and constant changes in the underlying topology. The routing protocols must deal with frequent changes in the routing topology and maintain link stability between vehicles. If the route is disconnected, a new route must be discovered instantly. In order to effectively maintain the route information in such dynamic networks, most routing protocols rely on geographic information as opposed to address-based identification that is typically used in MANETs. These techniques can be complemented with cross-layer designs that exploit the relation between MAC and network layers. For example, the routing function can leverage the information shared by the MAC function in predicting the life time of various links, and subsequently adjust the routes, if necessary. Thus there are various cross-layer approaches that make use of connections between MAC and network layers [34, 35, 36] Movement Prediction-based Routing (MOPR), Ad hoc On-demand Multipath Distance Vector (R − AOMDV) protocol that is based on AOMDV [37] protocol and CCBF [38] protocol based on cluster-based forwarding, are taken as an example of Network-MAC protocol.

D. Cross-layer Design for Transport-MAC Layers

Cross-layer design between transport and network layers helps in distinguishing between route interruption and channel congestion. The link disconnection problems that occur at the level of individual hops must be dealt at MAC layer. MAC protocols such as 802.11 handle link disconnection via packet retransmissions. If the sender does not receive the acknowledgments within a fixed number of retransmissions then the packet is dropped. In multi-hop vehicular networks, the issue of link disconnection is likely to be severe since the underlying network topology changes dynamically, thereby resulting in frequent packet retransmissions [39]. In multi-hop VANETs, the sequence of relay nodes between the source and destination nodes can be treated as a chain. Different links in such a chain experience different levels of interference [40]. TCP Contention Control (TCTC) [40] that adjusts the amount of data in the system based on the level of contention and throughput experienced by packets in each flow is an example of Transport - MAC protocol.

E. Cross-layer Design for Transport-Network Layers

There exist several cross layer protocols that operate between the transport layer and lower layers. Most of these protocols are aimed at supporting real-time and multimedia applications that require a reliable end-to-end connectivity with critical

QoS requirements. Cross-layer protocols are developed to assist in dealing with issues that emerge in vehicular networks. Vehicular Transport Protocol (VTP) [41], Ad-hoc TCP (ATCP) [42] are an example of Transport-Network protocol. Figure 2.6 shows classification of cross-layer routing protocol in VANET.

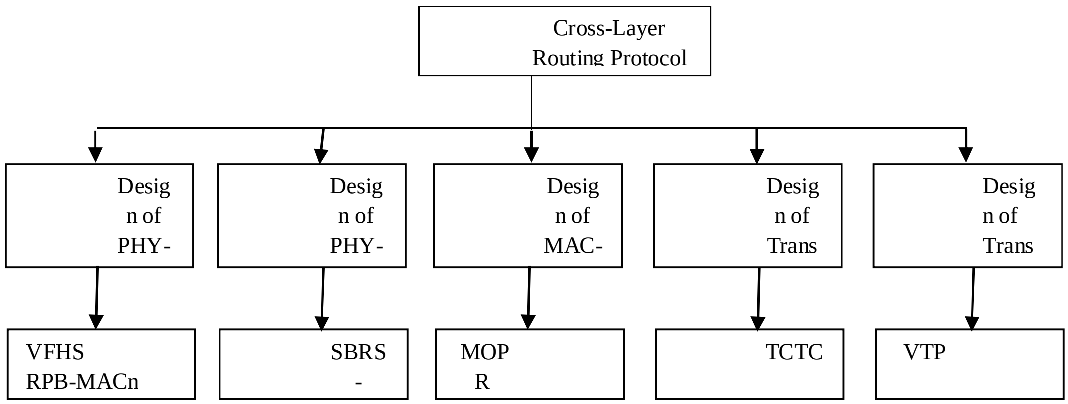

Figure 2.8: Classification of Cross-Layer Routing Protocol in VANET [29]

2.1.7 Hybrid Wireless Mesh Protocol (HWMP)

HWMP is a default MAC-layer protocol proposed by IEEE 802.11s draft [72], uses distance vector routing algorithm to discover best route to reach the destination and it will distribute the routing information when there is any changes occur in the topology of the network. Hybrid routing protocols uses only less power and memory when compared with link state routing algorithm. This protocol enables paths to be set up automatically. Paths are selected by choosing the best path based on the metrics. The concept of finding the best path is based on the Bellman-Ford or Dijkstra's algorithm [72], which solves the shortest path problem.

As in [73] HWMP is a mesh routing protocol that combines the flexibility of on-demand routing with proactive topology tree extensions. The combination of reactive and proactive elements of HWMP enables optimal and efficient path selection in a wide variety of mesh networks (with or without infrastructure). The routing is on layer 2. The routing protocol uses MAC addresses and a radio-aware routing metric. Figure 2.10 shows configuration cases for HWMP as in [74].

HWMP protocol "is hybrid, because it supports two kinds of path selection protocols. The protocols typically use a proactive approach to keep routes to neighborhood nodes (nodes within the vicinity of the source). But for the nodes beyond the vicinity area the protocol behaves like a reactive one. Although these protocols are very similar to routing protocols, but bear in mind, that in case of IEEE 802.11s these use MAC addresses for "routing", instead of IP addresses. Therefore, "path" was used instead of "route" and thus "path selection" instead of "routing". HWMP Control Messages are:

1. **Rout Announcement** (Broadcast): tells MPs about the presence and distance of Root-MP (root Mesh Point).

2. **Rout Request** (Broadcast/Unicast): asks the destination MP(s) to form a reverse route to the originator.

3. **Route Reply** (Unicast): forms a forward route to originator and confirms the reverse route.

4. **Route Error** (Broadcast): tells receiving MPs that the originator no longer supports certain routes.

Routing in HWMP uses a sequence number mechanism to maintain loop-free connectivity at all times. Each MP maintains its own sequence number, which is propagated to other MPs in the HWMP control messages.

HWMP uses a common set of protocol primitives, generation and processing rules taken from Ad Hoc On Demand (AODV) routing protocol adapted for Layer-2 address-based routing and link metric awareness. AODV forms the basis for finding on-demand routes within a mesh network while additional primitives are used to proactively set up a distance-vector tree rooted at a single root mesh point(MP). The root role that enables building of topology tree is a configurable option of an MP.

Two modes of operation [73]:

(1) On demand mode: this mode allows MPs to communicate using peer-to-peer routes. The mode is used in situations where there is no root configured. If a source MP needs to find a route using the on demand routing mode, it broadcasts a RREQ with the destination MP specified in the destination list and the metric field initialized

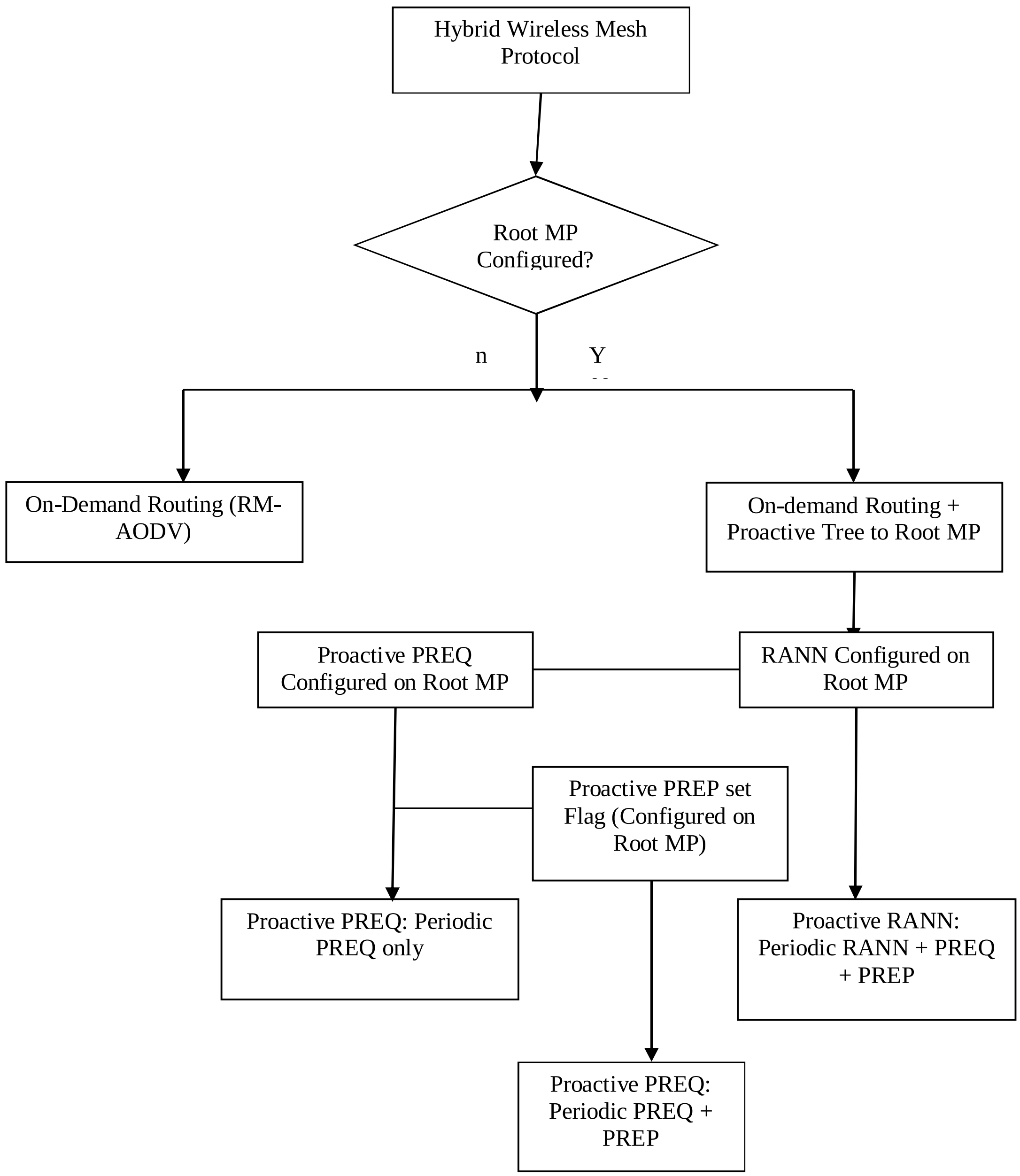

Figure 2.9: Configuration Cases for HWMP [23]

to 0. When a MP receives a RREQ it creates a route to the source or updates its current route if the RREQ contains a greater sequence number, or the sequence number is the same as the current route and the RREQ offers a better metric than the current route. If a new route is created or an existing route modified, the RREQ is also forwarded (re-broadcast). Each MP may receive multiple copies of the same RREQ that originated in the source, each RREQ traversing a unique path from the source to the MP. Whenever a MP forwards a RREQ, the metric field in the RREQ will be updated to reflect the cumulative metric of the route to the RREQ's source. Intermediate MPs generate RREPs only if the "Destination Only (DO)" flag is not set, e.g. DO = 0, corresponding destinations, provided that they have routes to these destinations. If the DO flag is set to 1, which is default, only the destination MP can generate a RREP. If an intermediate MP receives a RREQ with the DO flag set to 0 for a destination and this intermediate MP already has a valid route to the destination, it issues a unicast RREP to the source. Furthermore, if the "Reply and Forward (RF)" flag is set to 1 for the destination, this intermediate MP will forward the RREQ with the DO flag for the destination set to 1 (the reason to set the DO flag to 1 is to suppress any RREP messages from the subsequent intermediate MPs).

Intermediate MPs create a route to the destination on receiving the RREP, and also forward the RREP toward the source. When the source receives the RREP, it creates a route to the destination. If the destination receives further RREQs with a better metric, then the destination updates its route to the source to the new route and also sends a fresh RREP to the source along the updated route. Thus a bidirectional, best metric end-to-end route is established between the source and destination.

Note that in HWMP, the RREQ processing at intermediate MPs is controlled per destination.

(2) Proactive tree-based mode: this can be performed by using either the RREQ or RANN mechanism. There are two mechanisms for proactively disseminating routing information for reaching the root MP :

Proactive RREQ Mechanism: the RREQ tree building process begins with a proactive Route Request message sent by the root MP, The proactive RREQ is sent periodically by the root, with increasing sequence numbers. Any MP hearing a proactive RREQ creates or updates its forwarding information to the root MP, updates the metric and hop count of the RREQ, records the metric and hop count to the root, a MP updates its current route to the root if and only if the RREQ contains a greater sequence number, or the sequence number is the same as the current route and the RREQ offers a better metric than the current route to the root.

Proactive RANN Mechanism: the root periodically floods a RANN message into the network. The information contained in the RANN is used to disseminate route metrics to the root. Upon reception of a RANN, each MP that has to create or refresh a route to the root will send a unicast RREQ to the root via a MP from which it received the RANN. The root sends a RREP in response to each RREQ. The unicast RREQ creates the reverse route from the root to the originating MP, while the RREP creates the forward route from the MP to the root.

The forwarding information maintained by a MP consists at least of a destination, the sequence number of the destination, the next hop to the destination, the route metric to the destination and the lifetime of this forwarding information. The Hybrid Wireless Mesh Protocol uses the route discovery process well-known from AODV [75].

Two kinds of routing exist in HWMP [73]:

- On-demand Routing
- Tree-based Routing

The proposed IEEE 802.11s amendment [73] defines a default radio-aware routing metric for basic interoperability between IEEE 802.11s devices. The airtime link metric is a measure for the amount of the consumed channel resources when transmitting a frame over a particular wireless link. Equation (2.9) is used for the calculation of the airtime cost ca of each link. The path metric is the sum of the metrics of all links on the path.

$$C_a = \left[O_{ca} + O_P + \frac{B_t}{r}\right]\frac{1}{1- e_{fr}} \qquad (2.9)$$

The channel access overhead O_{ca}, the MAC protocol overhead O_p, and the number of bits B_t in a test frame are constants. Their values depend on the used IEEE 802.11 transmission technology such as IEEE 802.11b or IEEE 802.11g. The transmission bit rate r in Mbit/s is the rate at which the mesh point would transmit a frame of size B_t with frame error rate e_{fr}, based on the current conditions of the radio environment.

The data transmission time from a source to destination is known as ETE delay The lower the ETE delay, the better the performance [73]. The ETE delay is defined Equation (2.10).

$$ETE_{delay} = \frac{\sum T_R - T_S}{\sum N_P} \qquad (2.10)$$

where T_R denotes the time to receive the packets, T_S denotes the time to send the packets, and N_P denotes the number of packets.

2.1.8 WAVE architecture

A protocol model represents the function of the protocols within each layer; in addition, it describes the interaction with the layers above and below it. The Open Systems Interconnection (OSI) model is the most popular internetwork reference model which is consists of hierarchical set of related protocols. There are seven layers in this model, and each layer provides different functionality and services. In addition, this model defines the interaction of each layer with its upper and lower layers.

The key point of vehicular ad hoc network is facilitating the wireless communication between vehicles, so there is a need for developing a set of communication protocol. Consequently, IEEE defined WAVE standard which consists of IEEE 802.11p and IEEE 1609 protocol family.

2.1.8.1 Physical Layer

The physical and MAC layers of WAVE are based on IEEE 802.11p standard. IEEE 802.11p which covers the characteristics of vehicular ad hoc network: high dynamic mobility, high change of network topology, and low latency. The physical layer of IEEE 802.11P consists of seven channels of 10 MHZ bandwidth for each channel.

The physical layer of IEEE 802.11p is similar to IEEE 802.11a design, but the main difference is that the IEEE 802.11p use 10MHZ bandwidth for each channel instead of 20MHZ bandwidth in IEEE 802.11a. The physical layer of 802.11p uses orthogonal frequency-division multiplexing (OFDM) technology which is used for increasing data transmission rate and overcoming signal fading in wireless communication. One of the specifications of IEEE 802.11p is that the management functions are connected with the physical and MAC layers which are called physical layer management entity (PLME) and MAC layer management entity (MLME), respectively [11].

2.1.8.2 MAC Layer

The IEEE 802.11p uses the Carrier sense multiple access with collision avoidance (CSMA/CA) to reduce collisions and provide fair access to channel. In order to describe the functionality of CSMA/CA access method, it is necessary to explain two parameters:

- Arbitrary InterFrame Space (AIFS): It is the minimal time that a wireless device must sense the channel Idle before it can transmit the data.
- Backoff: it is a procedure which forces all the stations to stop transmitting for a random period of time.

When a station has data to transmit, it listens to the medium for an AIFS and if the medium is free, the station starts sending data. If the medium is busy, the station should execute backoff. The IEEE 802.11p MAC layer is based on multichannel operation of WAVE architecture and 802.11e Enhanced Distributed Channel Access (EDCA). The EDCA mechanism supports quality of service (QOS) and prioritizing important safety messages. This mechanism defines four different access categorizes (AC) for each channel. The access categories are indicated by AC0-AC3, and each of them has an independent queue [11].

The EDCA mechanism provides prioritization by assigning different contention parameters to each access category. AC3 has the highest priority to access medium, and AC0 has the lowest priority. So there are six service channels and one control channel and each of them has four different access categories. Consequently, during data transmission, there are two contention procedures to access the medium:

- Internal contention procedure which occurs inside each channel between their access categories
- The contention procedure between channels to access the medium is supported by different timer settings based on the internal contention procedure.

The internal contention procedure occurs by using the contention parameters which are described as follows:

- Arbitrary InterFrame Space (AIFS)
- Contention Window (CW): This parameter determines the initial random backoff time. The size of this parameter is controlled by CWmin and CWmax parameters. The primary size of contention window is defined by CWmin. For each failed transmission, the size of contention window will be doubled until the maximum value (CWmax) is reached.

Throughout data transmission, each frame is categorized into different access categories, depending on the importance of the message. Then the selected frames contend to access the medium using their contention parameters [118].

2.1.8.3 Network and transport layers

The IEEE 1609.3 defines the operation of services at network and transport layers. Moreover, it provides wireless connectivity between vehicles, and vehicles to roadside devices. The functions of the WAVE network services can be separated in two to sets:

- Data-plane services: they transmit network traffics and support IPV6 and WSMP protocols. WAVE short-message- Protocol (WSMP) provides this capability that applications can send short message to increase the probability of receiving the messages in time.
- Management-plane services: Their functions are to configure and maintain system, for instance: IPV6 configuration, channel usage monitoring, and application registration. This service knows as WAVE management entity (WME) [118].

2.1.9 Broadcast in VANET

One of the challenges which cause most of MANET routing protocols not be used in VANET is broadcast mechanism used in MANET to disseminate data and to send the control packet. VANET network is easily to be flooding because of its nature of high scalable network, high topology change, and frequency network disconnection. Many studies work proposed different scheme to alleviate the broadcast problem in VANET [119].

Most of the basic broadcast techniques rely on either 1-persistence or p– persistence [49]. 1-persistance requires that all the nodes rebroadcast the packet with probability of 1 which means whenever the node receives the packet to be broadcasted it must do that. Although this mechanism results a lot of overhead but it is adopted in most of VANET protocol due to its simplicity and high packet penetration rate. Conversely p-Persistence requires the node to predetermine the probability p before forwarding the packets. This technique is used mostly in gossip based routing.

2.1.9.1 Distance-based broadcast suppresses technique

According to [49] the distance based broadcast can be classified as follows:

A. Weighted p-Persistence Broadcasting

In this scheme, when the node receives the packet from another node, first it will check the packet ID. If it is a new packet, it will rebroadcast with probability P otherwise it will drop the packet. The probability p that is used to make a decision on forwarding the packet is calculated using equation 2.3, where D_{ij} is the relative distance between node i and j and R is the transmission range.

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$$p_{ij} = \frac{D_{ij}}{R} \tag{2.3}$$

When the node receives redundant packet from multiple sources within the waiting period of WAIT_TIME before retransmission, it selects the smallest p_{ij} value as its forwarding probability. If the node makes decision of not rebroadcasting the packet it will put the packet to buffer and waiting time increase to $WAIT\_TIME + \delta$ where is the one hop transmission and propagation delay which less than WAIT_TIME.

B. Slotted 1-Persistence Broadcasting

In this technique, a node checks the packet ID. If the packet is received for the first time and node has not received any duplication packet before its time slot arrived, the current packet will be rebroadcast with probability 1 at its corresponding assigned time slot $T_{S_{ij}}$. The time slot $T_{S_{ij}}$ is calculated using equation 2.4, where S_{ij} is assigned slot number which is computed using equation 2.5.

$$T_{S_{ij}} = S_{ij} \times \tau \tag{2.4}$$

$$S_{ij} = N_s(1 - \frac{[\min(D_{ij}, R)]}{R} \tag{2.5}$$

Where τ is the estimated one hop delays which includes the medium access delay and propagation delay and S_{ij} is the assigned slot number, D_{ij} is Relative distance between node i and j , R is the transmission range and N_s is the predetermined number of slots. This approach follows the same method used in weighting p-persistence scheme, but instead of calculating the forwarding probability, the vehicles uses GPS information to calculate the waiting time for retransmission.

2.1.9.2 Received Signal Strength based scheme

Other than using GPS to determine the broadcast probability or waiting time, this technique is used to receive signal strength instead of GPS as it is well known that there are some areas like in the tunnels, shadowed areas, urban areas with many high-rise buildings whereby the vehicles will not be able to receive GPS signal. The following is the modification of the previous schemes that adopted Receive Signal Strength in making decision for broadcast the packets.

A. Weighted p-Persistence scheme

In this scheme the RSS is used to calculate the broadcast probability using equation 2.6 in which RSS_{range} is calculated using equation 2.7.

$$p_{ij} = \frac{RSS_{ij} - RSS_{\min}}{RSS_{range}} \quad (2.6)$$

$$RSS_{range} = RSS_{\max} - RSS_{\min} \quad (2.7)$$

Where, RSS_{ij} is the RSS of the broadcast packet received by the node j, $RSS_{\max}$ and $RSS_{\min}$ are corresponding to the maximum and minimum possible values of RSS measured in considered environment.

B. Slotted Scheme

In slotted scheme the modification is only arise on finding the time slot or slot number for the node to broadcast. It uses RSS instead of using relative distance to determine the waiting time as it shown in equation 2.8.

$$S_{ij} = N_s - [\min \frac{(RSS_{range}, (RSS_{ij} - RSS_{\min}) \times N_s}{RSS_{range}}] \quad (2.8)$$

In this study, 1-persistance broadcast mechanism was used, means when never the node get the packet to broadcast it will broadcast immediate without delay to all its neighbors except where the packet is generated.

2.1.10 Advantages to Clustering in VANETs

The dynamic and dense VANET topology and harsh VANET environment, produce many challenges for communication and networking. In traditional Mobile Ad hoc Network (MANET) research, these difficulties were often overcome by a clustered topology. As a result, clustering has become a common topic in the VANET research community [23].

One of many challenges for VANETs is the dynamic and dense network topology, resulting from the high mobility and high node-density of vehicles [50]. This dynamic topology causes routing difficulties as well as congestion from broadcasting, and the dense network leads to the hidden terminal problem. A clustered structure can make the network appear smaller and more stable in the view of each node [51], [52]. By clustering the vehicles into groups of similar mobility, the relative mobility between communicating neighbor nodes will be reduced, leading to intra-cluster stability. In addition, the hidden terminal problem can be diminished by clustering [53].

Another issue generated by the dynamic and dense network, is the "broadcast storm problem" [54]. The broadcast storm problem describes the congestion resulting from rebroadcasts and broadcasting in a MANET. The dynamic topology of VANETs demand a high frequency of broadcast messages to keep the surrounding vehicles updated on position and safety information. In addition, many routing algorithms necessitate flooding the network to find routes, which in a dynamic network needs to be done frequently to keep routes updated. All of this flooding leads to severe congestion, which can be alleviated by a clustered topology [54], [55]. When the network is clustered, only the cluster head participates in finding routes, which greatly reduces the number of necessary broadcasts. In addition, MAC schemes using different CDMA codes in adjacent clusters can greatly reduce interference.

2.1.10.1 Clustering in VANETs

Vehicle ad hoc networks are considered as a special instance of MANETs, where the mobile nodes are vehicles with mobility that has both deterministic and stochastic qualities. The deterministic aspects of vehicular mobility include the assumption that vehicles will drive around the speed limit, and the assumption that vehicles will follow the speed of the vehicles in front of it. Some stochastic aspects of vehicular mobility include: speeding (or excessively slow driving), passing, lane-changing, and drastic speed changes caused by an accident or onset of heavy traffic.

The many challenges associated with VANETs provide sample motivation for a clustered network. VANETs suffer from the hidden terminal problem and have congestion issues caused by routing in the dense and highly mobile environment. Buildings and larger vehicles lead to shadowing, which results in a rapidly changing topology. Congestion, a dynamic topology, and the hidden terminal problem can all be alleviated by clustering the network. In addition, VANETs require Quality-of-Service (QoS) to deal with the delay-intolerant safety messages and the delay-tolerant data. Clustering has been shown to aid in fulfilling QoS requirements, as described in [59].

As a result of the advantages described above, there is sample recent research surrounding cluster-based VANETs. Most of this research has been focused on the development of cluster-based MAC protocols and cluster-based routing protocols instead of the clustering scheme itself. Cluster-based MAC protocols are presented in [53, 56,58, 60, 61, 62 and 63] and cluster-based routing protocols are presented in [57] and [64].

Much of the recent VANET research discussing cluster-based MACs and routing schemes, also present a low-maintenance clustering algorithm. Each of these algorithms works essentially the same way, whereby nodes periodically transmit HELLO beacons to indicate their present state. States can be one of the following: Undecided, Cluster head, Cluster Member, and sometimes Gateway. An undecided node will join the first cluster head that it hears a HELLO beacon from (or joins all cluster heads if Gateway nodes are allowed). If the node does not hear from a cluster head within a given time period, it will become a cluster head itself. In addition, protocols are introduced to deal with colliding clusters, which occurs when two cluster heads come within range of one another. During a cluster collision, one cluster head decides to give up its status to the other.

The above clustering techniques offer low complexity, but in the highly mobile VANET environment, they are lacking in cluster stability. The algorithms do not have a proactive approach to cluster stability, in that they make no attempt to select a stable cluster head during initial cluster head election.

Stable and effective cluster mechanism may add more stable connection on VANET. However, lack of stable clustering " in previous work" means that a lot of vehicles will not benefit from internet applications.

The main focus in this research will be at the boarder of the cellular network where the network quality starts to degrade. At the boarder of cellular network much interest will be given on providing an end to end solution by using gateway mechanism to assist other vehicles which are out of coverage and to connect to the cellular network in multi hop manner. This can be done by Simplified Cluster–Based Gateway Selection (SCGS) Scheme.

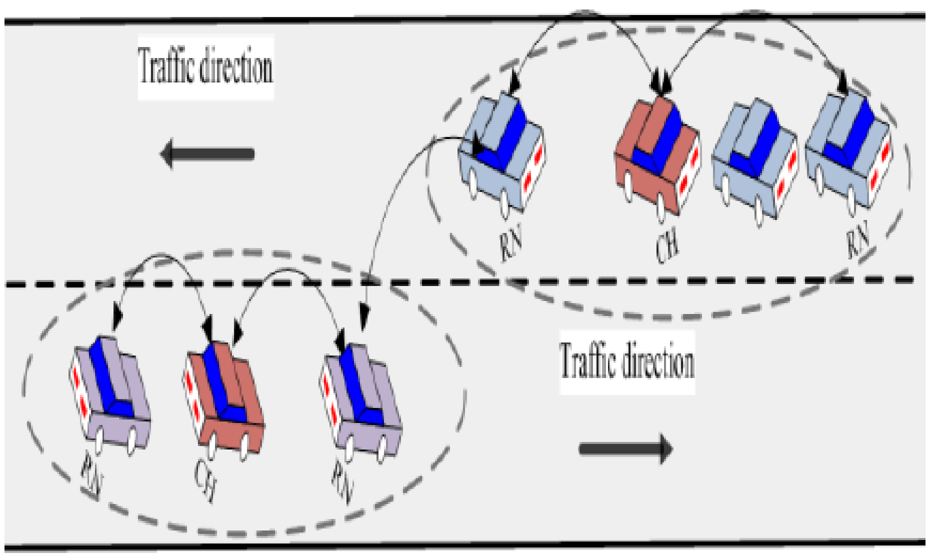

Figure 2.10: VANET Cluster Model [61]

2.1.10.2 Cluster-based MAC and Routing Protocols for VANETs

Motivated by the many advantages of clustering described above, there has been much research on cluster-based VANETs in the recent literature. Most of the research has been focused on developing cluster-based routing protocols, as in [56] and [57], and cluster-based MAC protocols, as in [53, 58].

The Cluster Based Location Routing (CBLR) algorithm [57] defines a simple way to form clusters. If a node is undecided, it starts a timer and broadcasts a Hello message. If the node hears a response from a cluster head before the timer expires, it becomes a member of that cluster head. Otherwise, the node becomes a cluster head itself. In

CBLR, the cluster head contains the position information of its neighboring clusters, and packets are routed to the cluster head nearest to the destination.

In both [53] and [58], the cluster head takes on a managerial role and facilitates intra-cluster communication by providing a TDMA schedule to its cluster members.

In [58], adjacent clusters are also assigned different CDMA codes to avoid interference between clusters. When compared to traditional 802.11 MAC, the work in [58] has been shown to substantially reduce probability of message delivery failure. In terms of the clustering algorithm used, many of the cluster-based MAC schemes use a version of the clustering method from CBLR. In [53], CBLR clustering is modified during cluster head contention (when two cluster heads are within range of one another). During cluster head contention, the winning cluster head is the one with both lower relative mobility and closer proximity to its neighbors. Alternatively, [56] uses CBLR but addresses mobility by classified nodes into speed groups, such that nodes will only join a cluster head of similar velocity.

The recent research in cluster-based MAC and routing protocols for VANETs motivates the need for an effective VANET clustering scheme. However, the clustering schemes used in the above research are lacking in cluster stability when faced with the highly mobile VANET environment. These algorithms do not exhibit cluster stability because they make no attempt to select a stable cluster head during initial cluster head election.

2.1.11 Gateway Selection

Existing research work considers VANET gateways as static one which needs to be deployed at each particular smaller distance, considers more cost and it does not provide proper handoff.

Shortcomings of static gateways [65]:

1) Deployment cost of Roadside Unit (RSU) is high

2) Dynamic topology nature of VANET communication affects stability of links between nodes and gateways .

3) Mainly proactive routing algorithms are used and hence also influenced with disadvantages of proactive routing .

To overcome these shortcomings Mobile gateways are introduced. Mobile gateway is a dual-interfaced node is equipped with radio interfaces for communication with both networks. One interface for communication within VANET and other interface for wireless technology used for connection with internet.

In order to find mobile gateway node all vehicle are arranged in group called as cluster. Clustering takes place based on metric values such as UMTS signal strength, Direction of movement, Link stability, route stability, TTL, inter-vehicle distance, residual energy, vehicle speed, IEEE 802.11p coverage range. Vehicles with similar metric values or metric which satisfies particular conditions are grouped together. For each group a captain or leader or controller is selected, which is called as cluster head. A cluster head is node which has capability to work as mobile gateway. All the cluster heads from network are with dual interfaces operating. Whenever network calls for gateway, it gets ready to flow traffic from VANET to internet and vice-versa. Among all available cluster heads, one of cluster head is selected to work as mobile gateway. The node with high weight is selected as gateway. Weight is calculated using metric values. A simple additive technique explained in [66]. There are different research paper [65, 67, 68, 69] which uses set of metric and based on these metric weight of node is calculated and then node with highest weight is selected as gateway.

2.2 Related Works

The problem of connecting VANET to the Internet or infrastructure network is also extensively studied in the literature. In this section some schemes and protocols that are closely related to the intended proposed scheme are reviewed and their strengths and weaknesses are highlighted and at the end suggestions have been given as what should be done to improve the current schemes. In addition to that, from this review it is observed that two recently scheme proposed by [2] and [3] has got some weaknesses where at the end they has been selected and their weakness are improved in VANET –UMTS scenario.

2.2.1 Relay Schemes and Algorithms

In [81], VANET connected to broadband and road side equipment's through multi-hop relay network. An experimental study evaluation conducted in this work used relay vehicle; when the source vehicle moves towards the cellular base station (BS) and when it moves away from the cellular base station (BS). This is scenario shown in

Figure 2.11. One to two hops relay connections involved in this experiment and the results show that relay mechanism can extend the coverage area of wireless broadband network (i.e. Internet connects). In addition to that, Vehicle to Vehicle Relay scheme (V2VR) is proposed. This scheme permits vehicle to set up the relay connection before join the road side unit (RSU), (i.e. Base station) coverage area. In V2VR the vehicles search for two vehicles that can act as alternatives, ahead (forward proxy) and back-end (backward proxy). The vehicle will use the forward proxy to connect to the RSU at the tassel of the RSU coverage and or when it joins the RSU cell. The vehicle make use of the backward proxy to relay traffic in travels away from the RSU coverage. The relay selection in this work was based on link quality and source vehicle direction.

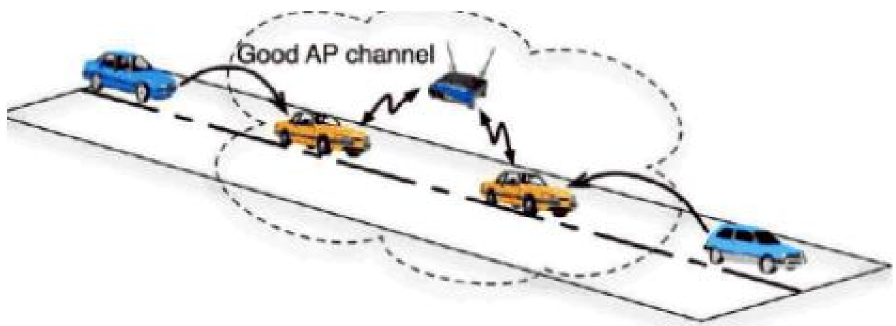

Figure 2.11: Access AP through a Relay [81]

The proposed relay mechanism in [81] improves the throughput and extends the AP coverage.

In [6], multiple end-to-end QoS parameters were identified: Perspective gateway selection scheme is proposed. In this research work, the gateway selection, discovery algorithm and also the QoS parameter propagation during gateway discovery process are discuss by the authors, their gateway selection scheme is analyzed in the hybrid gateway discovery algorithm, where each gateway advertises its parameters periodically within proactive region of k-hops by sending gateway advertisement message and the nodes that are out of the proactive zone discover a gateway in a reactive manner by sending gateway discovery message, as shown in Figure 2.12.

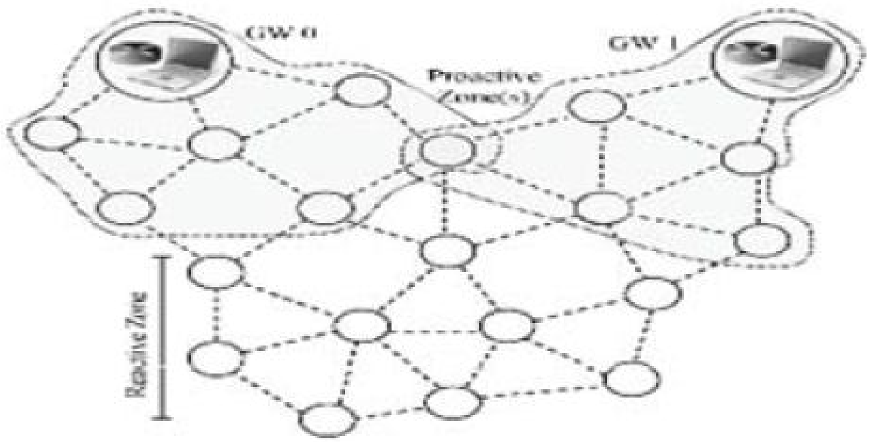

Figure 2.12: Hybrid Gateway Discovery Algorithm [6]

In [2], a simplified gateway selection (SGS) was proposed to enable vehicles to continue connecting to the internet or other mobile service (i.e. location map download). Also assumed that each vehicle located inside the coverage zone has two interfaces one to connect to infrastructure mode which is UMTS UTRAN interface and the other is to connect to the ad-hoc mode (IEEE802.11), both interfaces must be active all the time and vehicles located outside the coverage zone contained only one interface. This scenario, illustrated in Figure 2.13, involves vehicles moving on the highway into two opposite directions. All vehicles access the UMTS network via UMTS Node B over the UMTS radio interface (UTRAN). The vehicles will experience different signal strength (RSS) from Node B. All vehicles connect directly to Node B if they are inside of the coverage (using UMTS UTRAN interface) and once UMTS RSS fall to certain predefined threshold the vehicle will use it IEEE802.11 interface to find the partner to act as relay to connect to the UMTS Node B.

However, it should be noted that this solution is less reliable in terms of availability and complex in terms of cost of creating. In addition, the delay between broadcast Relay Request messages (RReq), receiving Relay Respond messages (RRep) (The source vehicle can receive numbers of RRep but choose the best one) is not taken into consideration. Therefore, in this work a new gateway selection mechanism is proposed by formulating a cluster only at the LTE cell edges. This is done by using received signal strength (RSS) threshold as a cluster formation indicator. In addition to that, a hybrid metrics of the Link Expiration Time (LET) to determine the stability of the link between the source vehicle and the GW vehicle along with the best route capacity selection to avoid overload and hence bottleneck in one gateway.

The use of multi metrics for gateway selection was also studied in [2] and [3].

In [1] reliable routing protocol for roadside to vehicle communication is proposed. The protocol is aimed in rural areas therefore it also considers the terrain effects which can block the communication. In their proposed protocol, if the vehicle is out of communication range of an AP or terrains block their communication; other vehicles will be used to rely the data traffic. When vehicle has data to send to the internet and does not have cached route, it first initiates the route discovery process by flooding the network with Route Request (RREQ) . The process used is same as one used in Dynamic source routing (DSR) protocol. However, in this work the APs are the ones which are responsible to conduct the route maintenance. For each flow the

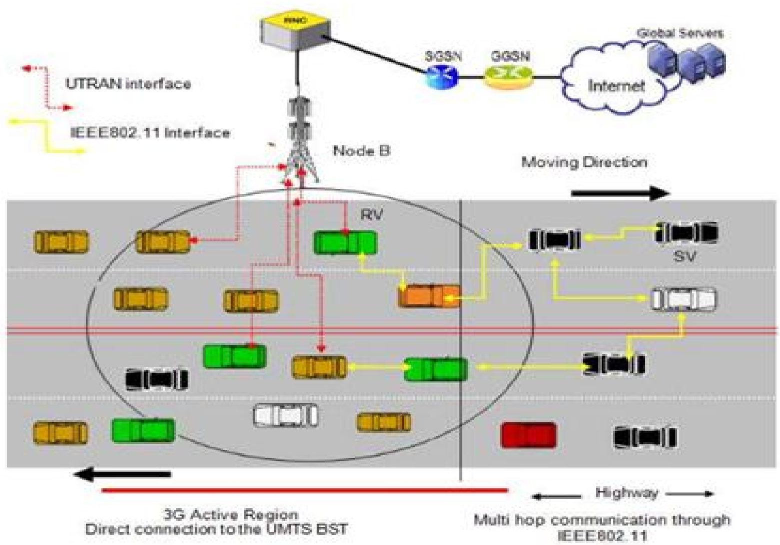

Figure 2.13: Simplified Gateway Selection Scheme used in [2]

corresponding AP executes the proposed routing algorithm every t_m seconds which is the route maintenance interval which can be set to the multiple of the mean packet arrival interval. If the new computed path is different from the current path and unsolicited RREP including new path will be sent to the source node. When the source node receives this RREP message, it will begin to use the new path to transmit data packet. This schema shows the better result because it reduces the probability of the route breakage which enhance the QoS for that route. The access point is stationary.

In [82], an adaptive gateway management mechanism for multi-hop B3G networks is proposed. In this research work, the authors discuss the issues associated with the selection of mobile gateways in an integrated MANET-UMTS heterogeneous network. They use multi-attribute decision making theory and simple additive weighting (SAW) techniques [4] to select an adequate gate-way based on residual energy, UMTS signal strength and mobility speed of the gateway candidates. In case the current serving gateway loses its optimality, the authors proposed a multi-metric gateway migration approach for handing over the responsibilities of the serving gateway to a newly-elected one. A comparison has been carried out between the existing heterogeneous wireless network architectures and theirs to infer that their proposed adaptive gateway management-based multi-hop architecture makes significant improvement in terms of sustaining the inter-connectivity and improving the throughput of the integrated network. Whilst our envisioned gateway selection mechanism is also based on different metrics (without considering the vehicle's residual energy, as battery is not a constraint for vehicles), the gateway selection mechanism is further refined by restricting its application to only gateway candidates of predetermined clusters.

In [126], the authors proposed gateway selection method considering traffic priority first, with the purpose of ensuring the Quality of Service (QoS) of different traffic data. Nevertheless, we note that most of the existing studies focus on the uplink strategy which indicates how to select a suitable gateway by source vehicle to upload message to a server, while the downlink message dissemination strategy is seldom considered.

In [7], a prediction-based routing (PBR) protocol is proposed specifically for mobile gateway. This protocol takes the advantage of the predictable mobility pattern of the vehicles on highways. The protocol allows the vehicles which have both WLAN and WWAN interfaces to act as mobile gateway and the normal vehicles contained only WLAN interface to use that mobile gateway to connect to Internet. The work assumes the vehicles moving into two opposite directions in the highway and source vehicle uses the link lifetime between the source vehicles and the mobile gateway to select the optimal mobile gateway. However, it can be noted that in this work different approaches have been used to determine the link lifetime. However, only velocity and location of the vehicles in relation to the mobile gateway were used in calculating the route lifetime. The minimum of the link lifetime along the route is used as the route life time utilized by the source vehicle in selecting the route. Two PBR variants are also proposed in this work: PBR-S and PBR-M in case when an old route breaks. A normal PBR during the event of the route break, the new nearest gateway is selected even though the route can be established using the same gateway. In PBR-S the same gateway is selected during the route failure until no route can be constructed to it. This mechanism reduces the gateway switching which has an impact on network performance. PBR-M selects the gateway among all those within a certain number of hops with largest predicted route lifetime whereas during the route breakage PBR-M selects a new gateway with the same largest predicted lifetime criteria.

2.2.2 Cluster Mechanisms

In [5], dynamic clustering and gateway management in vehicular ad-hoc networks are proposed. This method consider two types of the vehicles: first, gateway candidates (GWC) referred to the vehicles that have two interfaces, UTRAN interface and IEEE 802.11p interface and second, normal vehicles that include single interface (IEEE 802.11p). By means of the decided on VANET mobile gateways, VANET is connected to UMTS using the Universal Terrestrial Radio Access Network (UTRAN) interface. Dynamic clustering mechanism is used to organize the gateway candidates d into clusters. A minimum number of gateways, per time instance, are employed to attach the regular vehicles with the UMTS network. Route stability, mobility features, and signal strength of vehicles are all taken into consideration when clustering vehicles and selecting vehicle gateways. A Multi-metric Mobile Gateway Selection Algorithm (MMGSA) is proposed, it is employed upon the available CHs of the GWC sub-cluster. An optimal gateway is then selected by the source vehicle using the MMGSA mechanism this is shown in Figure 2.14.

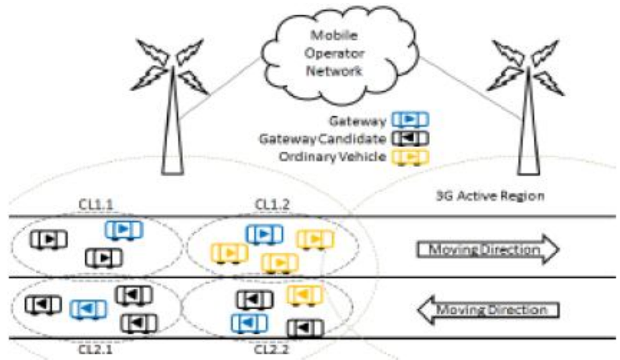

Figure 2.14: Envisioned VANET-3G Architecture [9]

In [120], a Clustering technique is proposed to group nodes into several clusters. Each node in the cluster structure plays one of three roles: Cluster Head (CH), Cluster Gateway (CG), and Cluster Member (CM) [120]. The cluster head in a cluster plays the roles as coordinator and backbone. It is in charge of all the communications inside a cluster, managing medium access and allocating the resource to cluster members. A CG is a border node of a cluster that can communicate nodes belonging to different clusters .

In [3], a Clustering-based Multi-metric Adaptive Mobile Gateway Management Mechanism (CMGM) is proposed. Here, two types of the vehicles were assumed: the vehicles which have two interfaces, UTRAN interface and IEEE 802.11p interface which are referred to as gateway candidates (GWC) and normal vehicles containing only one interface (IEEE 802.11p). The scheme allows minimum number of vehicles to connect to UMTS network by allowing normal vehicles to use the GWC to communicate with the UMTS network. Clustering mechanism is used to cluster the gateway candidates which depend on direction of movement, UMTS-RSS (Received Signal Strength), and IEEE 802.11p transmission ranges. GWCs closed to the cluster center are always selected as Cluster head. Normal vehicles use cluster heads to communicate to UMTS network as shown in Figure 2.15.

Multi metrics Mobile selection algorithm based on Simple Adaptive Weighting (SAW) technique [4] is used as well in [3]. Three metrics are used for mobile gateway selection; mobility speed, UMTS-RSS and link stability. The paper also discusses handoff mechanism and gateway management in VANET-UMTS integration. However, the scheme proposed in [3] is complex in terms of cost of creating and maintaining the clusters for rapid environment as in VANET. In addition to that, the cluster head election process was based only on the geographic position of the vehicles for a lower TTL value. This could result in the cluster heads not possessing the essential credentials to manage the VANET clusters and to enable them communicate with the UMTS also the signaling traffic and time that is used for clustering formation and cluster head selection is larger than the time of data traffic exchange.

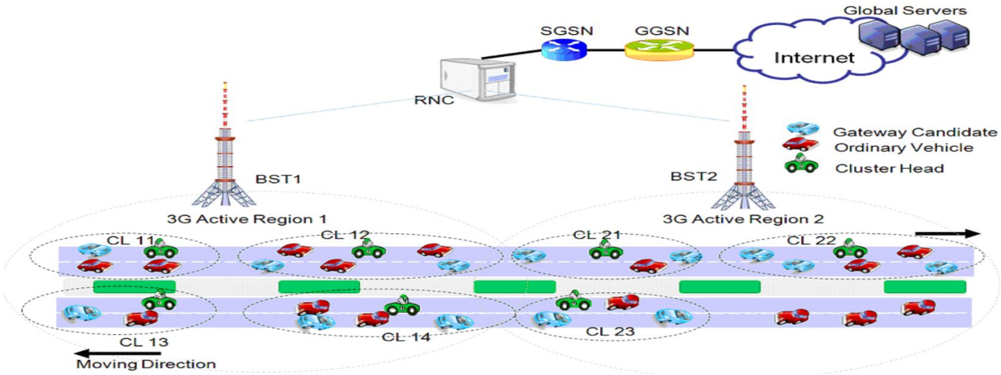

Figure 2.15: Clustering Scheme Used in [3]

In [121], the authors introduce VMaSC: Vehicular Multi-hop algorithm for Stable Clustering. VMaSC is a novel clustering technique based on choosing the node with the least mobility calculated as a function of the speed difference between neighboring nodes as the cluster head through multiple hops.

In [122], a two-layer novel Evolutionary Game Theoretic (EGT) framework is presented to solve the problem of in-stable clustering in VANETs. The aim of this research is to model the interactions of vehicular nodes in VANETs, to retain a stable clustering state of the network with evolutionary equilibrium as the solution of this game. A stable clustering scenario in VANETs is modelled with a reinforcement learning approach to reach the solution of an evolutionary equilibrium. Performance of the proposed \evolutionary game based clustering algorithm "is empirically investigated in different cases and he simulation results show that the system retains cluster stability.

Comparison between existing Heterogeneous wireless networks architectures are introduced in Table 1. The performance of all is affected by the number of vehicles (network size).

2.2.3 Vehicle to Vehicle (V2V) Scheme and Routing Protocols

In this section, scheme and protocol that are proposed for inter-vehicle communication (V2V) are studied where the strengths and weaknesses of the proposed scheme are highlighted.

Geographic Source Routing (GSR) [43] is a position-based routing method that is supported by a map of the city. According to Lochert, GSR is the first protocol to use the knowledge of the underlying map of the streets. The protocol assumed each vehicle on board uses a navigation system (i.e. GPS). .This GPS helps the vehicle to know its position and location and to use the vehicle reactive location service (RLC) to request the current position of the destination the vehicle needs to communicate with. RLC is a resemblance to route discovery mechanism used in topology based-routing. The source vehicle broadcasts the position request message for some specific node identifier. Upon receiving this request by the identified receiver, it will send the position by replying back to the source vehicle. The current position of the destination vehicle helps the source vehicle to compute the shorted path using Dijkstra shortest path calculation. Not only that, but the source vehicle will also compute a sequence of junctions the packet has to traverse in order to reach the destination. The source vehicle inserts the sequence of junction inside the packet head or it can be computed hop by hop. The protocol is compared with reactive routing protocol (AODV and DSR) and their results show that GSR outperforms topology-based routing. However, it can be clearly seen that the computation involved in this protocol is very high so as to bring extra routing overhead. In addition to that, inserting the whole series of junctions in the packet header brings extra packet overhead especially when the route is long. Furthermore, as it is mentioned that the protocol uses reactive location service to find the path to the destination by broadcasting the network with position request message. This mechanism can flood the network and thereby causes the wastage of bandwidth.

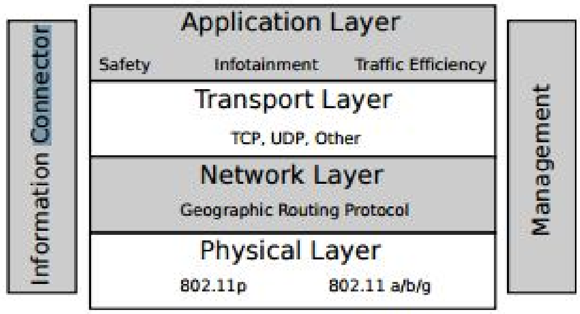

Figure 2.16:Geographic routing architecture for vehicular ad hoc networks [43]

GyTAR protocols [45] make their decisions on the street intersections which are influenced by traffic density. The street intersections are selected dynamically and when the node forwarding the packet, two factors will be used to assign a score to each of the intersections. The first factor is a traffic density between the current intersection and the potential intersection and the street with high density is selected. The second factor is the distance to the destination in road length and the shorter distance to the destination is always preferred. Before reaching the intersection an improved greedy algorithm is used to forward the node to intersection. The node will first predict the current positions of all its neighbors and select the nodes which are close to the next intersection. If local optimum is reached, a recovery mechanism is proposed to overcome this by allowing the forwarding node to carry the packet until the local optimum is eliminated. Furthermore, the node that carries the packet can forward the packet until it reaches an intersection or when it found the node in its transmission range that is closer to the next transmission range. CAR is Context-Aware Routing for Vehicular Ad hoc Network protocol proposed by [46]. This protocol extends the Advanced Greedy Forwarding (AGF) [47].

In AGF [47] the nodes forward a data packet to a neighbor that is geographically closer to the destination while in CAR the data packet is forwarded to the neighbor that is closer to anchor point. In CAR protocol, source has considered various factors such as road topology, traffic density and road access point when forwarding the packet while intermediate nodes make use of local context information such as locations, velocity and driving directions of neighboring vehicles to greedily forward the packet through the selected path. A source node sends HELLO beacon contains the information about its speed and moving direction. The intermediate node extracts this information and cache to its forwarding table. This information in a forwarding table becomes obsolete after the estimation nodes distance (current and neighbor) is greater than certain predefined threshold or after two successful HELLO intervals. Beacon interval in CAR depends on the number of the registered nearby neighbors. Meaning thereby when the number of neighbors is high, fewer HELLO beaconing are sent by the nodes. In contrast, when the number of neighboring nodes is few, the more HELLO beaconing messages are sent.

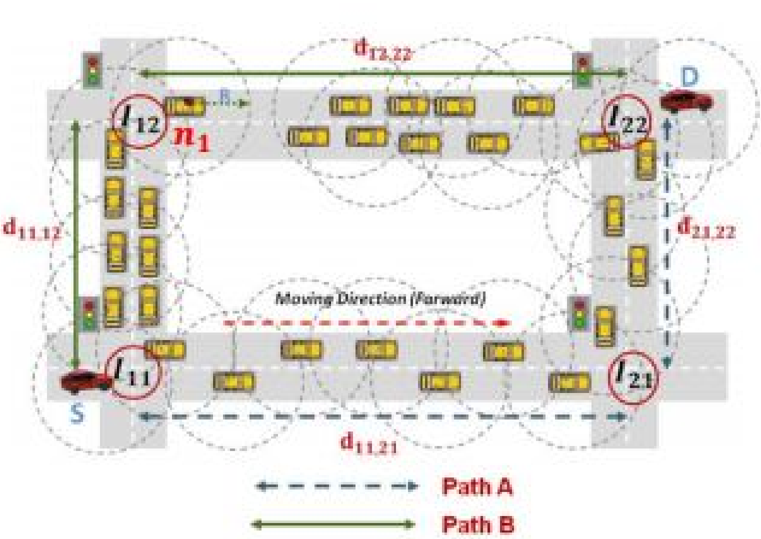

Figure 2.17: Packet forwarding scenarios [46]

GVGrid in routing protocol that provides the QoS in VANET proposed in [48]. It constructs a route on demand based from a source to vehicles that reside in or drive through a specified geographic region. The goal of GVGrid is to maintain a high quality route which is the robust route for the vehicles movement. Such route can be used for high quality communication and data transmission between roadsides and vehicles or between vehicles themselves. Digital map and position information of each vehicle are used in GVGrid to discover a network route which is expected to provide the best stability. It uses the characteristics of the movement and the driving route to determine the stability. It also offers a restore policy which restores the broken network routes while the vehicle is moving towards the destination. This protocol divides the map into grids, and each vehicle should know the destination to find the destination grid and send the RREQ messages toward that grid. Their experimental results have shown that GVGrid could provide routes with longer lifetime, compared with an existing method.

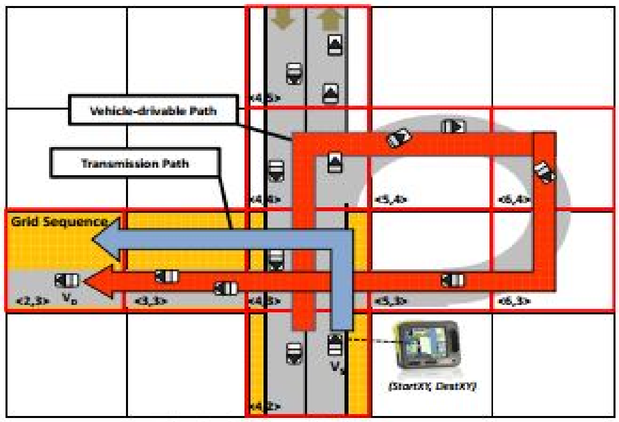

Figure 2.18: Grid map in high way scenario [48]

In [9] a fastest multi hop routing scheme (FMHR) is proposed for information dissemination in vehicular communication system. This work uses the speed of the vehicles and their distance to the destination to determine which vehicle must be used to forward the vehicle to the intended destination. Using speed and distance the time for each vehicle within the transmission range is calculated. This time is used in making decision to which vehicles are to be used as the next hop to forward the packet to destination. FMVHR uses the vehicle with least time as next hop to forward the packet to destination. In this respect, all vehicles are assumed to contain the GPS system. Therefore, with the help of GPS the location of every vehicle within the transmission range can be traced and the distance between the vehicles can be well known. Initial Vehicle (IV) sends the HELLO message that requests the position and speed of the all Next Hop Vehicle (NHV) reside in its transmission range. Upon receiving the HELLO message by NHV, any NHV will send back the acknowledgement together with the information regarding to their speed (V_r) and location(X_r,Y_r). When the IV gets this information from the NHV, the time taken by the traced vehicle to reach the destination will be calculated using equation 2.2 derived from equation 2.1. Whereby S_{NHV} the distance from the NHV to the destination vehicle (DV) and V_{NHV} is the velocity of next hop neighbour. The vehicle chooses the vehicle with the least time to reach the destination to be as next hop vehicle and the packet is forwarded through that vehicle.

$$S_{NHV} = V_{NHV} \times T_{NHV} \tag{2.1}$$

$$T_{NHV} = S_{NHV} / V_{NHV} \tag{2.2}$$

In [128], an optimized Hybrid Wireless Mesh Protocol had been suggested to construct a routing protocol over VANET. A real time packet loss estimation was utilized as an additional parameter to the parameters used in [3] (UMTS received signal strength, link stability and available relay capacity) to elect an efficient mobile gateway node for the transfer of packets without losing any of them.

In [129] the authors proposed spatial reusability-aware single-path routing (SASR) and any path routing (SAAR) protocols, and compare them with existing single-path routing and any path routing protocols, respectively. The evaluation results show that our protocols significantly improve the end-to-end throughput compared with existing protocols. Specifically, for single-path routing, the median throughput gain is up to 60 percent, and for each source-destination pair, the throughput gain is as high as 5.3x; for any path routing, the maximum per-flow throughput gain is 71.6 %, while the median gain is up to 13.2 %.

In [131] the authors propose a reliable multicast protocol, called CodePipe, with energy-efficiency, high throughput and fairness in lossy wireless networks. Building upon opportunistic routing and random linear network coding, CodePipe can not only eliminate coordination between nodes, but also improve the multicast throughput significantly by exploiting both intra-batch and inter-batch coding opportunities. In particular, four key techniques, namely, LP-based opportunistic routing structure, opportunistic feeding, fast batch moving and inter-batch coding, are proposed to offer significant improvement in throughput, energy-efficiency and fairness. Moreover, the authors design an efficient online extension of CodePipe such that it can work in a dynamic network where nodes join and leave the network as time progresses. The proposed protocol evaluated on ns2 simulator by comparing with other two state-of-art multicast protocols, MORE and Pacifier. Simulation results show that CodePipe significantly outperforms both of them.

In [133] the authors proposed a novel threshold credit-based incentive mechanism (TCBI) based on the modified model of population dynamics to efficiently resist the node compromise attacks, stimulate the cooperation among intermediate nodes, maximize vehicular nodes' interest, and realize the fairness of possessing the same opportunity of transmitting packets for credits. Then, a TCBI-based privacy-preserving packet forwarding protocol was proposed to solve the open problem of resisting layer-adding attack by outsourcing the privacy-preserving aggregated transmission evidence generation for multiple resource-constrained vehicles to the cloud side from performing any one-way trapdoor function only once. The vehicle privacy is well protected from both the cloud and transportation manager. Finally, formal security proof and the extensive simulation show the effectiveness of their proposed TCBI in resisting the sophisticated attacks and the efficiency in terms of high reliability, high delivery ratio, and low average delay in cloud-assisted vehicular DTNs.

In [134] the authors classify and describe the most relevant vehicular propagation and channel models, with a particular focus on the usability of the models for the evaluation of protocols and applications. First they classify the models based on the propagation mechanisms they employ and their implementation approach. They also classify the models based on the channel properties they implement and pay special attention to the usability of the models, including the complexity of implementation, scalability, and the input requirements (e.g., geographical data input). They also discuss the less-explored aspects in vehicular channel modeling, including modelling specific environments (e.g., tunnels, overpasses, and parking lots) and types of communicating vehicles (e.g., scooters and public transportation vehicles). They conclude their paper by identifying the under researched aspects of vehicular propagation and channel modeling that require further modeling and measurement studies.

2.2.4 Connectivity in VANETs

Connectivity in VANETs has been a topic of interest, especially due to the recently increasing research activity. Several researches have been done on analytical model to study connectivity in VANET.

In [83], authors have presented an analytical study on the information propagation speed when the carry and forward approach is used in both one- and two-way highway scenarios where vehicle arrivals are based on Poisson process and the vehicle speeds are uniformly distributed in a designated range. The authors provide numerical results on information propagation speed under two network models, which are low density network and high density network.

In [84], the authors modified the information propagation speed model from [83] by using a traffic density for Poisson arrival model and truncated Gaussian distribution for vehicles' speed. Nevertheless, the study done by [84] does not show any distribution model for the catch-up delay. Furthermore, the authors only include the results on the expected value for the information propagation speed for a VANET highway. The study does not show any development on the distribution model for end-to-end delay.

In [85], A Multi-metric, Map-aware Routing Protocol (MMMR) was proposed. MMMR is a protocol based on geographical knowledge of the environment and vehicle location. The metrics considered are the distance, the density of vehicles in transmission range, the available bandwidth and the future trajectory of the neighboring nodes. Thus, a node can select a node among all its neighbors, which is the best option to increase the likelihood of successful packet delivery, minimizing time and increasing a level of quality and service. A mechanism of anonymity in routing protocols based on the Crowd algorithm also included, which uses the idea of hiding the original source of a packet. This allowed the author to add some level of anonymity on VANET routing protocols. The analytical modeling of the available bandwidth between nodes in a VANET have been addressed in this study. The aim of this study is to design a framework to improve the interchange of information over vehicular ad hoc networks in urban scenarios. To achieve this goal, an efficient routing protocol specially designed for vehicular environments is needed. The author developed analytical models and algorithms to assist the routing scheme seeking to improve the performance of the VANET. Also, included a mechanism to minimize packet losses using a buffer to store packets in case that no neighbor was around. The author have designed a routing protocol that considers several metrics, focusing on the decrease of packet losses in VANETs, trying to maximize the number of packets delivered to their destination. It is important to highlight that the author proposals are based on hop-by-hop forwarding decisions to select the best forwarding node. Also, they are aware of the quick changes of topology present in urban scenarios. As the result, the proposal was saved trip time, petrol and C2C as a consequence, which helps to have sustainable smart cities.

In [86], authors was presented an analytical model to investigate the impact of vehicle speed on VANET connectivity assuming vehicles' transmission range to be deterministic. Closed form analytical expression is obtained for the network connectivity probability in the presence of Nakagami fading channel. The analytical results are validated by extensive simulations.

In [87], authors present an analytical model to compute the network connectivity probability of VANET on one-way street in the presence of channel fading. The analysis provides a general framework for investigating the dependence of various parameters such as vehicle arrival rate, vehicle density, vehicle speed, Highway length, and various physical layer parameters such as transmit power, receive signal-to-noise ratio threshold, path loss exponent, and fading factors on VANET connectivity.

A major limitation is that while the connectivity results show that higher mobility generally degrades the network connectivity as in [83], [84], [85], [86] and [87], the exact dependence on the mean and standard deviation of vehicle speeds is not addressed analytically.

2.6 Chapter Summary

The reviewed schemes and protocols with their major weaknesses are summarized and highlighted in this section as open issues that need to be addressed and studied for further improvement of the VANET to infrastructure network. Table 2.2 shows the summaries of the reviewed schemes that are designed to connect VANET to infrastructure network.

Table 2.1
A Comparison between the Existing HWN Architectures

Architecture	Network types considered	Optimization criteria	Gateway used (Yes/No) And Discovery	Gateway Migration (Yes/No)	Support of Out-of-coverage MNs
V2VR [81]	WLAN VANET	Packet loss Ratio, Throughput	Yes	Yes	yes
MMGSA [5]	3G/ UMTS/ VANET	Through, Packet Delivery Ratio, Packet Loss Ratio	Yes; Hybrid	Yes	yes
CMGM [3]	3G/ UMTS VANET	packet delivery ratio, Packet drop rate, delay, throughput, control packet overhead	Yes; Hybrid	yes	Yes
SGSS [2]	3G/ UMTS VANET	packet delivery ratio, delay, throughput, control packet overhead	Yes; Hybrid	yes	Yes
MMGSS [6]	MANET WLAN	Packet drop rate, delay, throughput, Control overhead, Energy Consumption	Yes; Hybrid	yes	Yes

Table 2.2
Reviewed Schemes that are designed to Connect VANET to Infrastructure Network

Authors/Year	Title	Description	
Wan, Tang, Wolff, (2008)	Reliable routing for road side to vehicle Communications in rural areas	The protocol was proposed to connect the VANET to the internet in rural area where the terrain effect bring extra challenge. In addition, the proposed protocol use stationary access points AP's in route maintenance.	- congestio selected th One metric i.e. link life tir
Barghi, Benslimane, Assi (2009)	A Lifetime based routing for connect VANETs to the Internet	A protocol proposed to connect VANET to internet, the gateway was assumed to be stationary and link life time was used as metric to select the best route from the vehicle to gateway.	- congestio selected th metric i.e. link life tir
Setiawan FP, Bouk SH& Sasase I (2008)	An optimum multiple metrics gateway selection mechanism in MANET and infrastructure networks	An optimum multiple metrics gateway selection algorithm based on the simple adaptive weighting (SAW) technique for mobile gateway selection was proposed. Three metrics were used for appropriate gateway selection, which include mobility, remaining energy, and number of hops.	-The algori cost of crea - less relial
Benslimane, Talib, Sivaraj (2011)	Clustering Adaptive Mobile Gateway Management in integrated VANET-3G Heterogeneous Wireless Network	VANET-UMTS architecture is invented and CMGM scheme was proposed which used clustering to allow a small number of vehicles to connect to UMTS network. UMTS-RSS, mobility speed and link life time was used to select the best mobile gateway for connecting to the UMTS network	- Involve h maintainin - Bottlene gateway examined work
Rashid Saeed, Mahmoud A. Alawi, Aisha A. Hassan, Othman O.Khalifa(2011)	Simplified Gateway Selection Scheme for Multi-Hop Relay Vehicular Network	VANET-UMTS architecture is invented and SGS scheme was proposed which used a relay mechanism to allow a small number of vehicles to connect to UMTS network. UMTS-RSS, available route capacity, and link life time was used to select the best mobile gateway for connecting to the UMTS network.	- Less - delay Requ recei mess cons

CHAPTER THREE

Methodology

3.1Introduction

An end to end scheme is introduced in this chapter. It reduces dead spots and extend coverage in cellular network. This scheme enables vehicles to continue to connect and enjoy internet or other services in the area whereby there is no network coverage. Also proposed an enhanced version of HWMP which is a combination of IEEE802.11p and IEEE802.11s for multi-hop vehicular communications.

In the proposed architecture, the proposed E-HWMP is used in forming a VANET and a radiAo link to connect a VANET to 3GPP LTE base station through a gateway. LTE network is used as the infrastructure network to provide internet access to vehicles.It is assumed that the network comprises with one LTE base station together with two types of vehicles; stationary and mobile vehicles moving on the highway without intersection.

As mentioned in Chapter 2, most of the related works use clustering mechanism in order to connect vehicles to the infrastructure network (V2I). The network topology is highly dynamic in VANET scenarios so that formation and maintenance clusters bring extra overhead and degrade network performance. Multi hop communication in vehicle to vehicle (V2V) increase the network coverage. However, the result of the selection of the best relay vehicle in multi hop scenario is adding additional overhead in VANET network.

The main objective of this chapter is to enable the vehicles which are out of coverage zone to still have the access of 3GPP LTE network. Integration of Vehicular Ad-hoc Network (VANET) and 3GPP network increase the network coverage offered by 3GPP network and high data rate obtained in VANET network. However, the dead spot areas and unsuccessfully hand off processes due to high speed of vehicles can disturb the implementation of this kind of architecture. However, a frequent network disconnection of VANET to 3GPP network is result to existing of dead spot area, there is a need of having a new simplified scheme that can increase network coverage in dead spot area with low overhead.

The proposed solution has been introduced in two stages; the first stage provide anew simplified gateway selection scheme, while the second stage provides a novel routing protocol in VANET (E-HWMP).In summary, Figure 3.1 shows the methodologies to be adopted in order to achieve the objectives of this research.

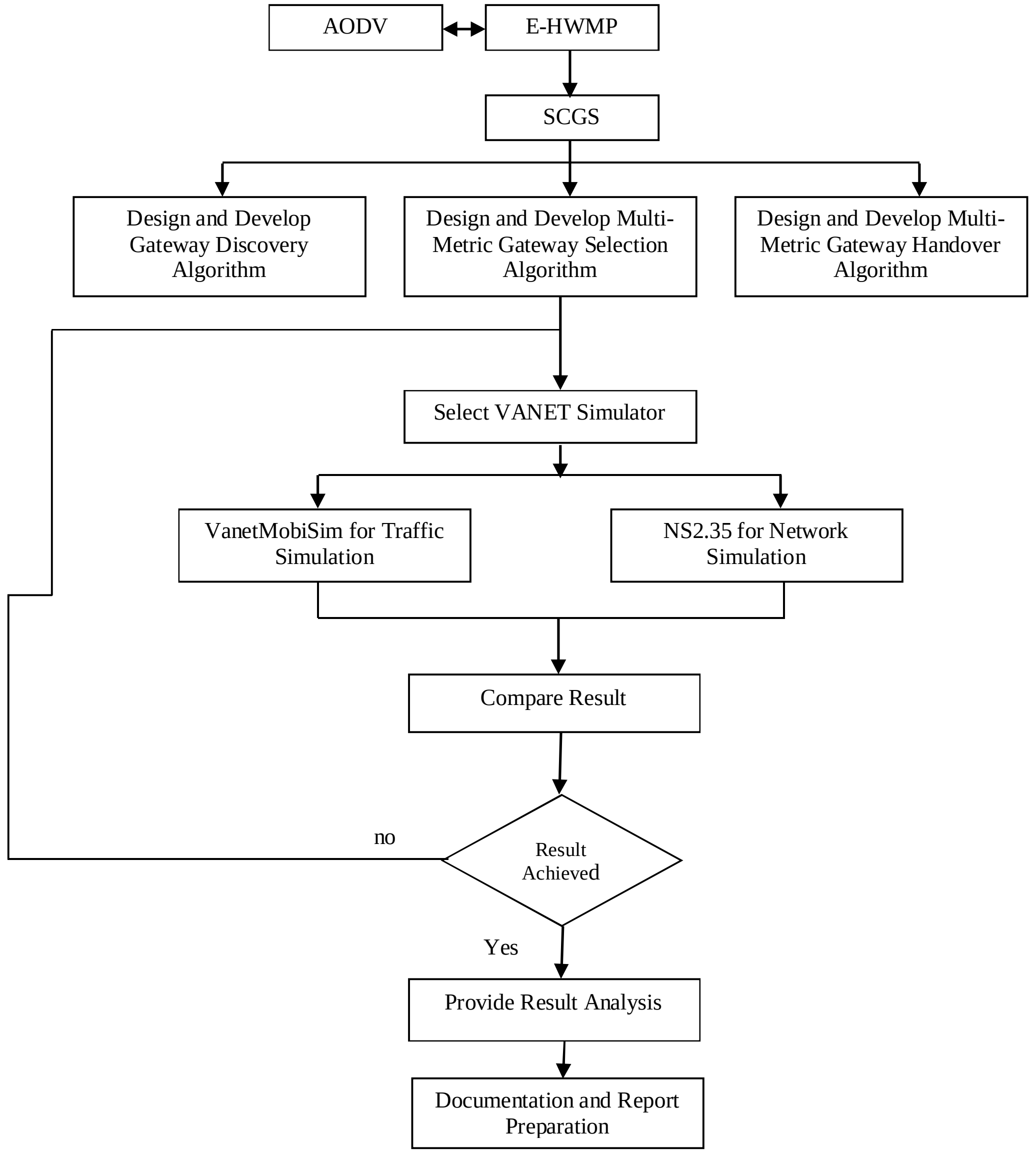

Figure 3.1: Methodology

3.2 System Model

The proposed system model shown in Figure 3.2 is cluster based, the clusters are formulated only at LTE cell edges. The topology of the proposed architecture consider a scenario of two different tracks over a particular road (e.g. Highway), with two lanes for each direction, involves vehicles moving on the highway into two opposite directions. Two types of the vehicles were assumed, vehicles inside the coverage zone have two interfaces: E-UTRAN interface and IEEE802.11p interface are called Gateway Candidates (GWCs), GWCs that are moving in the same direction are grouped into one cluster using a dynamic clustering mechanism, all GWCs having their 3GPP E-UTRAN interfaces activated and used it to connect direct to LTE network other type of vehicles occupied with only one interface (IEEE802.11p) are called ordinary vehicles, those vehicles connect to LTE network through gateway(GW), GW is the cluster head (CH) of the cluster. For position all vehicles have built-in GPS device, connect to different LTE signal strength along the road. To reduce the delay of handovers between gateways, a new gateway elected when serving gateway near tolose its optimality. Communication over the VANET network is multi-hop and the nodes of VANET communicate with each other on a peer- to-peer basis. In the proposed architecture, the IEEE802.11p WLAN mesh, forms the standard for wireless access for vehicular environment (WAVE), which utilizes vehicular communication among vehicles (V2V). The standard does not support vehicle to infrastructure (V2I) communication. An LTE eNode B is used to provide connectivity of internet to the V2V network.

An enhanced hybrid wireless mesh protocol (E-HWMP) assists any source vehicle to deliver its packet to eNodeB through GW in multi-hop manner. The main components of the LTE network are:

- Base Station Transceiver eNodeB: Communication with the GW and GWc via E-UTRAN interface.
- Serving Gateway (S-GW): Serving gateway and forward between base station and P-GW .
- Packet Data Network Gateway (P-GW): Through P-GW, LTE network is connected to the external IP networks.

In this research an Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) protocol is used to form routing over the VANET network with improved gateway selection scheme. VANET is connected to internet through LTE network using the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) interface. The number of gateway is required to be minimized to avoid bottleneck at LTE eNodeB, save access network resources and reduce hand-off frequencies .

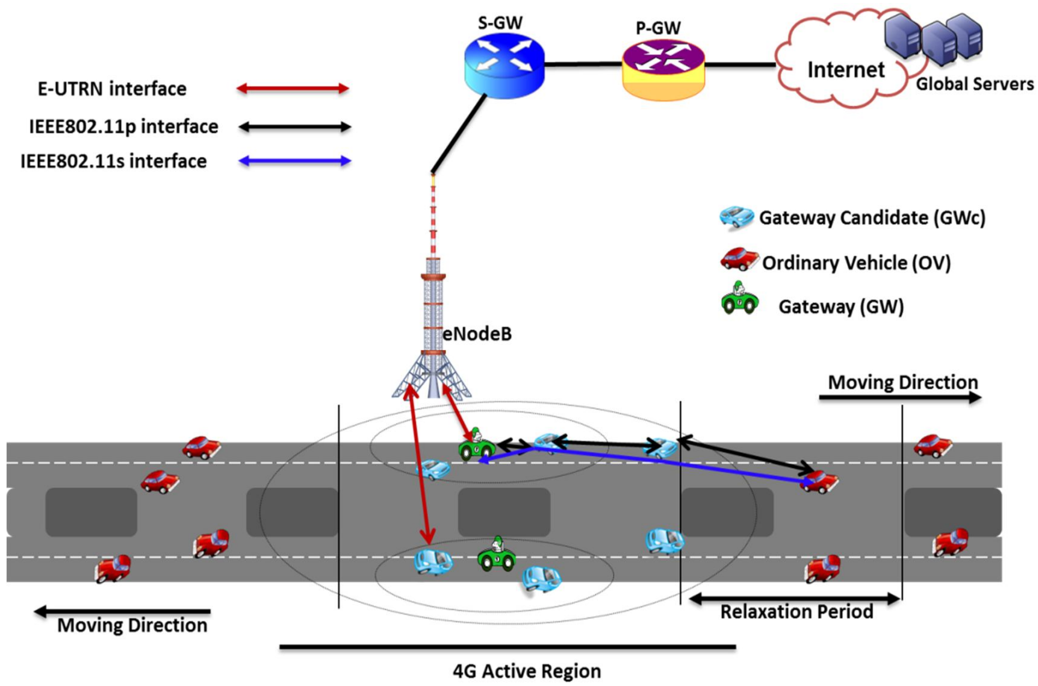

Figure 3.2: Envisioned VANET- Broadband Architecture

3.3An Enhanced Hybrid Wireless Mesh Protocol (E-HWMP)

Wireless LAN Mesh Networks (WMNs) is a type of ad-hoc networks, have gained considerable popularity and are increasingly deployed in a wide range of application scenarios, including emergency response communication, intelligent transportation systems, mining and video surveillance. WLANsis self-organizing wireless multi-hop networks and self- configured with nodes in the network, automatically establishing an ad-hoc network between nodes such that network connectivity is maintained.

An enhanced version of Hybrid Wireless Mesh Protocol (E-HWMP) is a combination of IEEE802.11p (AODV Routing Protocol) and IEEE802.11s (HWMP Routing Protocol. Proposed protocol provides a tradeoff between reactive and proactive gateway discovery solutions and bypasses the drawbacks of previous hybrid protocols, which consists of adjusting the scope for the gateway advertisement for proposed protocol. AODV was chosen over HWMP as the routing protocol to be modified. The basic idea behind hybrid routing protocols is to use proactive routing mechanisms inside the coverage zone and reactive routing on demandto be able to connect to the network through gateway in multi-hop manner.The layer-3 approach (E-HWMP) implements mesh functionality at network layer.

3.4.1 E-HWMP: Proactive Routing Protocol

E-HWMP is a proactive routing protocol for VANETs that periodically broadcast information about a route to connect toactive GW with all nodes inside the coverage zone (GWCs). At each GWC when a route information is received, a route to the GW is created and updates its E-HWMP routing table.

3.4.2 E-HWMP: Reactive Routing Protocol

E-HWMP is a reactive routing protocolfor VANETs that creates road-based paths (or routes) on-demand,this happen when the vehicle is out of coverage zone and need to continuo connect to the network, it uses a reactive mechanism to find a route in multi-hop manner through intermediate node.

Message exchanges of the E-HWMP protocol are:

1. **Gateway Announcement (GANN)**(Broadcast): use to inform about the presence of Gateway (GW). Active GW periodically broadcast GANN to all Gateway candidates (GWCs) in the cluster, Table 3.1 illustrates the GANN field. The information contained in the GANN is used to disseminate route metrics to the GW. At each GWC when GANN is received a route to the GW is created and updates its E-HWMP routing table.

IF (route entry for GANN node exists)
update route entry
ELSE
create route entry for GANN node
ENDIF

Table 3.1
Gateway Announcement (GANN)

Field	Description
Sequence Number	Destination Sequence Number
GANN ID (unique)	Identification of the Announcement Message
Destination Identification	Address of the Destination
Source Identification	Address of the source vehicle
Lifetime	The lifetime of the route to this GW.

2. **Gate Request (GREQ):** When a source node needs to connect to a gateway node,E-HWMP is designed to assist source vehicle to connect to the gateway in multi-hop manner.The source vehicle starts to sends Gateway Requestmessage (GREQ), Table 3.2 illustrates the GREQ field. GatewayRequests message are initially sent with small Time-to-Live (TTL) field, the time which a SV wait before sending another GREQ to another nearest node,. Gateway Discovery Mechanism illustrate later in this chapter.

IF (the neighbor vehicle is a GWC)
SV send multi-hop cluster request
IF (receives OK)
send their packets
Else
IF (the neighbour vehicle within multi-hop cluster)
updates the HWMP table and sends multi-hop cluster request
IF (receives OK)
send their packets
Else
IF (the neighbour vehicle is not GWc cluster nor within multi-hop cluster and reply time out)
SV search for hop to LTE
Else
SV buffer packet for available hop to LTE
ENDIF
ENDIF
ENDIF
ENDIF
ENDIF

Table 3.2

Gateway Request Message (GREQ)

Field	Description
Sequence Number	Source Sequence number
GREQ ID (unique)	Identification of the Request Message
Source Identification	Address of the source vehicle
Time to Live (TTL)	defines the scope of the GREQ in number of hops.
Hop count	field in the GREQ message provides information on the number of nodes in the path

3. **Gate Replay (GREP**) (**ACK)**: Upon receiving the GREQ by the nearest node, GREP message send by the nearest node of the source vehicleTable 3.3

illustrates the GREP field, if its GWC cluster or it's not GWC cluster but within multi-hop cluster. If a GREP is not received by the source within a short time limit after it sends GREQ, the source send GREQ to other nearest node.

IF ((nearest vehicle is GWC or within multi hop cluster)
nearest vehicle send ok to the SV
ELSE
SV send GREQ to other nearest node.
ENDIF

When the source vehicle receives the GREP it will update the E-HWMP routing table and start to send its packet.

Table 3. 3
Gateway Response Message (GREP)

Field	Description
Sequence Number	Destination Sequence number
Destination Identification	Address of the Destination
Source Identification	Address of the source vehicle
Lifetime	The lifetime field contains the lifetime of the route to this GW
Hop count	Number of hop from the source to the Relay vehicle

4. **Message Error (MERR):** Notify the source of the broken link, it is propagated to all the affected destinations.

E-HWMP works depend on three main metrics for cluster and three algorithms for gateway management. The three metrics are:

a. Direction of Movement (θ).

b. LTE Signal Strength.

c. IEEE 802.11p wireless transmission range.

The three algorithms are:

a. Multi-metric Mobile Gateway Selection.
b. Gateway Discovery/Advertisement.
c. Multi-metric Mobile Gateway Handover.

E-HWMP is designed to assist source vehicle to connect to the gateway in multi-hop manner. The destination sequence numbers are used by E-HWMP in order to detect stale routing information. Newly received routing information with a smaller sequence number than the sequence number of the corresponding information already known to the node will be discarded, because it is outdated, this avoids the creation of routing loops. The E-HWMP uses the route discovery process difference from AODV. The time to live field (TTL) defines the scope of the GANN in number of hops. Figure 3.2 show the routing mechanism evaluation.

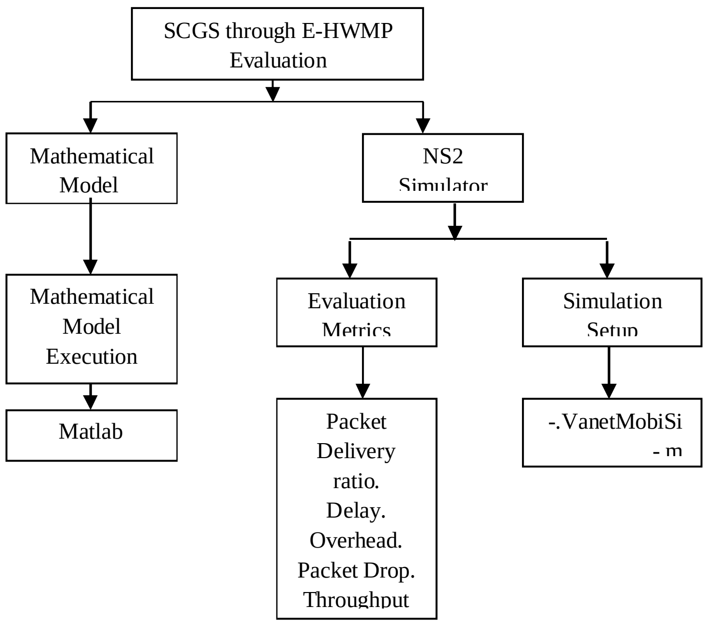

Figure 3.3: Routing Mechanism Evaluation

The main modifications has been done in aodv.cc. Here, the most important modifications are explained.

Modifications in aodv.cc

1) **void AODV::sendRequest(nsaddr_tdst, u_int8_t flag)**

   This function is invoked when a SV needs to find a route to a GW node by sending a GREQ. The GREQ is sending to the nearest node. According to the algorithm 1 described in Section 3.5

2) **void AODV::recvRequest(Packet *p)**

   This function is invoked when a nearest vehicle receives a GREQ message. The message is processed differently depending on if the nearest vehicle is a GWc or a GW a GREP is unicast back to the originator of the GREQ message. If the node is not a GWc but within multi hop cluster, tries to unicast back a

GREP to the originator of the GREQ message.

3) **void AODV::sendReply(nsaddr_tipdst, u_int32_t hop_count, nsaddr_trpdst, u_int32_t rpseq, u_int32_t lifetime, double timestamp, u_int8_t flag)**

   This function is invoked by a node that has received a GREQ and either it is the GW or has a fresh route to the GW. The function just unicasts back a GREP to the originator of the GREQ.

4) **void AODV::recvReply(Packet *p)**

   This function is invoked when a SV receives a GREP, all packets queuedin the buffer are forwarded toward the gateway.

5) **rt_entry* AODV::find_send_entry(rt_entry *rt)**

   A function that searches the routing table and returns the correct route that a packet should be sent to (the function just return the next hop as indicated in the routing table).

Modifications in aodv_packet.h:

structhdr_aodv_announcement

Gateway Announcement (GANN) (Broadcast): This new AODV message, which has been named gateway announcement (GANN), Table 3.1 illustrates the GANN field used to inform about the presence of Gateway (GW). Active GW periodically broadcast GANN to all Gateway candidates (GWCs) in the cluster. At each GWc when GANN is received a route to the GW is created and updates its E-HWMP routing table**.**

3.4 Simplified Cluster–based Gateway Selection (SCGS) Scheme

SCGS scheme allows the vehicles outside the 3GPP LTE coverage area to continue connect to 3GPP LTE network through gateway in multi-hop manner. E-HWMP is designed to assist source vehicle to connect to the gateway in multi-hop manner. Figure 3.4 shows SCGS mechanism through E-HWMP and Figure 3.5 shows the flow chart of proposed SCGS through E-HWMP when nearest node is GWc and Figure 3.6 shows the flow chart of proposed SCGS through E-HWMP when nearest node is not GWc but in multi-hop cluster. All the vehicles which are inside the 3GPP LTE coverage zone, named Gateway Candidate (GWc), use E-UTRAN interface to connect to the LTE network at the same time continuing to monitor its LTE RSS. When the LTE RSS falls below the threshold (γ), this means that the vehicle starts to move outside the 3GPP coverage area or enter to the dead spot zone.

Vehicles that are inside the coverage and move in the same direction start to form a cluster and select a cluster head (CH) to be a gateway for the cluster. The clusters are formulated only at LTE cell edges. This done by using received signal strength (RSS) threshold as a cluster formation indicator. The strong part ofthe SCGS scheme it allows the vehicle to form clusteronly at the boarder of LTE cell when the GW observed its LTE-RSS near to fall below specific threshold, at this time a cluster formulated and anew gateway elected according to the proposed algorithm of selecting the best gateway (Algorithm 2). This technique dramatically avoided the delay between the actual GW breakage, notification and new found (a new gateway selected before serving gateway lose its optimality).

Clustering enhances relay of messages, and reduces overhead associated with signaling, as links among vehicles within the same cluster tend to be more stable. The main challenge in cluster lies in the dynamic topology changes in VANET and hence, an efficient cluster should be based on adequate metrics and should take into account the frequent topology changes. The next step is to determine the TTL (Time to Live) value for each cluster (TTLc). TTLc is used for an effective relaying of control messages within the cluster. The TTLc value of the cluster is then defined as the maximum hop-length between the selected cluster head and the source vehicle. The traditional gateway discovery mechanisms are reactive or proactive in nature. In the proposed mechanism we adopt a hybrid one that combines the advantage of both approaches. Hybrid gateway discovery mechanism is an integration of Proactive and Reactive Gateway Discovery mechanisms Periodic Broadcast of GANN by active Gateway and On-demand send of GWSOL (GREQ) by Active Sources in VANE.

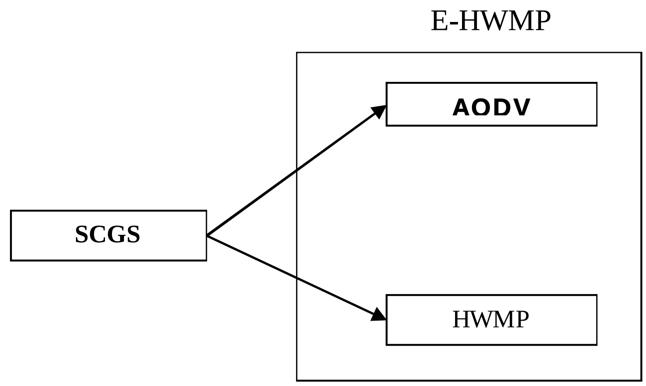

Figure 3.4: SGS Mechanism through E-HWMP

3.5 Gateway Discovery Mechanism

The proposed algorithm shown in algorithm (1) is employed to allow source vehicle to connect to LTE network through Gateway. In the proposedGateway Discovery mechanism there is no need to broadcast the packet to all the neighboring nodes, as this has an impact on reducing the overheads generated. A peer to peer mode can be utilized as a communication technique between vehicles. The proposed algorithm done in the following steps:

1. When the LTE receive signal strength (RSS) is degrades below the threshold, it means that the vehicle is nearly to move outside current LTE cell area. This will be followed by handoff to next cell or enter to the dead spot zone. The source vehicle (SV) connects to the LTE network through multi-hop and with the help of cluster head. SV sends a message for multi-hop cluster. For scalability reasons, the message includes time to live (TTL) value, which defines the scope of the GREQ in number of hops that needed to connect with the GW that can forward the source vehicle to the LTE network, and to mitigate the broadcast storm.
2. If the nearest vehicle is a GWc cluster then the SV send multi-hop cluster gateway request message (GREQ).
3. If nearest node send back GREP message to the source to inform about the route to the GW then SV send their packets, if not repeat steps 1 to 3.
4. If its nearest vehicle is not a GWc cluster but within multi-hop cluster, the source vehicle updates the HWMP table and sends GREQ (each node

maintains a route table in which next-hop routing information for destination nodes is stored. Each routing table entry has an associated lifetime value. If a route is not utilized within the lifetime period, the route is expired otherwise, each time the route is used, and the lifetime period is updated so that the route is not prematurely deleted).

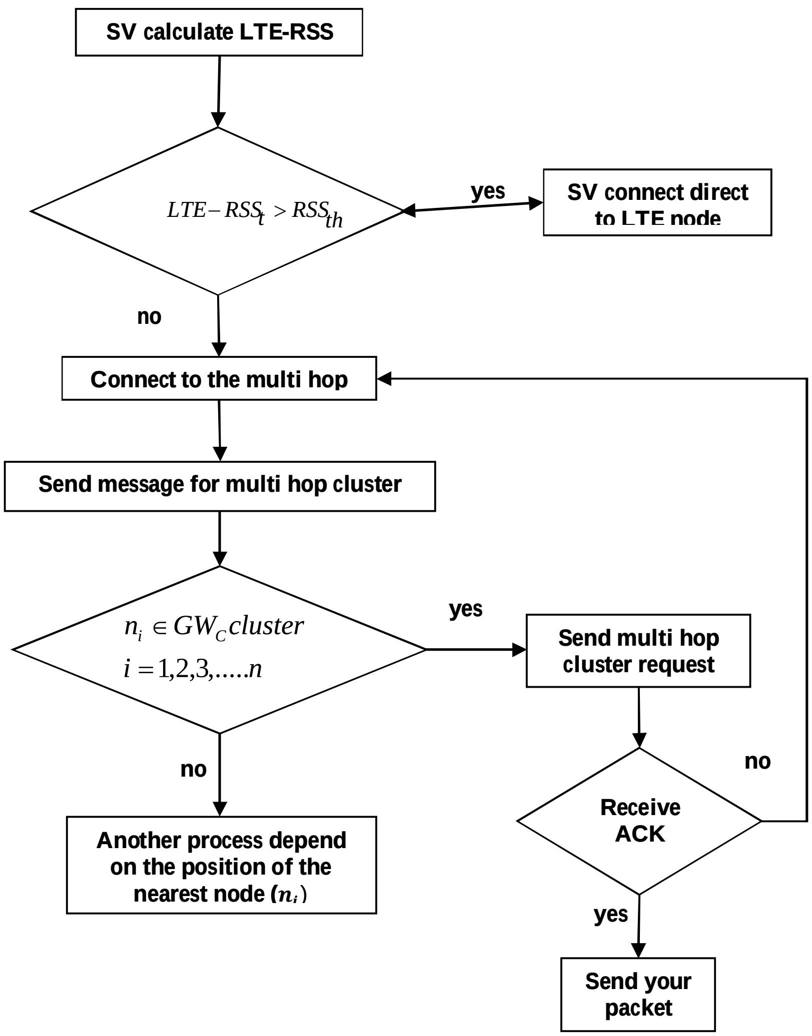

Figure 3. 5: SCGS mechanism through E-HWMPwhen Nearest Node is GWC

5. If nearest node send back GREP message to the source then SV send their packets, if not it repeats the steps 1 to 3. If nearest vehicle is not GWc cluster

nor within multi-hop cluster and reply time out, source vehicle search for hop to LTE .

6. If its nearest vehicle is neither a GWc cluster nor within a multi-hop cluster but the reply time does not out, the source vehicle socket information buffered for available hop to LTE) the idea is to buffer packets for which there is no path to the destination and attempt to deliver these buffered packets when an alternative route is found or to pass them to neighbors who might eventually be able to establish a route to the destination).

This mechanism reduces the amount of time required to find the route since all the nodes inside the cluster have already know the route to the GW

.

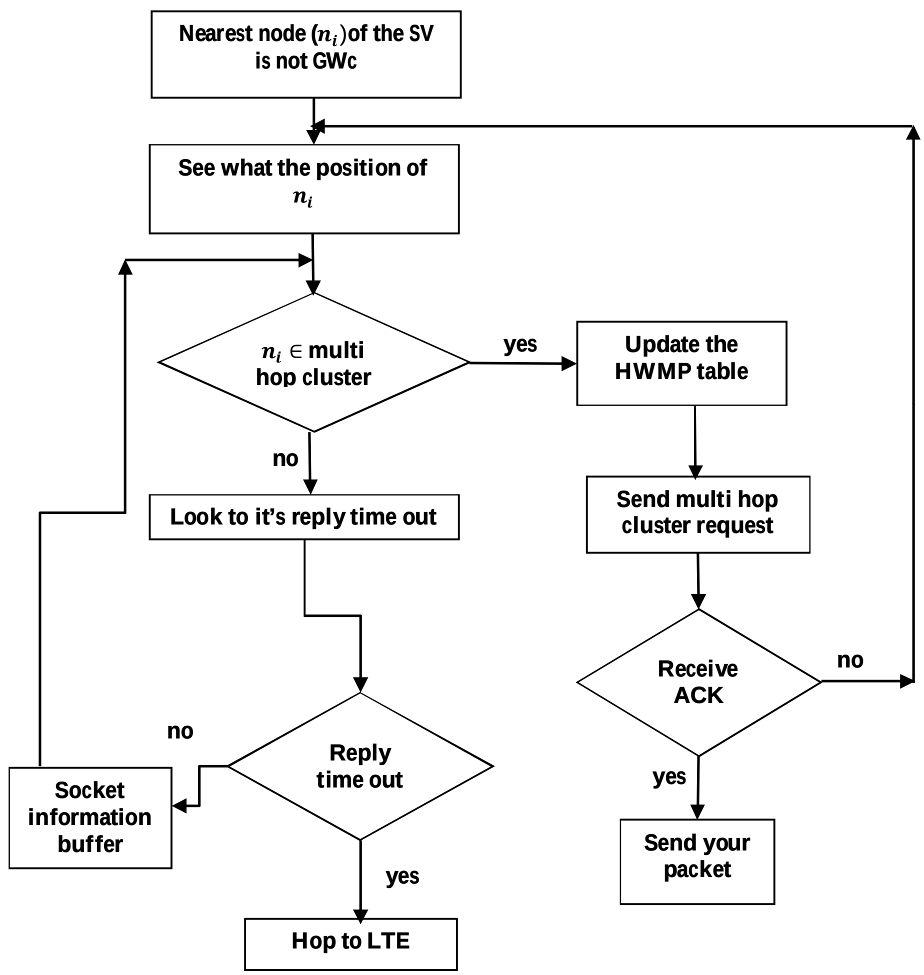

Figure 3. 6: SCGS Mechanism through E-HWMPwhen Nearest Node is not GWc

Begin Algorithm 1

1. When the source vehicle LTE receive signal strength (RSS) is degrades below the threshold, the source vehicle (SV) connects to the LTE network through multi-hop and with the help of cluster head.

2. SV connect to the multi hop and send GREQ message for multi hop cluster.

3 .When receiving GREQ by the nearest vehicle:
if (Nearest vehicle _ Type == GWc) **then**
3.1 .Source vehicle send GREQ message for multi hop cluster
if (Source vehicle receive GREP message) **then**
3.1.1Send their packet.
else
3.1.2Repeat step 2 to 3 for selecting a new nearest vehicle.
end if
else
if (Nearest vehicle _ Type != GWc and in multi hop cluster **then**
3.2Source vehicle update its HWMP table and send GREQ message for multi hop cluster.
if (Source vehicle receive GREP message) **then**
3.2.1Send their packet.
else
3.2.2Repeat step 2 to 3 for selecting a new nearest vehicle.
end if
else
4 .Look to its reply time out.
if (reply time out>1) **then**
4.1Socket information buffering.
else
4.2Source vehicle search for hop to LTE.
end if
end if
end if
End of Algorithm 1

Algorithm 1: Gateway Discovery Algorithm

3.6 Gateway Selection Parameters

The proposed Simplified Gateway Selection (SGS) flow chart shown in Figure 3.7 employed upon the available GWcs. Multi metric gateway selection algorithm is proposed (algorithm (2)) which based on the three metrics, LTE receive signal strength, available route capacity and link stability.

3.6.1LTE Received Signal Strength

In VANET, the nodes are moving in high speed which cause the frequently change LTE received signal strength. Normally, when the vehicle moves toward enodeB, its RSS is increases and if it moves away, its RSS decreases. However, the faster a vehicle moves towards or away from the enodeB, the faster the increase or decrease in its received LTE signal strength.

The LTE- RSS of the vehicles at the time t is computed as in [3]. Suppose that the velocity of the vehicle at time t is v_t and at time t-1 is v_{t-1}.The current vehicle RSS_t for LTE is calculated as shown in "Eq.3.1"

$$RSS_t = RSS_{t-1} \pm \left(1 + e^{\frac{|v_t - v_{t-1}|}{\alpha}} \right) \tag{3.1}$$

Where:

- v_t and v_{t-1}: are the vehicle speed at time t and t -1.
- α : is constant defines the rate of variation of the mobility speed in a particular movement direction relative to position of the LTE Base Station Transceiver (BST).
- $\left(1 + e^{\frac{|v_t - v_{t-1}|}{\alpha}} \right)$: denotes the changes in LTE-RSS by the corresponding changes in the mobility speed of vehicles.
- RSS_{t-1} : is the received signal strength at the time t-1.

3.6.2Available Route Capacity (AVC)

In multi hop scenario, a multiple route have vehicles common in the route from the source vehicle to relay or gateway vehicles. This causes bottleneck problem on route or on the relay node buffer as shown in Figure 3.6. To overcome these problems, the source vehicle (SV) selects the route based on available route capacity λ. Available route capacity (λ) can be defined as the minimum available load capacity at any nodeincluding intermediate nodes and the gateway node, in that route, is computed similar to the process in [6]. Suppose the maximum load capacity of node $m$is $C_{\max}$ and the current traffic load handled by m is TL_m then available load capacity of the node m is λ_A , it is computed using"Eq.3.2", and the current traffic load can be calculated using "Eq.3.3",where TL_m is the current traffic load on the node m andp_{r_j}&p_{k_j}denote the probability of theaverage packet arrival rate and the probability of the average packet size of the traffic from source j, respectively.

$$\lambda_A = C_{\max} - TL_m \quad (3.2)$$

$$TL_m = \sum_{j=1}^{s} p_{r_j} * p_{k_j} \quad (3.3)$$

The overall residual load capacity λ_i of route j is the minimum available load capacity at any vehicle. λ_i is computed in as "Eq.3.4",whereλ_j denotes the residual capacity of the intermediate nodes in the route including gateway node.

$$\lambda_i = min \sum_{j=0}^{n} \lambda_j \quad (3.4)$$

where j denotes vehicles in a route including GW vehicle.

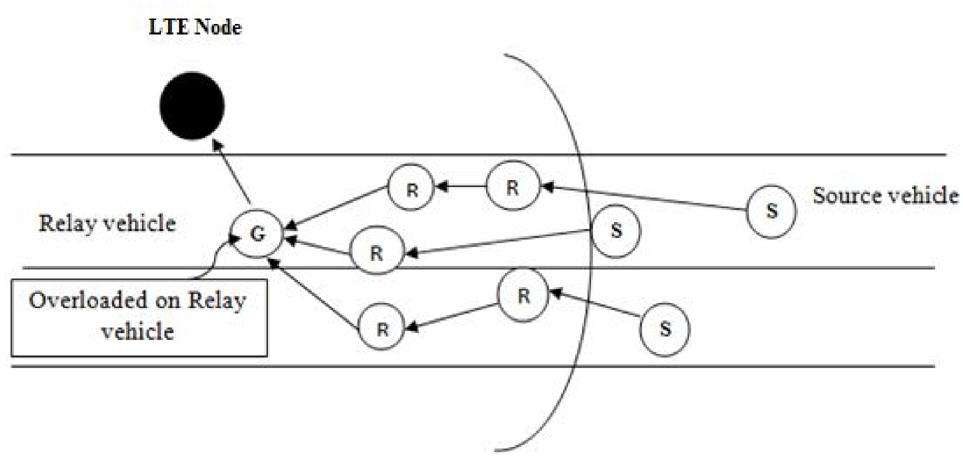

Figure 3.7 Overload problems of relay gateway vehicles

3.6.3 Link Stability(LS)

Link Stability (LS) which depends on the link Expiration time (LET) and the Route Expiration Time (RET) between the source and the CH. LET is the link lifetime between the two adjacent vehicles and the minimum lifetime between the vehicles to select gateway which is referred as (RET). Intuitively the larger the value of the LET, the higher is the stability of the link LET and RET are calculated as "Eq.3.5"and "Eq.3.6"similar to the process in [4].

$$LET_{ij} = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)R^2 - (ad - bc)^2}}{a^2 + c^2} \tag{3.5}$$

Where:

$a = v_i cos\theta_i - v_j cos\theta_j$
$b = x_i - x_j$
$c = v_i sin\theta_i - v_j sin\theta_j$
$d = y_i - y_j$

$$RET_{n-1} = \min\{ LET_{i,i+1}\}, i = 1,2,3,..., n-1. \tag{3.6}$$

(x_j, y_j) and (x_i, y_i) denote the Cartesian coordinates of two neighbor vehicles i and j , moving at speeds v_i and v_j , along two roads inclined at θ_i and θ_j $(0 < \theta_i, \theta_j < 2\pi)$ with respect to the axis, respectively. R denotes the maximum wireless transmission range.

3.7 Multi-metricGateway Selection Mechanism

The proposed Simplified Gateway Selection (SGS) algorithm is shown in algorithm (2) Similar to [2] and [3] all vehicles within the LTE coverage zone communicate through LTE E-UTRAN interface. When the LTE radio signal strength (RSS) deteriorates below the threshold, indicating that the vehicle starts to move outside the 4G coverage. Vehicles formulate cluster and select a cluster head (CH) to be a gateway for the cluster. The delay between the actual relay breakage, notification and new found are avoided (the new gateway is already elected).

It is employed upon the available GWcs (vehicles inside the converge zone and equipped with dual interface) cluster. The algorithm is based on the Simple Additive Weighting (SAW) technique [2], is used as well to outrank the optimum gateway node. Three metrics are used for mobile gateway selection: LTE RSS, available route capacity and link stability. Given the fact that, the hybrid gateway discovery mechanism is employed. The metric information of each CH lies with the GWcs of the cluster .

(SAW) technique as in [2] is used to calculate the overall metric score as the weighted sum of all metric values. There are three fundamental steps of SAW method calculations:

1. scaling the comparable value.
2. applying the weighting factors.
3. summing up the weight values of each metric .

1. **Scaling method**

Each metric has different range and value unit. Hence; we firstly have to scale the metrics to bring their values into non-dimensional values. This scaling has two ways, the positive criteria and the negative criteria [3]. Whereas in this case LTE-RSS, link stability and available route capacity are all metrics with positive criterion(i.e., more optimality with increase in values) .The best score of any criterion is 1, and the worst one is 0.Metric with positive criterion is calculated as "Eq.3.7" and Metric with negative criterion is calculated as "Eq.3.4".

$$M_i = \frac{Z_i - Z_{\min}}{Z_{\max} - Z_{\min}} \tag{3.7}$$

$$M_i = \frac{Z_{\max} - Z_i}{Z_{\max} - Z_{\min}} \tag{3.8}$$

Where:

- M_i is scaled metric value of themetric.
- $Z_{max}$is maximum value of the metric.
- Z_{min} is the minimum value of the metric.
- $Z_i$is the value of the metric.

2. **Weighting Factor**

After normalize each metric to the comparable scale, scaled values are then weighted based on the priority given to each metric. Weight is the priority given to each metric out of 1 and hence the sum of weights is always equal to 1, is computed similar to the process in [2] as shown in "Eq.3.9"There are some ways to determine these weight factors, such as Eigen vector method [88], direct specification [89], and pair comparison [90]. Direct specification method is used to define the weight factors. Weight factor assignment is flexible where every node can select weightfactors according to their priority. Below is the prerequisite of weight factor assignment where PF is a priority factor selected by the Source Vehicle (SV), i is number of metrics, PF_1, PF_2, PF_3 are weight factors of all metrics, respectively.

$$\sum_{i=1}^{3} PF_i = 1. \qquad (3.9)$$

The last step is to calculate the final weight value (W) for each gateway candidate, are computed similar to the process in [3] as shown in "Eq.3.10".

$$W_{GWc} = \sum_{i=1}^{3} (Z_i [PF] * M_i) \qquad (3.10)$$

Where PF is priority factor selected by the source node.

The GWc with the maximum weight is selected as the gateway(CH) of the cluster. Flow chart of gateway selection mechanism is shown in Figure 3.8.

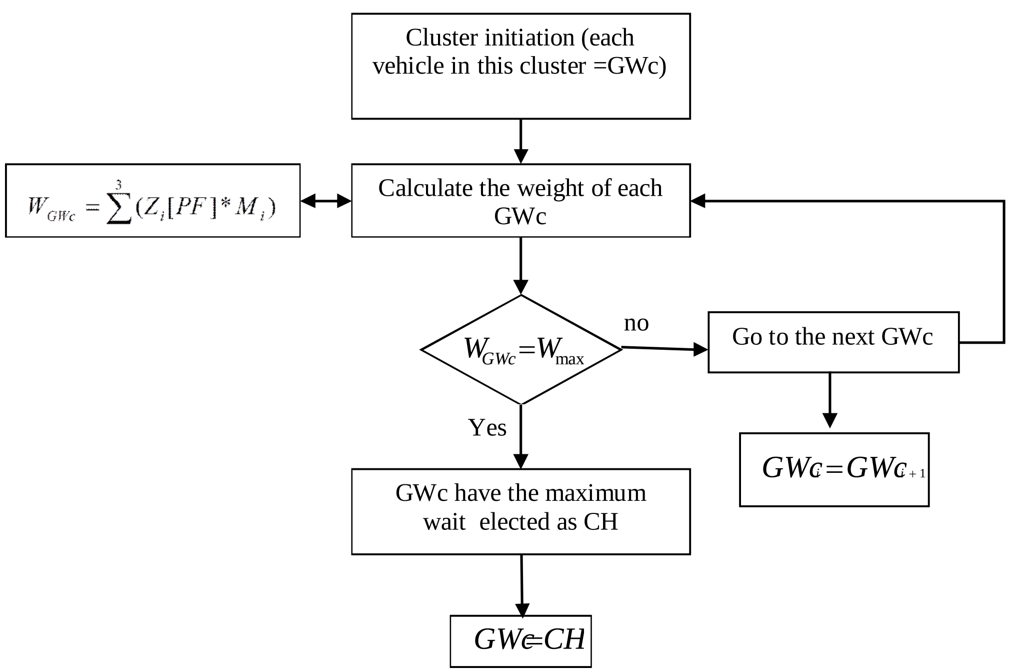

Figure 3.8: Gateway election (CH) algorithm

Begin Algorithm 2

1. Dynamic cluster initiation when serving GW observed its LTE-RSS near to fall below specific threshold (γ).

2. When the LTE radio signal strength (RSS) for serving Gateway near to fall below the specific threshold:

if (LTE-RSS[GW] == LTE-RSS_{th}) then

2.1 Calculate the weight of each GWc.

2.1.1 The scaled metric M_i must be calculated as fallow.

For each metric Z_i of the GWc, where $1 \leq i \leq 3$, **do**

if (Z_i [CRITERION] is POSITIVE) then

$$M_i = \frac{Z_i - Z_{\min}}{Z_{\max} - Z_{\min}}$$

else

if (Z_i [CRITERION] is NEGATIVE) then

$$M_i = \frac{Z_{\max} - Z_i}{Z_{\max} - Z_{\min}}.$$

end if

end if

end for

2.1.2 $W_{GWc} = \sum_{i=1}^{3} (Z_i[PF] * M_i)$.

2.2 **if (** $W_{GWc} == W_{\max}$ **)** then

The GWc with the maximum weight elected as a (CH) GW

else

2.3 **if** ($W_{GWc} < W_{\max}$)then

Go to the next GWc.

Repeat Steps 2.1 to 2.3 for electing a new *GW*.

end if

end if

end if

3. When serving GW loses its optimality the new elected GW takes place.

End of Algorithm 2

Algorithm 2: Multi-metric gateway selection algorithm

3.8 Multi-metric Gateway Handover Mechanism

To perform handover of the serving gateway to one or more optimal gateways when the serving gateway loses its optimality.

The proposed algorithm shown in algorithm (3) when LTE RSS of the gateway goes below the signal strength threshold and/or if the RET of the gateway with the source vehicle goes below its pre-determined threshold, migrate the responsibilities of the currently serving gateway to the ready new gateway, selected by SGSS. Handover, thus, aims to sustain the inter-connectivity of the integrated network to pursue the data transaction. Of course, there is no common neighbour GWc between the two different clusters

Begin Algorithm 3

Migrate the responsibility of the currently serving gateway to the new elected one with respect to its sources.

if (LTE-RSS[GW]<LTE-RSS_{th}) or (RET[GW] <RET_{th}) then

the new elected GW will take place.

Forward source vehicle data to the new elected GW.

GWc gives information about the new elected GW by using a hybrid gateway discovery and advertisement mechanism.

end if

Elected GW starts serving GW and the source vehicle starts to forward the data through the new elected GW in multi hop manner.

End of Algorithm 3

Algorithm 3: Multi-metric Gateway Handover Algorithm

3.9 ChapterSummary

In this chapter, the main aspects of the proposed “end to end” multi-hop mechanism and the main aspects of the proposed E-HWMP protocol are discussed at length.In the next chapter these proposed mechanisms will be implemented in the selected simulation tool and study the performance of the proposed scheme and compare it with the existing schemes.

CHAPTER FOUR

Simulation Models

4.1 Introduction

The Vehicular ad hoc network has recently become one of the most popular research domains in the area of Intelligent Transportation System and wireless networking, so it is necessary to evaluate the VANET protocols and applications in the real world. However, implementing and deploying VANET system in a real world can be prohibitively expensive and difficult. Consequently, most of the research in the area of Vehicular wireless communication is based on simulation for evaluation [91].

Simulations can be implemented in a personal computer and enable users to define many factors in their scenarios, for instance the number of vehicles, vehicles speed, road elements, parameters of wireless transceivers, and routing protocols. All of the statistical data about the network traffic will be collected throughout the simulation, and the researcher can use this data to evaluate VANET protocols performance. In addition, the simulators can provide the visualization trace to illustrate all the events performed in the simulation.

Simulation in VANET consists of two components: traffic simulation and network simulation. In Figure 4.1 the simulation Architecture is shown. After defining a mobility scenario in a XML file, launching the VanetMobiSim framework is necessary in order to produce a node mobility trace file in NS2 format (node identifier, time, position, speed). This file must be incorporate to the communications definition file, implemented in Tcl language. After running NS2 a trace file which logs all routing events during simulation is generated. Eventually, AWK tool is needed to filter that events trace file extracting all significant data, allowing an evaluation of the scenario.

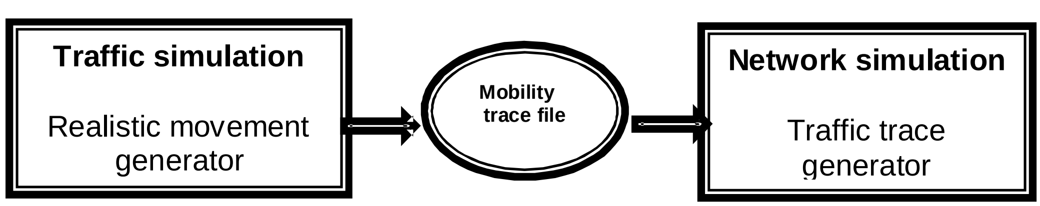

Figure 4.1:Simulation Architecture

The following sections study the vehicular mobility modelling for VANET anddescribe the characteristics of popular mobility simulators and network simulators.

4.2 Simulation Tools

The following tools take part in the VANET simulation described in this thesis: VanetMobiSim, NS2 and AWK. All the three are open-source applications and are described in more detail below.

4.2.1 VanetMobiSim

VanetMobiSim is an extension to CanuMobisim [103] which is a general purpose mobility simulator.Mobility model is a framework which describes the vehicular movement pattern and it categorized into two main classes [92]:

- Macroscopic mobility model: This model defines the macroscopic characteristic of the vehicular traffic, for instance vehicles motion constraint, road topology, velocity of vehicles, and number of lanes .
- Microscopic mobility model: This model defines the personal actions of each driver, for example it defines the behaviour of the each driver in traffic jam or car queues.

VanetMobiSim supports both micro-mobility and macro- mobility in simulating the realistic movement in the road. Thus, this application was chooses to make the simulation be more realistic and cover up as more as possible the behavior of vehicular movement in the road. After design the mobility model in VanetMobism and generate the trace file which can be imported in NS2 as mobility file. Simulation scenarios for VanetMobiSim are defined in XML format.

4.2.2 NS2.35

Network Simulator (Version 2), widely known as NS2, is simply an event driven simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2.The network simulator (ns2) contains all commonly used IP protocols. The network animator (NAM) is used to visualize the simulations. NS-2 [107] fully simulates a layered network from the physical radio transmission channel to high-level applications.After simulation, simulation produces two output file [107]:

- Trace file:This file provide a full details about the events that take place at the network.
- NAM file: It provides network animation.

In Figure 4.2, NS2 gives a text based output which can be interpreted graphically and interactively by a network animator (NAM).

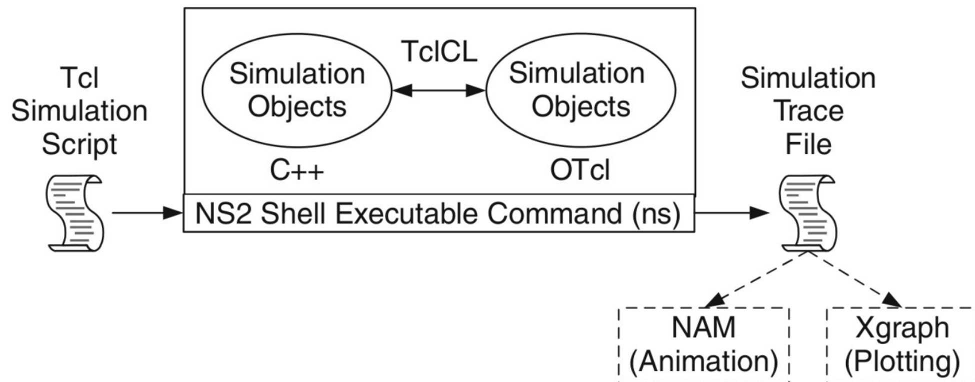

Figure 4.2: NS2 Architecture [107]

An overview of how our simulation is done in ns2 is shown in Figure 4.3.

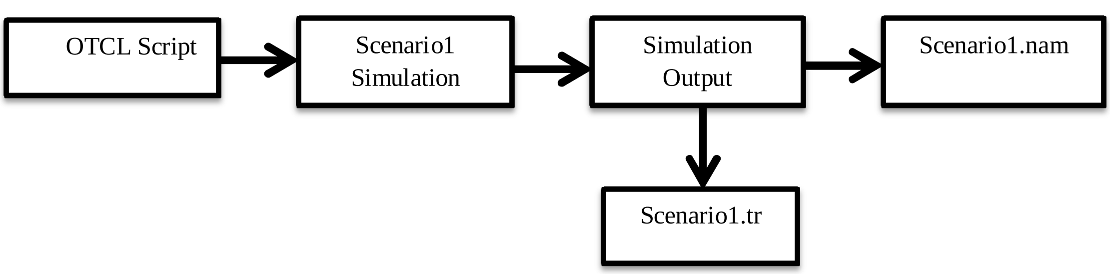

Figure 4.3: Network Simulator

4.2.3 AWK

The AWK utility [110] is a data extraction and reporting tool that uses a data-driven scripting language for the purpose of producing formatted reports. In other words, AWK is an excellent filter and files of text processor. It was created at Bell Labs in 1970s, and its name was derived from the family names of its authors – Alfred Aho, Peter Weinberger and Brian Kernighan.

A file is treated as a sequence of records, and by default each line is a record. Each line is broken up into a sequence of fields, so we can think of the first word in a line as the first field, the second word as the second field, and so on. AWK reads the input a line at a time. Then a line is scanned for each pattern in the program, and for each pattern that matches, the associated action is executed [111].

These scripts are available at AppendixC.

4.3 Scenarios and Simulation Setup

After defining the problem, introducing the essential background and implementing the proposed scheme using the proposed protocol, in this section, various simulation scenarios are run based on the tools that have been described in the previous section.

The simulations were conducted on a computer with these specifications: an Intel ® Pentium® Dual CPU at 2.17 GHz, 4 GB of RAM running Linux Ubuntu 12.04.

It has already been mentioned that the proposed scheme is implemented using the proposed protocol in ns-2. Three scenarios are implemented in the simulation that will be demonstrated in the following sections.

4.3.1 Solution Scenarios

4.3.1.1 Simulation Scenario1 with 10vehicles

Scenario 1, consider a scenario of two different tracks over a particular road (e.g. Highway), with two lanes for each directionand ten vehicles moving in these four lanes. Vehicles are assumed to be equipped with GPS devices, connect to different LTE signal strength along the road. The vehicles is designed to move in a three dimensional topology. However the third dimension (Z) is not used. That is the mobile node is assumed to move always on a flat terrain with Z always equal to

0.Thus the mobile node has X, Y, Z (=0) co-ordinates that is continually adjusted as the node moves. (x_1,y_1) = initial position. Speed limit for each lane is5 m/s and 50 m/s. 18 km/hr and 180 km/h were used respectively as the minimum and maximum speeds for the vehicles. The distance between each lane in the same direction is 50 meters and the distance between the two directions is 60 meters. The number of the vehicles was 10. The source vehicle is constant bit rate traffic sources. 500 seconds is considered as the simulation time. Simulations run twenty five times.

The simulation involves one Base station (E-Node B) which is connected to cellular network and the number of vehicles which use E-Node B to connect to the cellular network. This study uses only one base station in the simulation since the proposed model does not allow handover process between base stations. This has been done as one of the objectives that intends to study how multi hop communication can be used to increase the network coverage in the area whereby no coverage. However, handover process can take place between the selected gateway vehicle to another gateway vehicle which are used to forward the packet to E- Node B when the formal one loss their optimality. When the simulation starts all the vehicles connect directly through the E-Node B, the transmission range of E-Node B is set to 10km. When the vehicles are in transmission range no clustering are formed and all the vehicles use their EUTRAN interfaces to connect to E- Node B. When the vehicle moves away from the E-Node B and found that its LTESRSS falls below the Threshold(γ), this is the point where the vehicles start to form clusters by using multi hop communication to connect to the E-Node B. Formation of clusters inside the LTE cell was eradicated in order to reduce the overhead and to simplify the gateway selection for connection to the cellular network.

Each of the selected vehicles will initiate FTP application and send data to cellular network through E-Node B. Vehicles which located inside the coverage zone starts to send the packet to E-Node B which is part of wired network and when the vehicle observe that its LTE-RSS from the E-Node B falls below the predefined value, the vehicle will start to initiate the searching of the mobile gateway by sending the GREQ with the TTL value 10 and waiting for the reply. If no reply for about 5s which is sending time interval suggested in [20] the vehicle increases the TTL value by 10 and send again the GREQ.

It will continue to increase the TTL value and send the GREQ until it received the GREP. After getting the GREP, the vehicle will start to connect to E-Node B using multi hop communication. The migration of one gateway to another will take place if the received signal strength (RSS) drops below 25% and priority factors for three metrics in Algorithm 2 are assigned equal values (i.eMi = 1/3   for i = 1,2,3) as in [3]. Table 4.1 shows the configuration of the network in NS2 for measuring the performance of the proposed scheme. A screenshot of the simulation scenario1 is shown in Figure 4.4.

Figure 4.4: Screenshot of the Simulation Scenario1 with 10 Vehicles

4.3.1.2 Simulation Scenarios with 30 and 50 Vehicles

In order to evaluate the effect of different vehicles sizes on the performance metrics we implement another two scenarios in which the size of the vehicles 30 and 50 vehicles respectively. A screenshot of the simulation scenario2 is shown in Figure 4.5 and simulation scenario3 is shown in Figure 4.6.

Table 4.1

Simulation Parameters

Parameters	Value
Area	8000*1000
Channel	Channel/wireless channel
Propagation Model	Propagation/TwoRayGround
Network Interface	Phy/WirelessPhyExt
Mac Interface	Mac/802 11Ext
Peak Wireless Transmission Range	300m
Seed	0.0
Interface Queue Type	Queue/DropTail/PriQueue
Interface Queue Length	20 packets
Antenna Type	Antenna/OmniAntenna
Routing Protocol	E-HWMP
Total Number of VANET Vehicles	Varies between 10, 30, 50
Applications	FTP
Peak Mobility speed	50 ms−1
Mobility Model	VanetMobiSim
Simulation stop	500
LTE RSS Threshold	-94 dBM
Uplink Frequency	1.925
Downlink Frequency	2.115
Peak E-UTRAN UL Channel Bit Rate	5.2
Peak E-UTRAN DL Channel Bit Rate	10.3
Transmission Range of eNodeB	10
Node B Interface Queue length	20 packets

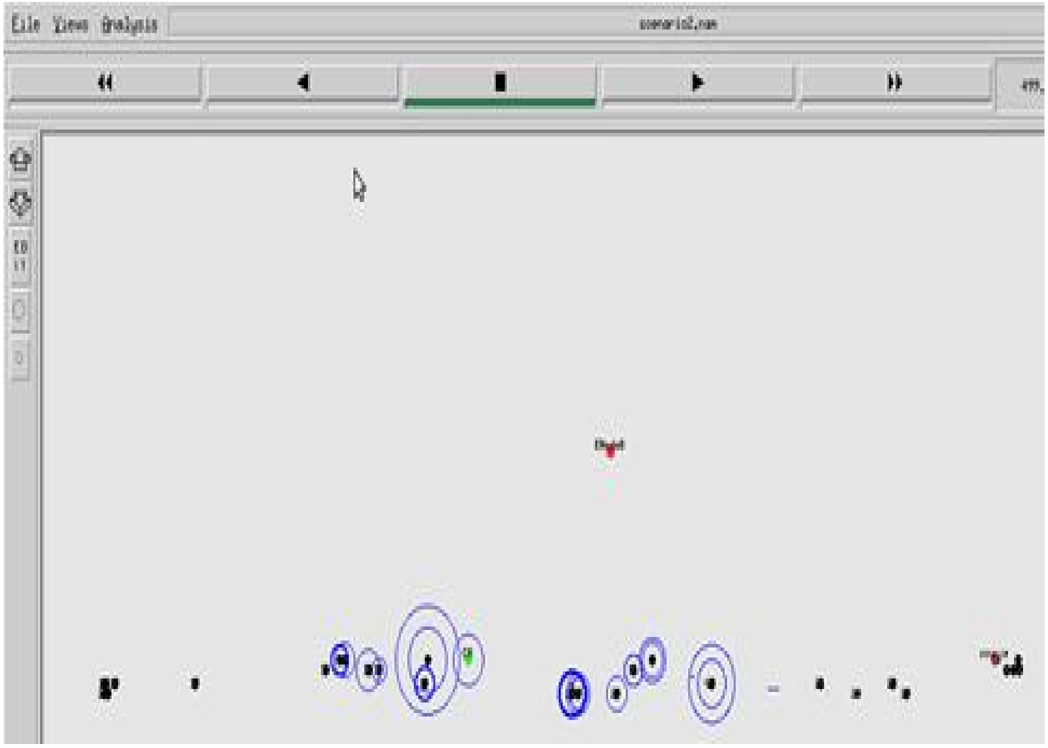

Figure 4.5: Screenshot of the Simulation Scenario2 with 30 Vehicles

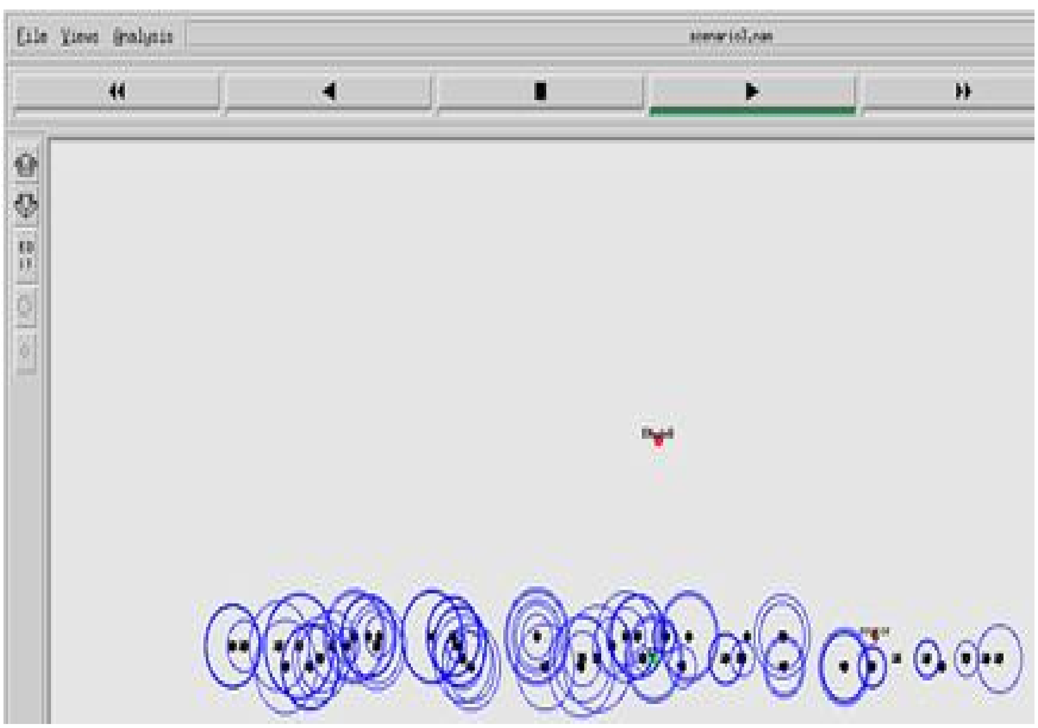

Figure 4.6: **Screenshot of the Simulation Scenario3 with 50 Vehicles**

4.3.2 Simulation Setup

4.3.2.1 Vehicular Mobility Simulation

In order to have a realistic vehicular movement pattern, it is necessary to define the attributes of this model, for instance the velocity of the vehicles, trip motion, and road topology. How to define a realistic vehicular movement model for scenario1, scenario2 and scenario3 it will be explaining in VanetMobiSim.The simulation specific parameters values are used in the VanetMobiSim-1.1 model are listed in Table 4.2. VanetMobiSimfor scenario1, scenario2 and scenario3 is shown in Figure 4.7 and Figure 4.8 and Figure 4.9.

Table 4.2

Scenario Mobility Features

Mobility Feature	Parameters/value
Type of road	Highway
Topology size	8000 × 1000
Number of lanes	2 lanes for each direction, vehicle move in opposite direction
Maximum speed	Varies between 5 to 50 m/s and from 18 to 180 km/hr
Number of.	Varies between 10, 30, 50
Simulation period	Simulation period 500s
Stop time	1 to 3s

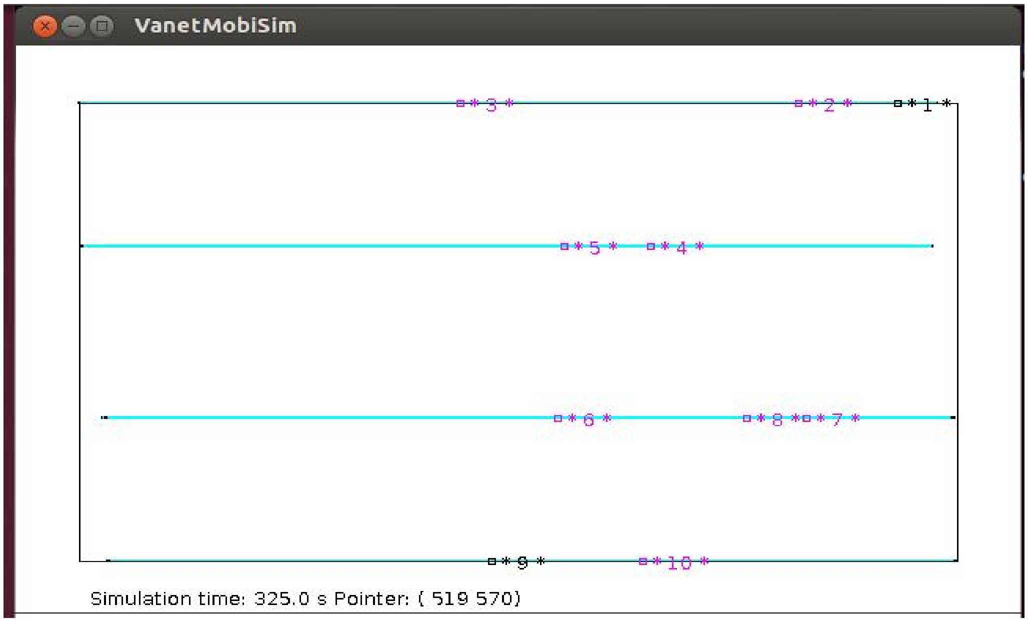

Figure 4.7: Vehicles Mobility Model for 10 Vehicles in the Highway

Our scenarios comprises with the creation of the highway with two lanes for each direction whereby the vehicles are moving in opposite directions as shown in Figure 4.7 and Figure 4.8 and Figure 4.9 and base station which is connected to the wired network. But this base station and other part of wired network are configured in network simulator and topology size of our scenario is kept to be 8000 to 1000. The scenario is defined in xml format.

After design the mobility model in VanetMobism, we simulate and generate the trace file which can be imported in NS2 as mobility file.
The set of extensions provided by VanetMobiSim consists mainly on the two following :

A vehicular spatial model, composed of spatial elements and their attributes and the relationships linking these spatial elements in order to describe vehicular areas. The spatial model is created from topological data obtained in:

- User-defined – The user defines a set of vertices and edges composing the backbone of the vehicular spatial model (.

A set of vehicular-oriented mobility models, whose main components are the support of a microscopic level mobility models. simulation scenarios for VanetMobiSim are defined in XML format.

Furthermore, it is possible in VanetMobiSim to change the number of vehicles on the road. Figure 4.7, shows only 10 vehicles in the roads but we varies the number of vehicles for different scenarios, starting from 10 to 50 vehicles From this it is understood that we change the number of vehicles in this order for the purpose of getting much details of the network behavior upon increasing of the number of vehicles.

Moreover, it is possible in VanetMobiSim to change the speed of vehicles, so we study our scheme performance in different vehicle speeds because speed of the vehicles can affect the network performance. For our simulation we change the vehicle speed the vehicles from 18 to 180 km/hr and the stop time is between 1 to 3 second. Our simulation is set to be 500s second in both VanetMobiSim and NS2 which is long enough to precisely observe the network performance.

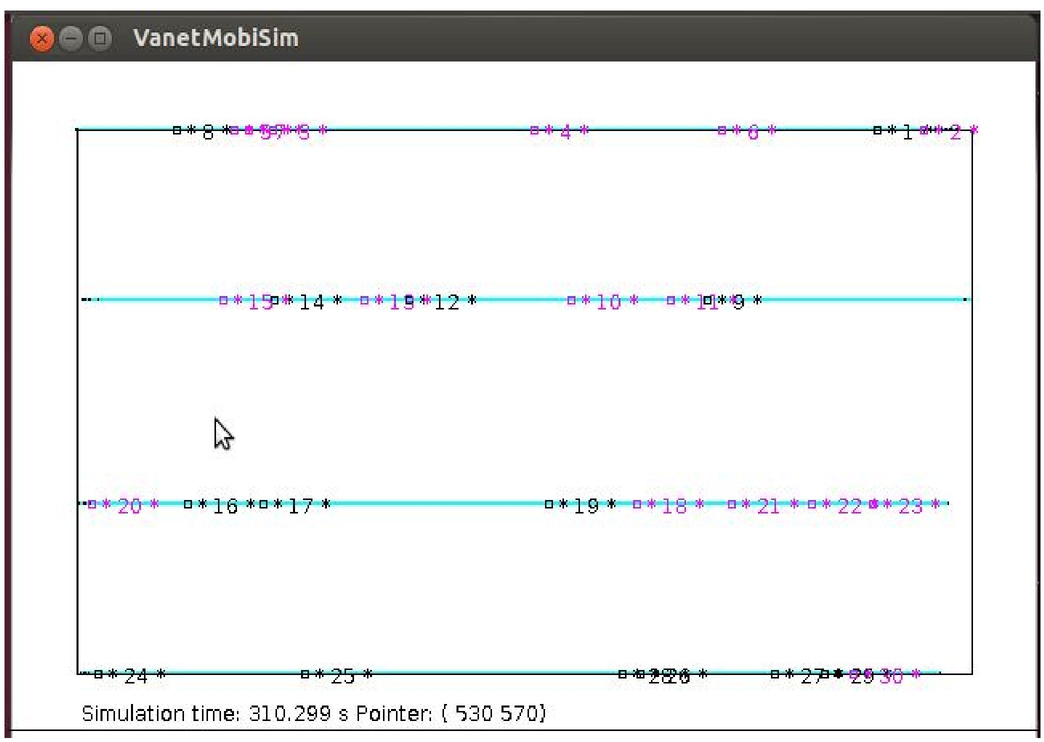

Figure 4.8: Vehicles Mobility Model for 30 Vehicles in the Highway

Macroscopic and microscopic mobility patterns and their building block is define in a XML format. The definition are:

- Road topology and path motion: define the road as a graph for each vehicle by specifying the graph’s vertex

```
<extension class="eurecom.usergraph.UserGraph" name="userGraph">
<vertex><id>0</id><x>0</x><y>550</y></vertex>
<vertex><id>1</id><x>7000</x><y>550</y></vertex>
</extension>
```

- Trip motion, initial and final destinations: define the trip motion for each vehicle by specifying the source and destination of this trip
- Human driving patterns: Define vehicle' motion with Intelligent DriverModel with Intersection Management (IDMIM). Maxim and minim speeds of each vehicle was specified. (In m/s)
- Output: VanetMobiSim generates a TCL file which defines the realistic movement of each vehicle in ns-2 simulator.

The complete xml file is available in the Appendix A .

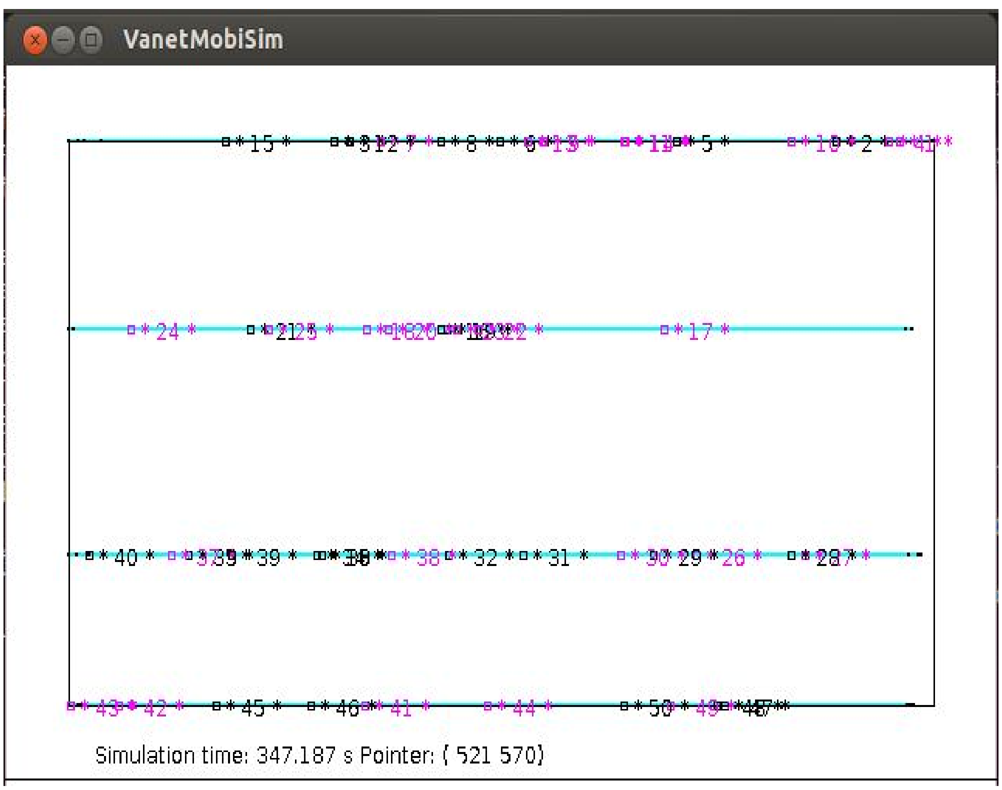

Figure 4.9: Vehicles Mobility Model for 50 Vehicles in the Highway

4.3.2.2 Network Simulation

The important part of TCL script for network simulationwill describe in this section. The complete TCL script is available in the Appendix B:

- Defining the basic parameter for simulation: This step define the information for different layers. These parameters are used for configuration of each vehicle.
    - Define the IEEE 802.11p parameter from tcl/ex/802.11: The network simulation is valid when we define all the parameter accurately.
    - Import the output file of VanetMobiSim:

puts "Loading scenario file..."

source $val(sc)

- Two-ray ground model gives more accurate prediction at a long distance.
- $ns_ trace-all $tracefile: This is the command used to setup tracing in ns.
- $ns_ namtrace-all-wireless $namfile $val(x) $val(y): This command sets up nam tracing in ns.
- To load afile you can just provide the file name without any path.
- Traffic generator CBR.
- God object stores the total number of mobile nodes and a table of shortest number of hops required to reach from node to another. The next hop's information is normally loaded into god object from movement pattern files, before simulation begins, since calculating this on the fly during simulation runs can be quite time consuming.

4.4 ChapterSummary

This chapter**,**presents and describes the simulation system and tools (VanetMobiSim, NS2 and AWK).

CHAPTER FIVE

Analytical Model

5.1 Introduction

An analytical model is developed to explain the effect of vehicle mobility on the network connectivity probability of a VANET for the two-way street scenario. The highway and vehicle mobility model that employed for the analysis is based on the work presented in [2, 3]. Consider a VANET formed by vehicles on a two-way highway operating in the free flow state, in which the vehicle speed and traffic flow are independent; thus one can drive as fast as he/she wants and can even overtake other vehicles. Vehicles enter the highway in a time interval of length Tfollowing a Poisson distribution with random speed.

The free flow traffic state has been assumed for the analysis since the connectivity of the network is very low in this state. Further the vehicle speed is assumed to be a Gaussian random variable. Based on the model; a simple closed-form expression for probability of connectivity in VANET is derive. The impact of transmission range and network density on the connectivity metrics is studied as well. In a sparse network, the density of vehicles is sufficiently low so that the vehicle radio range is quite small compared to the average inter-vehicle gap.

In a dense network, the average distance between two neighboring vehicles is similar to or smaller than the vehicle radio range, mobility models, play a key role in the performance evaluation of VANETs. If the density of the vehicles at a typical street is low, i.e. a sparse scenario in which different vehicles having independent mobility patterns. However, if the density of the vehicles increases, the mobility patterns of the vehicles affect each other.

In fact, when the street is crowded enough, there is no possibility for maneuvers and overtaking. Therefore, in general, that the distribution of speeds at that street deviates from uniform and diverts to a new distribution with more weight on lower speeds. In order to validate the approach of this thesis, results from the analytical models are compared to simulations performed with the network simulator NS2.35.

The proposed analytical model is based on the following assumption:

1) Nodes enter the highway following a Poisson distribution with arrival rate λ.
2) A highway segment with length H.
3) Random and independent vehicle mobility. Vehicles move independently at their chosen velocity.

This model is only applicable when traffic is not congested and there are no disturbing factors such as traffic signals, so is more applicable to uncongested freeway traffic.

5.2 System Model

The system model used for the connectivity analysis, which includes models for highway and vehicle mobility is briefly described as follows:

Empirical studies have shown that Poisson distribution provides an excellent model for vehicle arrival process in free flow state [112]. In this model, an arbitrary starting point of the highway is first defined, and the probability of the number of vehicles that cross the starting point at given period in each lane is modeled as Poisson process with average rate λ_i veh/s. Thus the inter-arrival times are exponentially distributed with parameter λ. Further, assume that there are K discrete levels of constant speed vi, i = 1,2,…..,K where the speeds are independent of the inter-arrival times. Let the arrival process of vehicles with speed v_i be Poisson with rate λ_i, i =1,2,…,K, that the total number of vehicles per second that cross that point are shown in "Eq. 5.1".

$$\sum_{i=1}^{K} \lambda_i = \lambda \tag{5.1}$$

These arrival processes are independent and the probability of occurrence of each speed is shown in "Eq.5. 2"

$$p_i = {}^{\lambda_i}/_{\lambda} \tag{5.2}$$

The inter-vehicle distances (IVD's) are exponentially distributed with probability is computed as shown in "Eq. 5.3"as in [113].

$$P = \sum_{i=1}^{K} {}^{\lambda_i}/_{v_i} = \lambda \sum_{i=1}^{K} {}^{p_i}/_{v_i} \tag{5.3}$$

Empirical studies have shown that the vehicle speed V in free flow state follows a Gaussian probability distribution [112]. To avoid dealing with negative speeds or speeds close to zero, two limits are defined for the speed, i.e.,v_{max} and v_{min} for the maximum and minimum levels of vehicle speed, respectively. For this, a truncated Gaussian PDF shown in "Eq. 5.4"is used as given by [114].

$$g_v(v) = \frac{f_v(v)}{\int_{v_{min}}^{v_{max}} f_v(u)du} \tag{5.4}$$

Where

$$f_v(v) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(v - \mu)^2}{2\sigma^2}\right]$$

In the Gaussian PDF, μ = average speed, σ= standard deviation of the vehicle speed, $v_{max} = \mu + 3\sigma$ is the maximum speed, $v_{min} = \mu - 3\sigma$ is the minimum speed. Substituting for $f_v(v)$in (5.4), the truncated Gaussian PDF, $g_v(v)$ shown in "Eq. 5.5" used as is given by [114]:

$$g_v(v) = \frac{2f_v(v)}{\operatorname{erf}\left[\frac{v_{max}-\mu}{\sigma\sqrt{2}}\right] - \operatorname{erf}\left[\frac{v_{min}-\mu}{\sigma\sqrt{2}}\right]}, v_{min} \leq v \leq v_{max} \tag{5.5}$$

Where erf(.) is the error function. With this model, the cumulative distribution function (CDF) of inter vehicle distance $X_i$shown in "Eq.5. 6".

$$F_{X_i}(x) = 1 - e^{\rho x}, x \geq 0 \tag{5.6}$$

Where

$$\rho = \lambda \sum_{i=1}^{M} \frac{\rho_i}{v_i} = \lambda E[{}^{1}/_{V}]$$

Here E[.] is the expectation operator and ρ represents the probability of the average vehicle density (veh/km). When the vehicle speed follows truncated Gaussian PDF, the probability of the average vehicle density ρ is computed as shown in "Eq. 5.7" is used as is given by [114]:

$$\rho = \frac{2\lambda\sqrt{2\pi}\sigma}{\mathrm{erf}\left[\frac{v_{max}-\mu}{\sigma\sqrt{2}}\right]-\mathrm{erf}\left[\frac{v_{min}-\mu}{\sigma\sqrt{2}}\right]} \times \int_{v_{min}}^{v_{max}} \frac{1}{v} \exp\left[\frac{-(v-\mu)^2}{2\sigma^2}\right] dv \qquad (5.7)$$

It may be noted that the probability of the average vehicle density given in (5.7) does not have a closed form solution, but has to be evaluated by numerical integration. Since each vehicle enters the highway with random speed, the number of vehicles on the highway segment of length H is a random variable. The probability of the average number of vehicles on the highway segment, in the steady state is then given by $N = \rho H$.

5.3 Analysis of Network Connectivity

Consider the two-way street (consisting of lower and upper streets) shown in Figure 3.2. Assume that vehicles are moving from right to left on the lower street; and from left to right on the upper street. Let ρ_1 and ρ_2 respectively represent probability of the average vehicle densities on the lower and the upper street; and let N_1 and N_2 respectively represent the probability of the average number of vehicles on these streets. Further, assume V_1 and V_2 to be the random variables representing vehicle speed and λ_1 and λ_2 respectively represent the vehicle arrival rates on these streets. Assume that μ_i and σ_i $(i = 1,2)$ respectively be the mean and the standard deviation of vehicle speed on these streets. Then, we have $N_1 = \rho_1 H$ and $N_2 = \rho_2 H$, where H is the highway length; ρ_1 and ρ_2 are computed according to "Eq. 5.7". It is assumed that packets are relayed from the left to the right of the road segment on the lower street, which means that packets are relayed in the opposite direction of vehicle movement. This is a reasonable assumption because traffic information such as safety warning, is usually relayed from the source vehicle to the vehicles following it. A multi-hop route established between two vehicles may get disrupted due to mobility of the source, the destination (GW), or the intermediate vehicles, causing route failures to occur.This study proceed to derive an analytical expression for the network connectivity on one-way street (lower street), and use this expression to find network connectivity on two-way street.

5.3.1 Network Connectivity on One-Way Street

Consider the network formed by vehicles on the main (lower) street, where the probability of the average number of vehicles is equal to N_1, which corresponds to (N_1-1) links on the street. Two consecutive vehicles in the network will be connected if the inter-vehicle distance between them is smaller than vehicle's transmission range R. Accordingly, the probability that two consecutive vehicles M_i and M_{i+1} are connected is given by $P_r(X_i \leq R)$ where X_i is the inter-vehicle distance. The network will be connected if there is a path connecting any pair of vehicles. More precisely, it is required that the inter-vehicle distances$X_i \leq R$ for $i = 1,2,3, \ldots, N_I - 1$. Let P_{LC} be the probability that a pair of consecutive vehicles in the network are connected (link connectivity probability). As mentioned before, this probability is computed as P_{LC} = $P_r(X_i \leq R)$. It may be noted that both X_i and R are independent random variables. Accordingly, we find this probability is computed as shown in "Eq. 5.8":

$$\rho_{LC} = 1 - \int_0^{\infty} \rho_{r}\{R < x | X_n = x\} f_{x_i}(x)dx \tag{5.8}$$

where $f_{x_i}(x)$ is the PDF of the inter-vehicle distance . Let P_{NC} be the probability that the network is connected. It follows that

$$\rho_{NC} = \rho_r(X_1 \leq R, X_2 \leq R, \ldots, X_{N1-1} \leq R)$$

Note that $\{X_n; n \in i, \ldots, N_I - 1\}$are random variables [115]. Hence the network connectivity probability of one-way street ($P_{NC,1-way}$) is computed as shown in "Eq.5.9".

$$P_{NC.1-way} = \left[1 - \int_0^{\infty} Pr\{R < x | X_n = x\} f_{x_i}(x)dx\right]^{N_I - 1} \tag{5.9}$$

5.3.2 Network Connectivity for the Two-Way Street

This section present the connectivity analysis for the two-way street scenario. Consider the two-way street scenario shown in Figure 3.1, where source vehicles on the lower street or on upper street is nearly to move outside current LTE cell area, The source vehicle continuo connects to the network, relay packets opposite to their direction of motion, through multi-hop and with the help of cluster head. The nodes of the VANET communicate with each other on a peer-to-peer basis. Let P_{LB} be the probability that connectivity on a specific link is lost (i.e., the link is broken) on the lower street. This happens when the IVD between a pair of vehicles becomes greater than the transmission range. Accordingly, P_{LB} is equal to the complement of the link connectivity probability P_{LC}. Thus we have,

$$P_{LB} = P(X_i \geq R) = 1 - P_{LC} \qquad (5.10)$$

where P_{LC} is computed using "Eq. 5.8". Out of a total of (N_1 – 1) links on the lower street, the probability that J of these links will be broken, is given shown in "Eq. 5.11" as in [114]

$$P_J(j) = (P_{LB})_j = (1 - P_{LB})_{(N_I - 1) - j}; j = 0,1, \dots, N_1 - 1 \qquad (5.11)$$

If all of the broken links on the lower street are fixable with the help of vehicles on the upper street, the network connectivity on the lower street can be continuous. Consider the broken link between vehicles M_i and M_{i+1}. This broken link is fixable if there is at least one vehicle on the upper street in the interval of length 2R centered onMi. Let U be a random variable denoting the number of vehicles that are present in the interval of 2R on the upper street. According to the system model described earlier in thischapter, the IVDs on the lower as well as the upper street are exponential with parameters ρ1 and ρ2 respectively. Hence the number of vehicles on the lower and upper street is Poisson with parameters ρ1 and ρ2 respectively. Accordingly U is also Poisson with probability mass function given as shown in "Eq. 5.12":

$$P(U = u | R = r) = P_{U/R}(u/r) = \frac{(2r\rho_2)^u}{u!} e^{-2r\rho_2} \qquad (5.12)$$

A broken link on the lower street is not fixable if there are no vehicles in the interval of 2R on the upper street. Thus the conditional probability that broken link is not fixable is computed as$P(U = 0 | R = r) = e^{-2r\rho_2}$.

Conditioning, the probability that a broken link is not fixable ($P_{L,nf}$) is calculated as shown in "Eq. 5.13":

$$P_{L,nf} = \int_{r=0}^{\infty} e^{-2rp_2} f_R(r)dr \quad (5.13)$$

where $f_R(r)$ is the PDF of R.

Let $P_{NC,J}$ be the conditional network connectivity probability given that there are J broken links. Since the probability that each broken link is fixable is equal to 1- $P_{L,nf}$, Pc/j is computed as shown in "Eq. 5.14":

$$P_{(NC.\because J=j)} = (1 - P_{L,nf})_j ;j=0,1,2,\ldots,N1-1 \quad (5.14)$$

The network connectivity probability on the two-way street is then computed as shown in "Eq. 5.15" as in [114]:

$$P_{NC,2-way} = \sum_{j=0}^{N_1-1} P_{(C.\because J=j)} P_J(j) \quad (5.15)$$

It may be noted that, to compute $P_{NC,2-way}$ according to (5.15), Equations (5.11), (5.14) must be used.

5.4 ChapterSummary

In this chapter, the main aspect of the proposed analytical model is discussed at length. In the next chapter the result obtained from the analytical model will be compared to the result obtained from simulation.

CHAPTER SIX

Results and Discussions

6.1 Introduction

The objective of this chapter is to evaluate the performance of E-HWMP and investigate within the effectiveness of the SGS scheme implemented in this standard. In order to achieve this aim, five performance metrics are analyzed: Packet Delivery Ratio, End-to-End Delay, Control Packet Overhead, Throughput and Packet Loss. The definitions of network performance metrics are written based on these papers: [115], [116], [117].

- **Packet delivery ratio**

The number of received packets compared to the number of generated packets is defined as the packet delivery ratio. This parameter determines the protocol's performance in terms of delivery of packets, while speed, acceleration or payloads are variables. This property can be defined as:

Packet delivery ratio = (**received packets / generated packets)**

Note that packet drop ratio can be calculated as: 1 - (packet delivery ratio).

- **Delay metric**

This refers to time elapse since the Source Vehicle (SV) send the GReq until the gateway is selected.

- **Control Packet Overhead**:

This measures the ratio of the total number of control packets to the total number of packets generated within the VANET- cellular network integration.

- **Throughput**

This is defined as the total amount of data a receiver receives from the sender divided by the time between receiving the first packet and last packet.

6.2 Simulation Results

To study the performance of the proposed scheme, the scheme is implemented using E-HWMP routing protocol and the scenario is simulated using the network configuration as shown in Table 4.4. The number of the vehicles varies between 10, 30 and 50, the transmission range of vehicle wireless device kept constant. The vehicles are moving with high speed with the minimum speed is 18km/h and the maximum was 180km/h.

In Figure 6.1 it is observed that the packet delivery ratio is higher. For lower speed of vehicles but when the speed of the vehicles is increased the packet delivery ratio decreased. Also it is observed that the packet delivery ratio is higher when there is a large density of vehicles with low speed more than the small density of vehicles with low speed.

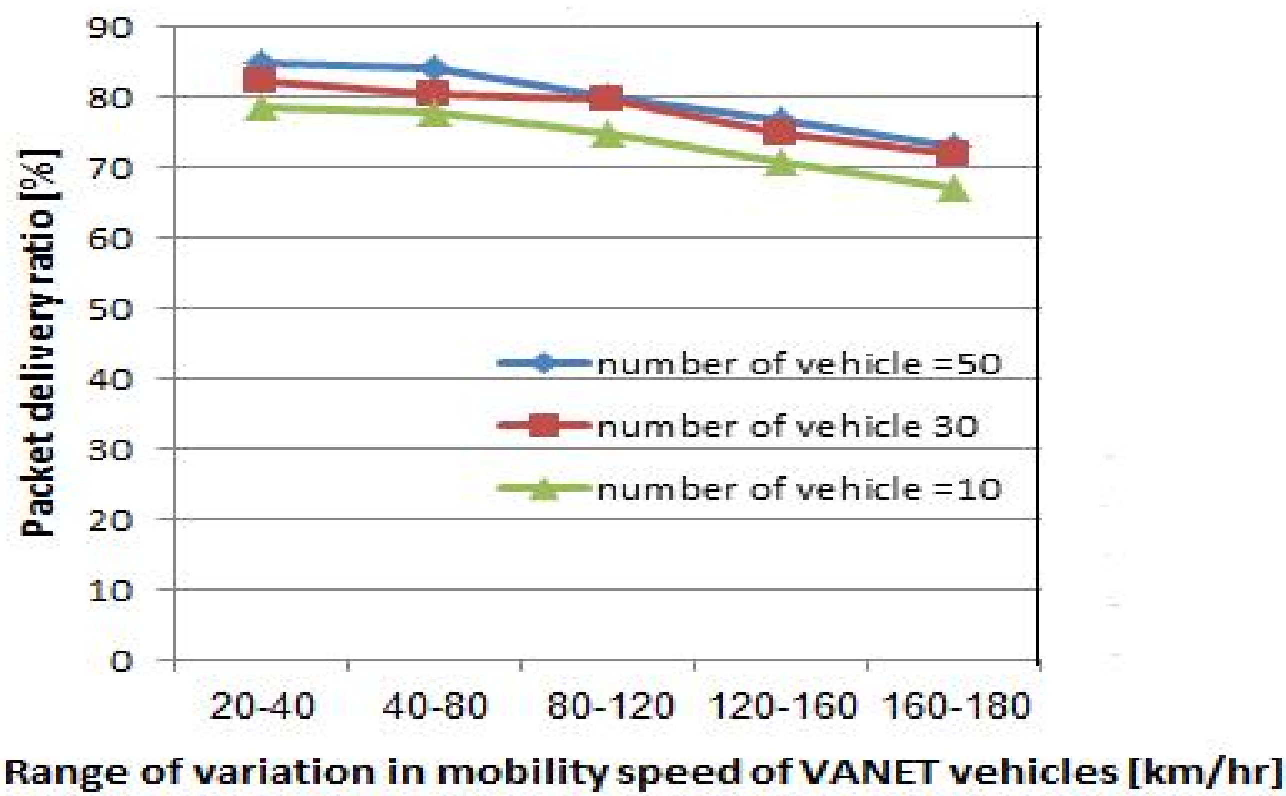

Figure 6.1 Packet Delivery Ratio of the Proposed Scheme with E-HWMP Routing Protocol with Variation of Mobility Speed of Vehicles

In Figure 6.1 it is observed that the packet delivery ratio is higher for lower speed of vehicles but when the speed of the vehicles was increased the packet delivery ratio was decreased. Also it is observed that the packet delivery ratio is higher when there is a large density of vehicles with low speed more than the small density of vehicles with low speed.

In Figure 6.2 it is observed that the packet drop ratio was increased for high speed of vehicles but when the speed of the vehicles was decreased the packet drop ratio was decreased. Also it is observed that the packet drop ratio is lower when there is a large density of vehicles with low speed more than the small density of vehicles with low speed.

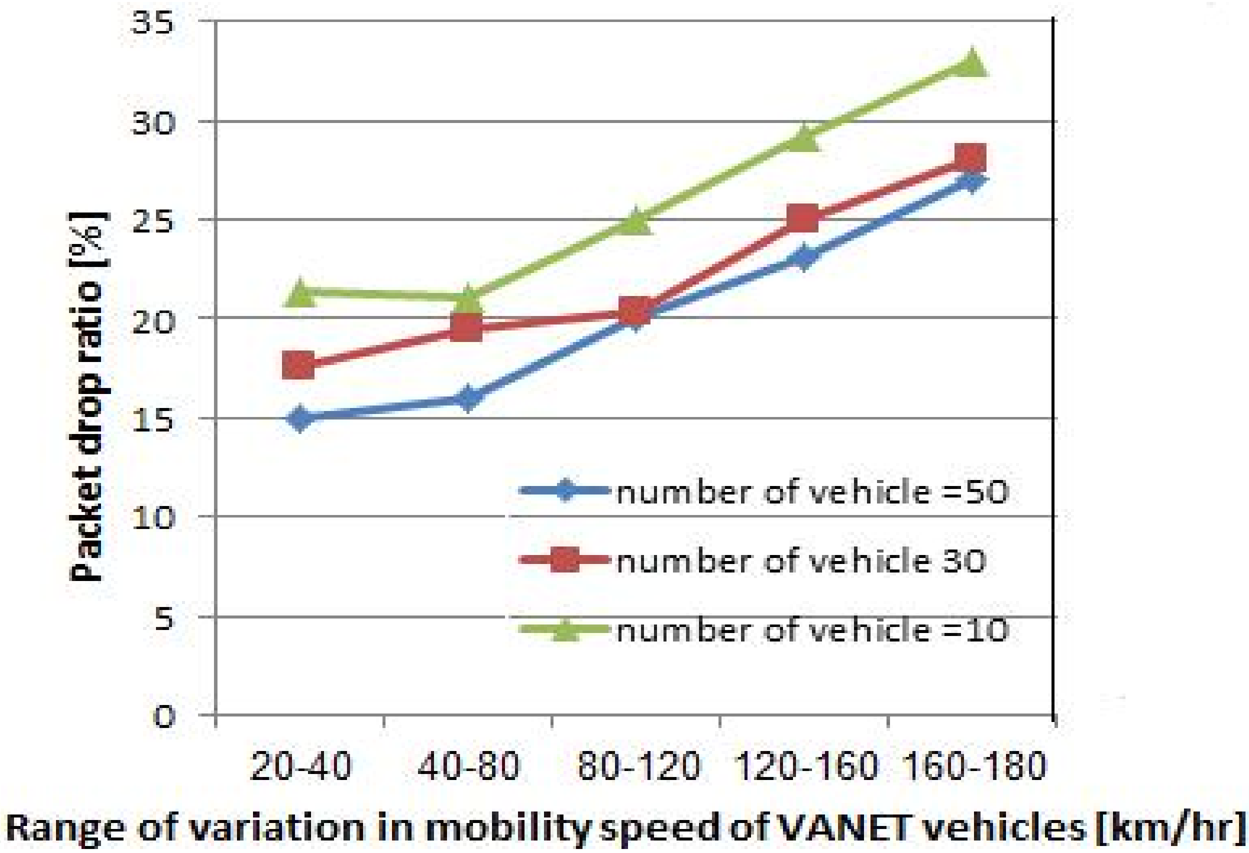

Figure 6.2 Packet Drop Ratio of the Proposed Scheme with E-HWMP Routing Protocol with Variation of Mobility Speed of Vehicles

In Figure 6.2 it is observed that the packet drop ratio was increased for high speed of vehicles but when the speed of the vehicles was decreased the packet drop ratio was decreased. Also it is observed that the packet drop ratio is lower when there is a large density of vehicles with low speed more than the small density of vehicles with low speed.

In Figure 6.3 it is observed that the gateway selection delay of the proposed scheme is increased for small number of vehicles but when the number of the vehicles increases the gateway selection delay of the proposed scheme decreases.

In Figure 6.4 it is observed that the average throughput of the proposed scheme is increase for large number of vehicles but when the number of the vehicles decreases the throughput of our scheme decreases.

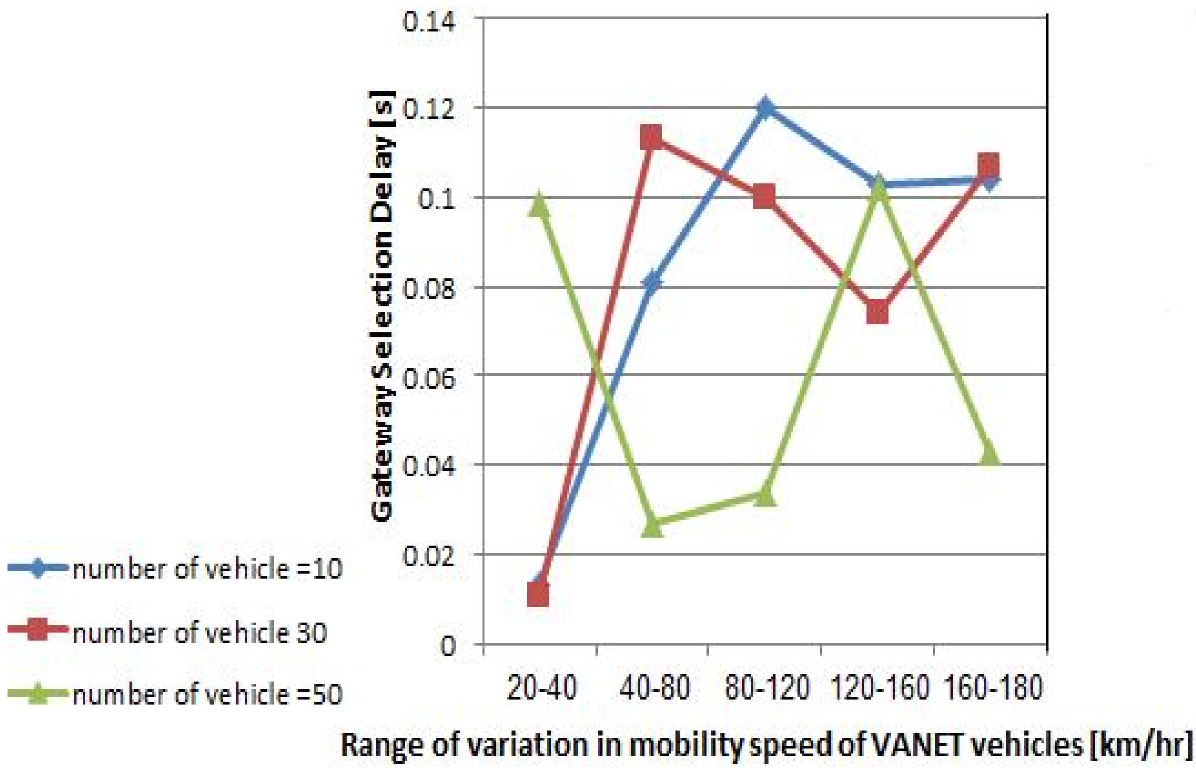

Figure 6.3 Gateway Selection Delay of the Proposed Scheme with E-HWMP Routing Protocol with Variation of Mobility Speed of Vehicles

In Figure 6.3 it is observed that the gateway selection delay of the proposed scheme is increase for small number of vehicles but when the number of the vehicles increase the gateway selection delay of the proposed scheme decrease.

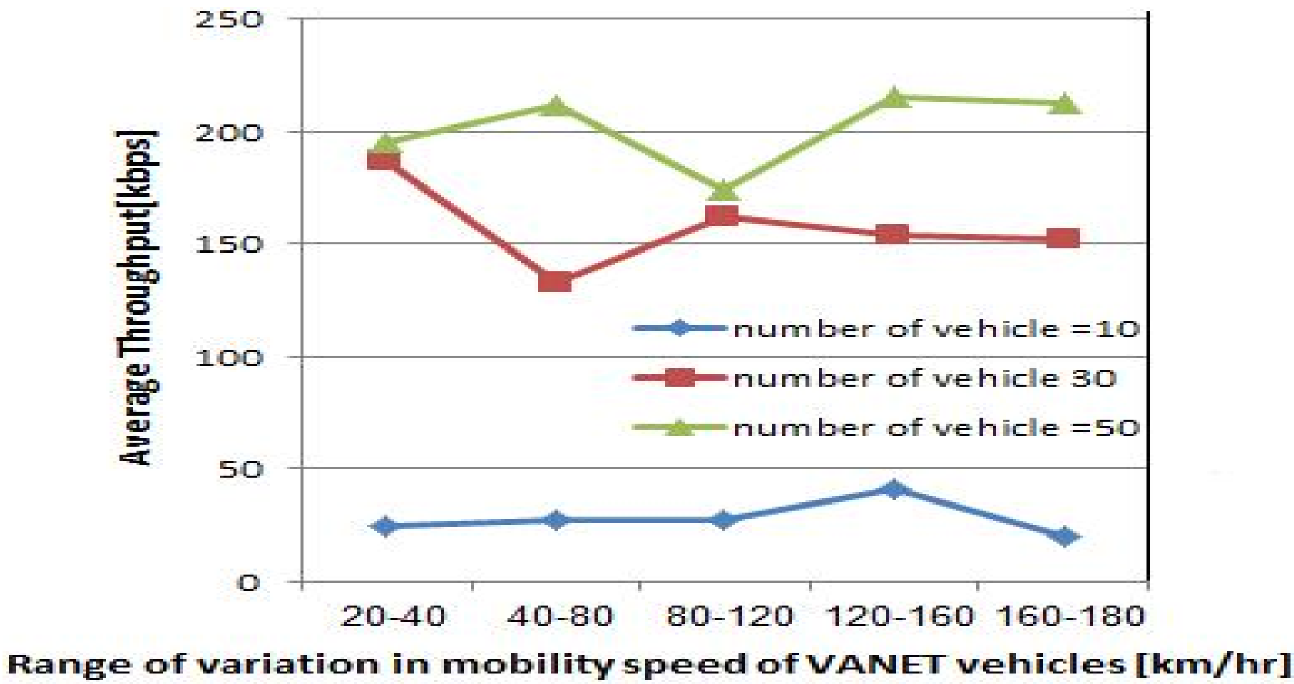

Figure 6.4 Throughput of the Proposed Scheme with E-HWMP Routing Protocol with Variation of Mobility Speed of Vehicles

In Figure 6.4 it is observed that the average throughput of the proposed scheme is increase for large number of vehicles but when the number of the vehicles decrease the throughput of the proposed scheme decrease.

In Figure 6.5 it is observed that the proposed mechanism achieve a good performance in terms of lower packet drop ratio compared to the CMGM and SGS schemes. It can be pointed out that the reason for this is the fact that in the scheme all vehicles inside the coverage zone are allowed to communicate directly to the base station, which reduces the frequent network disconnection. When the vehicles are outside the coverage, E-HWMP assists any source vehicle to deliver its packet to BST. Regardless of the underlying protocol, indeed, the number of sources increases, the packet drops, subsequently increases, especially when the gateway is on the verge of losing its optimality.

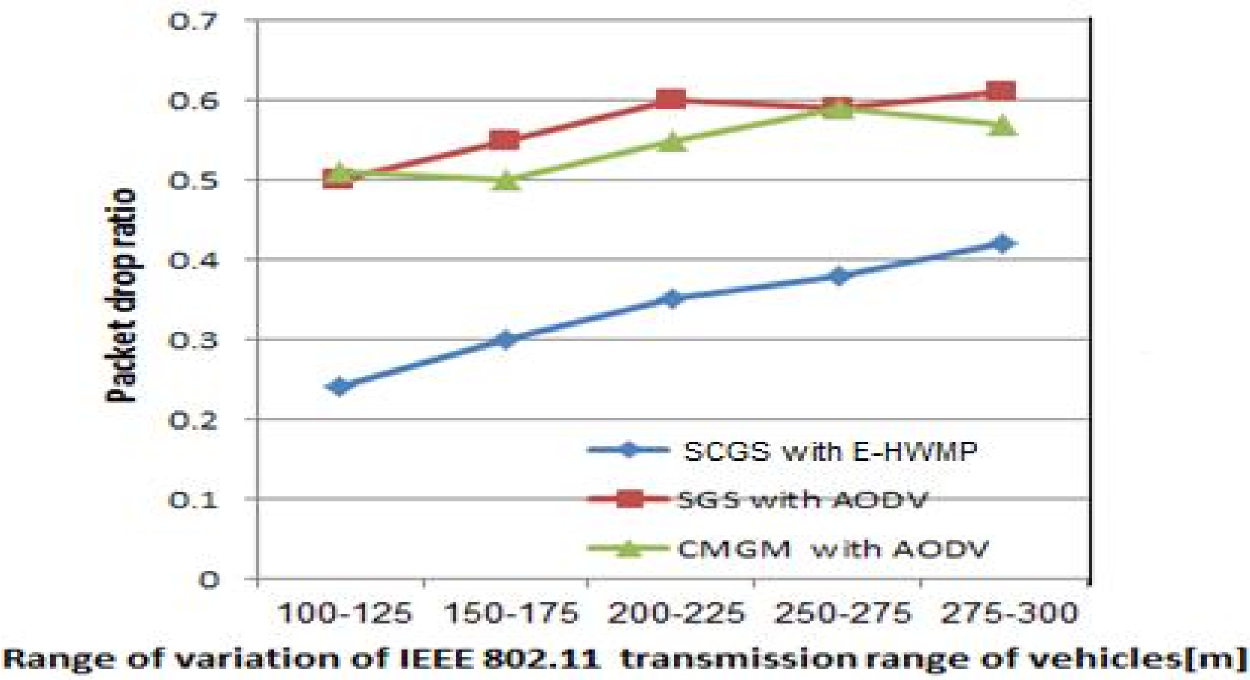

Figure 6.5: Packet Drop ratio of SCGS with E-HWMP, SGS with AODV and CMGM with AODV in a range of Variation of IEEE802.11 Transmission Range of Vehicles

In Figure 6.6 it is observed that the proposed mechanism achieve a good performance in terms of less control packets overhead compared to the CMGM and SGS schemes in a range of variation of ieee802.11 transmission range of vehicles.

In Figure 6.7 it is observed that the proposed mechanism achieve a good performance in terms of higher packet delivery ratio compared to the CMGM and SGS schemes. It can be pointed out that the reason for this is the fact that in the proposed scheme all vehicles inside the coverage zone are allowed to communicate directly to the base station, which reduces the frequent network disconnection; when the vehicles are outside the coverage, E-HWMP assists any source vehicle to deliver its packet to BST.

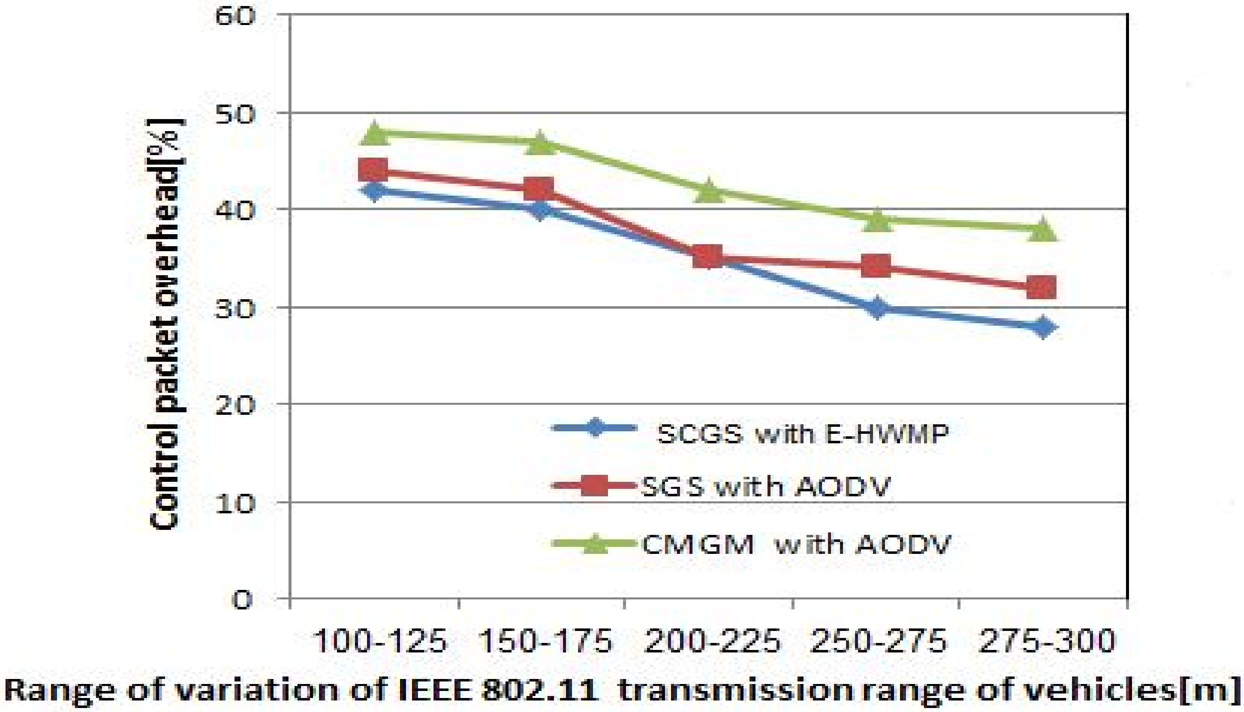

Figure 6.6 Control Packets overhead of SGSS with E-HWMP and with AODV and CMGM with AODV in a Range of Variation of IEEE802.11 Transmission Range of Vehicles

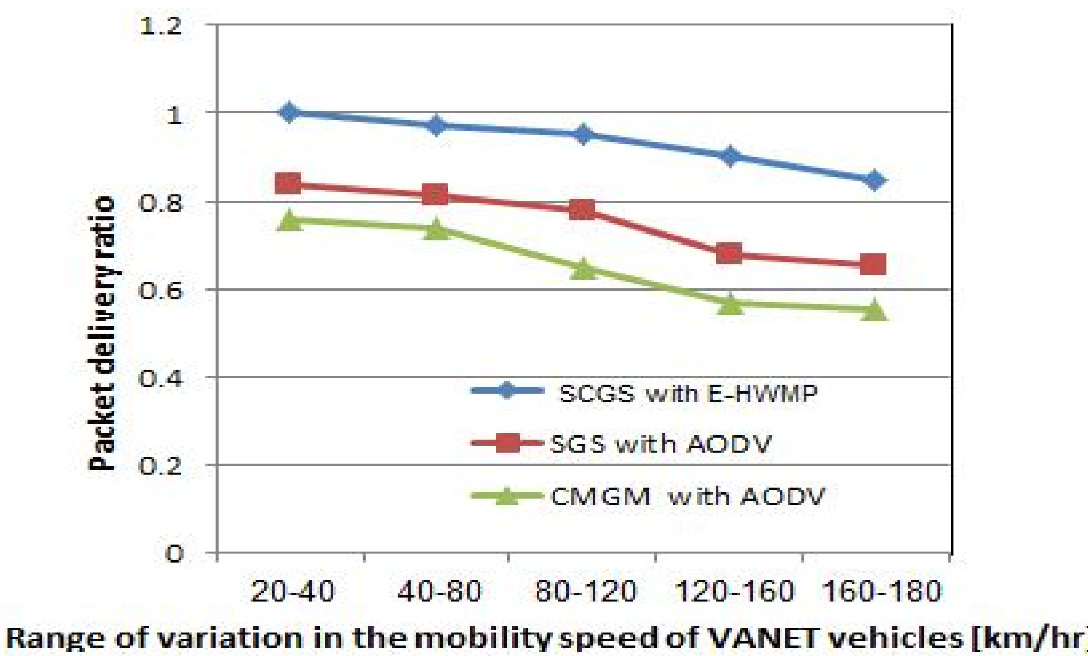

Figure 6.7: Packet Delivery ratio of SGSS with E-HWMP and with AODV and CMGM with AODV in a range of Variation of IEEE802.11 Transmission Range of Vehicles

In Figure 6.8 it is observed that the proposed mechanism achieve a good performance in terms of less delay compared to compared to the CMGM and SGS schemes. It can be pointed out that the reason for this is the fact that in the proposed scheme all vehicles inside the coverage zone are allowed to communicate directly to the base station, which reduces the frequent network disconnection; when the vehicles are outside the coverage, E-HWMP assists any source vehicle to deliver its packet to BST.

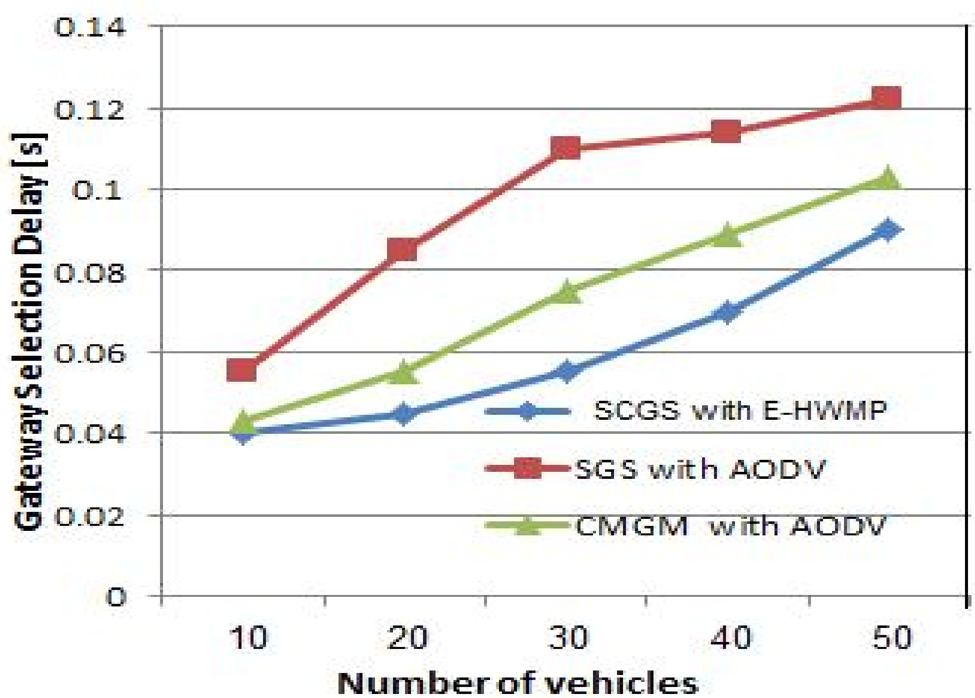

Figure 6.8: Gateway Selection Delay vs. Different Numbers of Vehicular s in the VANET

Finally, in the validation process, the results obtained by the simulation will be compared to the results from analytical models.

6.3 Analytical Results

This section presents results for the network connectivity. The analytical results are obtained using MATLAB.

Table 6.1

Normal Speed Statistics [114]

μ[km=h]	σ[km=h]
70	21
90	27
110	33
130	39
150	45

From Figure 6.9, the probability of the number of vehicles that enter the highway at a given period is given as shown in "Eq.5.2". The shape of the distribution changes dramatically to a more symmetrical (”normal") form as the value of arrival rate and number of vehicles increase, this means a probable increase in the numbers of arrival vehicles.

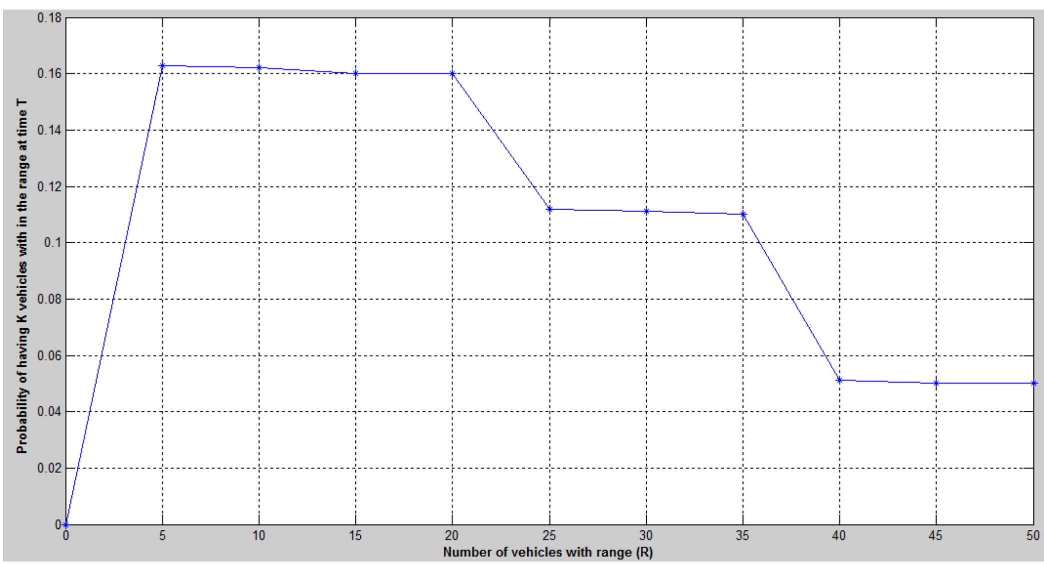

Figure 6.9: The Probability of the Number of Vehicles that Enter the Highway at a Given Period

From Figure 6.10. The Probability of the Inter–vehicles Distances (IVD's) on the road is given as shown in "Eq.5.3". The shape of the distribution changes dramatically to a more symmetrical (”normal") form as the number of vehicles increase, this means The Probability of the Inter–vehicles Distances (IVD's) on the road decreased as the number of vehicles increased .

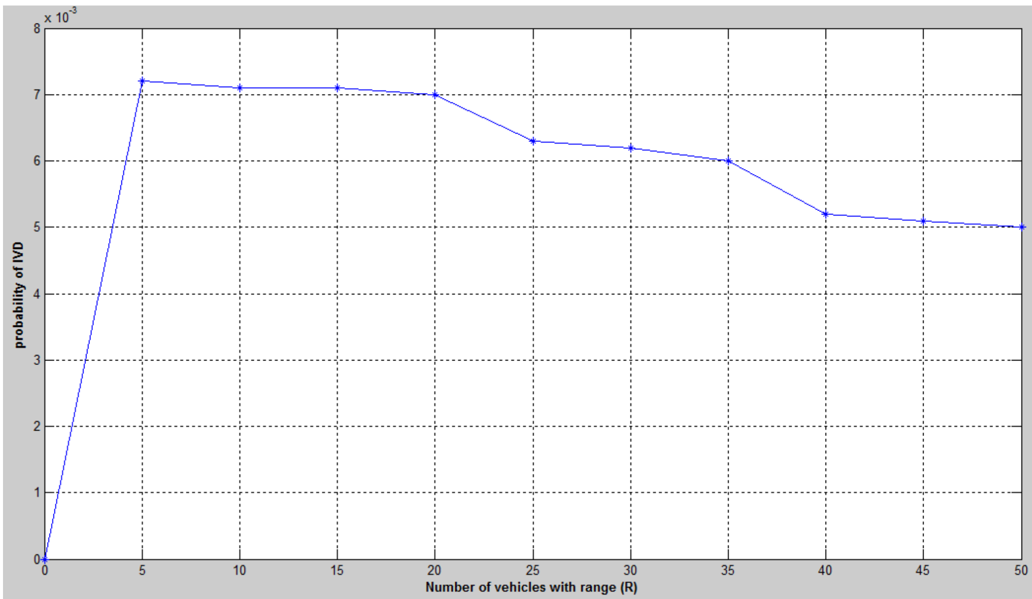

Figure 6.10: The Probability of the Inter–vehicles Distances (IVD's) on the Road

From Figure 6.11. The Probability of the Density of vehicles on the road is given as shown in "Eq.5.7". Vehicles speed across the road is uniformly distributed with mean (70, 110,150 respectively) as shown in Table1.The shape of the distribution changes as the average speed of vehicles increased, this means probable decrease in the Density of vehicles on the road when the average speed of vehicles increased. As expected, the connectivity probability increases as average vehicle density increases. The result show that increasing the average vehicle speed degrades connectivity

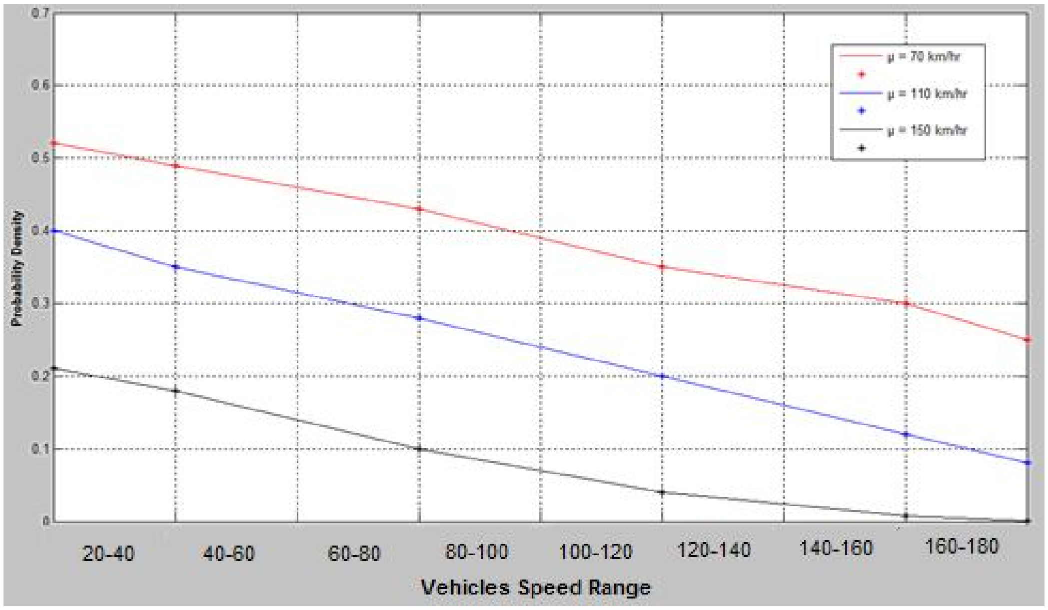

Figure 6.11: Probability of the Density of Vehicles on the Road

The results show that increasing the average vehicle speed degrades connectivity.

In Figure 6.11 the Probability of the Density of vehicles on the road is given. The shape of the distribution changes as the average speed of vehicles increased, this means probable decrease in the density of vehicles on the road when the average speed of vehicles increased. As expected, the connectivity probability increases as average vehicle density increases.

When comparing the above simulation result and the analytical result, the results show that:

I. Increasing the average vehicle speed degrades connectivity, this means:
   - Increase in packet loss ratio
   - Decrease in packet delivery ratio
   - Decrease the average throughput

II. The connectivity probability increases as average vehicle density increases, this means:
   - Decrease in packet loss ratio
   - Increase in packet delivery ratio
   - Increase the average throughput

6.4 Compare E-HWMP with HWMP

An Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) proposed as enhanced version of HWMP. HWMP is layer 2 routing protocol while proposed E-HWMP is layer 3 routing protocol because AODV was chosen over HWMP as the routing protocol to be modified, so that layer 3 approach implements mesh functionality at network layer. The result of this implementation are less connection delay, increase packet delivery ratio and decrease packet drop ratio.

6.5 Chapter Summary

This chapter presents and analyzes the simulation system and the analytical result. The results from the analytical models are compared to simulations result to validate the approach of this thesis. Both analytical result and simulation result agreed that: the connectivity probability increases as average vehicle density increases and increasing the average vehicle speed degrades connectivity.

CHAPTER SEVEN

Conclusion and Future Work

7.1 Conclusion

Vehicular Ad-hoc Network (VANET) and cellular network integration are promising architectures for future machine-to-machine application. In this research, a new network architecture is proposed for integration VANET - cellular network to enhance the heterogeneity in vehicular communication.The proposed scheme is implemented using the proposed E-HWMP protocol.The implementation of E-HWMP mechanism has led to enhancement of the integration between VANET and cellular network, such as LTE, and extended the coverage in the area where there is no coverage, and reduced the amount of overhead, and reduced delay metrics, and increased the packet delivery ratio, and also reduced the dead spot in the multi-hop VANET- 3GPP LTE network. The mechanism involves a multi-hop relay communication for the VANET over wireless mesh networksto connect to 3GPP LTE networkwhen the vehicle is nearly to be outside the coverage zone.

Theprocesses involved in E-HWMP scheme are: gateway management, gateway selection andgateway handoff, all performed in a dynamic way using different metrics.

An integrated simulation environment combining VanetMobiSim and NS2 was developed to evaluate the performance of the overall architectureand analytical model by Matlab to calculate the optimized calculation for E-HWMP. Two types of comparison were made to validatethe performance of the proposed scheme. The first study aimed to determine which routingprotocol (E-HWMP or AODV) proposed scheme is to be implemented. The result showsthat the E-HWMP protocol performed better than Ad-hoc on Demand Distance Vector (AODV) routing protocol. The second study compared E-HWMP with other cluster-based gateway selection that used in previous works. The result shows that E-HWMP protocol (proposed by this study) outperforms the other cluster-based gateway selections schemes in terms of connection delay, control packet overhead, packet delivery ratio and overall throughput.To validate the approach of this thesis, the results from the analytical models are compared to simulations performed with the network simulator NS2.35.

The most important point which should be considered is that the nature of vehicularcommunication is based on the movement. Therefore, it is necessary to implement a realisticvehicular movement in the vehicular network simulation. In other words, all theimportant parameters should be implemented accurately in the VANET simulation.

7.2 Recommendation and Future Work

Security and privacy are the most challenging topics in vehicular network communication. In VANETs, there is a possibility of different security attacks because vehicular safety communications consist of periodic broadcast messages between neighbouring vehicles.Consequently, it is crucial to develop an appropriate security architecture for vehicular communication.

In this thesis, the performance of the proposed scheme is studied through simulations. As a future direction of this work in the area of vehicular ad hoc network, we propose the following issues which need further investigation in this area of study.

- Evaluating the performance of the proposed scheme in real life environment using vehicular ad hoc network testbed.
- Applied MAC layer collision avoidance technique to reduce packet collision and increase the throughput of the system.
- Incorporate Quality of Service (QoS) to differentiate service that enables high priority applications like Ambulance, police and fire information to be treated differently than normal vehicles.
- Studying the interaction between MAC and routing layer i.e. cross-layer, and its effects on the routing protocols performance.

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Publication

1. Amal A. Eltahir, Rashid A. Saeed, Amitava Mukherjee and Mohammad Kamrul Hasan, " Evaluation and analysis of an enhanced hybrid wireless mesh protocol for vehicular ad hoc network", EURASIP Journal on Wireless Communications and Networking (2016) 2016:169, Pp 1-11, Published online 15 July 2016, DOI 10.1186/s13638-016-0666-5.
2. Amal A. Eltahir, Rashid A. Saeed, "Performance Evaluation of an Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) Protocol for VANET", International Conference On Computing, Control, Networking, Electronics And Embedded Systems Engineering (ICCNEEE 2015), (paper presented in ICCNEEE 2015 and uploaded in IEEEXplore), Page(s): 95 - 100, Sep 2015 .
3. Amal A. Eltahir, Rashid A. Saeed, & Rania A.Mokhtar, "Vehicular Communication and Cellular Network Integration: Gateway Selection Perspective", International Conference On Computer & Communication Engineering (ICCCE 2014), (paper presented in ICCCE 2014 and uploaded in IEEEXplore), Page(s): 64 - 67, Sept 2014 .
4. Amal A. Eltahir, Rashid A. Saeed, & Mahmoud A. Alawi, "An Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) Protocol for Multi-hop Vehicular Communications", International Conference On Computing, Electrical And Electronic Engineering (ICCEEE 2013), (paper presented in ICCEEE 2013 and uploaded in IEEEXplore), Page(s): 1 - 8, Aug 2013.
5. Amal A. Eltahir, Rashid A. Saeed, "Implementation of an Enhanced Hybrid Wireless Mesh Protocol (E-HWMP) Protocol for VANET," 17th IEEE International Conference On Advanced Communication Technology (Manuscript submitted to ICACT 2015), July 2015.
6. Amal A. Eltahir, Rashid A. Saeed and Amitava Mukherjee " The effect of vehicle mobility on the network connectivity probability of Vehicular Ad- Hoc Networks", Journal of Network and Systems Management (Manuscript submitted), Sep 2016.
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Appendix A

Scenario 1

XML file implemented on VanetMobiSim


```
<?xml version="1.0"?>
<universe>
<dimx>8000.0</dimx>
<dimy>1000.0</dimy>
<extension output="small.tcl"
class="de.uni_stuttgart.informatik.canu.mobisim.extensions.NSOutput"/>
<extension
class="de.uni_stuttgart.informatik.canu.mobisim.simulations.TimeSimulation"
param="500.0"/>
<extension class="de.uni_stuttgart.informatik.canu.spatialmodel.core.SpatialModel"
min_x="0"
max_x="8000" min_y="0" max_y="1000">
<reflect_directions>false</reflect_directions>
<number_lane full="true" dir="false">2</number_lane>
</extension>

<extension class="eurecom.usergraph.UserGraph" name="userGraph">
<vertex> <id>0</id> <x>0</x> <y>550</y> </vertex>
<vertex> <id>1</id> <x>7000</x> <y>550</y> </vertex>
<vertex> <id>2</id> <x>10</x> <y>550</y> </vertex>
<vertex> <id>3</id> <x>7090</x> <y>550</y> </vertex>
<vertex> <id>4</id> <x>20</x> <y>550</y> </vertex>
<vertex> <id>5</id> <x>7020</x> <y>550</y> </vertex>


<vertex> <id>6</id> <x>30</x> <y>500</y> </vertex>
<vertex> <id>7</id> <x>7050</x> <y>500</y> </vertex>
<vertex> <id>8</id> <x>40</x> <y>500</y> </vertex>
<vertex> <id>9</id> <x>7040</x> <y>500</y> </vertex>


<vertex> <id>10</id> <x>7200</x> <y>440</y> </vertex>
<vertex> <id>11</id> <x>200</x> <y>440</y> </vertex>
<vertex> <id>12</id> <x>7210</x> <y>440</y> </vertex>
<vertex> <id>13</id> <x>210</x> <y>440</y> </vertex>
<vertex> <id>14</id> <x>7230</x> <y>440</y> </vertex>
<vertex> <id>15</id> <x>230</x> <y>440</y> </vertex>



<vertex> <id>16</id> <x>7240</x> <y>390</y> </vertex>
<vertex> <id>17</id> <x>240</x> <y>390</y> </vertex>
<vertex> <id>18</id> <x>7250</x> <y>390</y> </vertex>
<vertex> <id>19</id> <x>250</x> <y>390</y> </vertex>
```

```
<edge> <v1>0</v1> <v2>1</v2> <speed>25</speed> </edge>
<edge> <v1>2</v1> <v2>3</v2> <speed>20</speed> </edge>
<edge> <v1>4</v1> <v2>5</v2> <speed>10</speed> </edge>


<edge> <v1>6</v1> <v2>7</v2> <speed>17</speed> </edge>
<edge> <v1>8</v1> <v2>9</v2> <speed>13</speed> </edge>


<edge> <v1>10</v1> <v2>11</v2> <speed>12</speed> </edge>
<edge> <v1>12</v1> <v2>13</v2> <speed>5</speed> </edge>
<edge> <v1>14</v1> <v2>15</v2> <speed>7</speed> </edge>

<edge> <v1>16</v1> <v2>17</v2> <speed>13</speed> </edge>
<edge> <v1>18</v1> <v2>19</v2> <speed>10</speed> </edge>


</extension>

<extension name="Gen1"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="1a">
<location>
<x>0</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="1b">
<location>
<x>7000</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>1a</src>
<dest>1b</dest>
<p>1.0</p>
</transition>
```

</extension>
<extension name="Gen2"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="2a">
<location>
<x>10</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="2b">
<location>
<x>7090</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>2a</src>
<dest>2b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen3"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="3a">
<location>
<x>20</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="3b">
<location>

<x>7020</x>
<y>550</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>3a</src>
<dest>3b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen4"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="4a">
<location>
<x>30</x>
<y>500</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="4b">
<location>
<x>7050</x>
<y>500</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>4a</src>
<dest>4b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen5"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"

```
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="5a">
<location>
<x>40</x>
<y>500</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="5b">
<location>
<x>7040</x>
<y>500</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>5a</src>
<dest>5b</dest>
<p>1.0</p>
</transition>
</extension>


<extension name="Gen6"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="6a">
<location>
<x>7200</x>
<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="6b">
<location>
<x>200</x>
<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
```

```
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>6a</src>
<dest>6b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen7"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="7a">
<location>
<x>7210</x>
<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="7b">
<location>
<x>210</x>
<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>7a</src>
<dest>7b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen8"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="8a">
<location>
<x>7230</x>
```

<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="8b">
<location>
<x>230</x>
<y>440</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>8a</src>
<dest>8b</dest>
<p>1.0</p>
</transition>
</extension>

<extension name="Gen9"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="9a">
<location>
<x>7240</x>
<y>390</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="9b">
<location>
<x>240</x>
<y>390</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
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<src>9a</src>
<dest>9b</dest>
<p>1.0</p>

</transition>
</extension>

<extension name="Gen10"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.ActivityBasedTripGener
ator"
path_algorithm="de.uni_stuttgart.informatik.canu.tripmodel.pathalgorithms.Pedestria
nStochPathSelection" theta="0.01">
<reflect_directions>false</reflect_directions>
<activity id="10a">
<location>
<x>7250</x>
<y>390</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<activity id="10b">
<location>
<x>250</x>
<y>390</y>
<p>1.0</p>
<minstay>0.0</minstay>
<maxstay>0.0</maxstay>
</location>
</activity>
<transition>
<src>10a</src>
<dest>10b</dest>
<p>1.0</p>
</transition>
</extension>

<node id="* 1 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen1" tripgenerator="Gen1">
<minspeed>22</minspeed>
<maxspeed>24</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 2 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen2" tripgenerator="Gen2">
<minspeed>18</minspeed>

```
<maxspeed>20</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 3 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen3" tripgenerator="Gen3">
<minspeed>8</minspeed>
<maxspeed>10</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 4 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen4" tripgenerator="Gen4">
<minspeed>15</minspeed>
<maxspeed>17</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 5 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen5" tripgenerator="Gen5">
<minspeed>12</minspeed>
<maxspeed>13</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 6 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen6" tripgenerator="Gen6">
<minspeed>10</minspeed>
<maxspeed>12</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 7 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen7" tripgenerator="Gen7">
<minspeed>3</minspeed>
```

```
<maxspeed>5</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 8 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen8" tripgenerator="Gen8">
<minspeed>5</minspeed>
<maxspeed>7</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 9 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen9" tripgenerator="Gen9">
<minspeed>11</minspeed>
<maxspeed>13</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>
<node id="* 10 *">
<type>car</type>
<extension class="de.uni_stuttgart.informatik.canu.uomm.IntelligentDriverMotion"
initposgenerator="Gen10" tripgenerator="Gen10">
<minspeed>8</minspeed>
<maxspeed>10</maxspeed>
<step>1.0</step>
<stay random="false">0</stay>
</extension>
</node>


<extension class="de.uni_stuttgart.informatik.canu.mobisimadd.extensions.GUI">
<width>640</width>
<height>480</height>
<step>1</step>
</extension>
</universe>
```

Appendix B

TCL Script for NS-2.35 Simulator

```
set contador_nodos 0
set t 0.0

#====================================
# Define Options
#====================================
set val(chan)       Channel/WirelessChannel              ;# channel type
set val(prop)       Propagation/TwoRayGround             ;# radio-propagation model
set val(netif)      Phy/WirelessPhyExt                   ;# network interface type
set val(mac)        Mac/802_11Ext                        ;# MAC type
set val(ifq)        Queue/DropTail/PriQueue              ;# interface queue sbetween LL
and MAC
set val(ll)         LL                                   ;# link layer type
set val(ant)        Antenna/OmniAntenna                  ;# antenna model
set val(ifqlen)     50                                   ;# max packet in ifq
set val(nn)         11                                   ;# number of mobilenodes
set val(x)          8000                                 ;# X dimension of topography
set val(y)          1000                                 ;# Y dimension of topography
set val(stop)       500                                  ;# time of simulation end
set val(sc)         /home/amal/mobility/small.tcl        ;# mobility scenario
set val(rp)         AODV                                 ;# routing protocol
set val(seed) [lindex $argv 0]                           ;# seed the random number
generator
set val(ptr)        300                                  ;# Peak Wireless Transmission
Range
set val(pms)        50                                   ;# Peak Mobility speed
set val(mm)         VanetMobiSim                         ;# Mobility Model
set val(lte)        -94                                  ;# LTE RSS Threshold
set val(tlp)        UDP                                  ;# Transport-Layer protocol
set val(app)        CBR                                  ;# Application
set val(pkt_size)   1024                                 ;# Packet Size
set val(upl_frq)    1.925                                ;# Uplink Frequency
set val(downl_frq)  2.115                                ;# Downlink Frequency
set val(pupl)       5.2                                  ;# Peak E-UTRAN Uplink Channel
Bit Rate
set val(pdownl)     10.3                                 ;# Peak E-UTRAN Downlink
Channel Bit Rate
set val(tr)         10000                                ;# Transmission Range of LTE
ENodeB
set val(nbifqlen)   20                                   ;# ENodeB Interface Queue length
set val(ENodeB_type) RrFfMacScheduler                    ;# ENodeB Scheduler Type
set val(Gw_adv)     0.5                                  ;   # gateway broadcast annoncement
interval
set val(Gw_discov)  hybrid                               ;#gateway discovery method
```

```
#====================================
#802.11p parameters
#====================================
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set CSThresh_ 1.559e-11
Phy/WirelessPhy set RXThresh_ 1.58e-10 ;#Sensibilidad: -98 dBm.
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set Pt_ 0.00175
Phy/WirelessPhy set freq_ 916e+6
Phy/WirelessPhy set L_ 1.0
Phy/WirelessPhy set Pt_consume_ 0.002 ;# // power consumption for transmission
(W)
Phy/WirelessPhy set Pr_consume_ 0.002 ;# // power consumption for reception (W)
Phy/WirelessPhy set P_idle_ 1.0; # // idle power consumption (W)
Phy/WirelessPhy set P_sleep_ 0.00005; #// sleep power consumption (W)

Mac/802_11Ext set CWMin_                15
Mac/802_11Ext set CWMax_                1023
Mac/802_11Ext set SlotTime_             0.000013    ;# 20us
Mac/802_11Ext set SIFS_                 0.000032    ;# 10us
Mac/802_11Ext set ShortRetryLimit_      7           ;# retransmittions
Mac/802_11Ext set LongRetryLimit_       4           ;# re transmittions
Mac/802_11Ext set HeaderDuration_       0.000040
Mac/802_11Ext set SymbolDuration_       0.000008
Mac/802_11Ext set BasicModulationScheme_     0
Mac/802_11Ext set use_802_11a_flag_     true
Mac/802_11Ext set RTSThreshold_         2346        ;# bytes
Mac/802_11Ext set MAC_DBG               0
Mac/802_11Ext set basicRate_ 1Mb
Mac/802_11Ext set dataRate_  2Mb

#==================================
#configure RF model parameters
#==================================
Antenna/OmniAntenna set X_ 0
Antenna/OmniAntenna set Y_ 0
Antenna/OmniAntenna set Z_ 1.5
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

Propagation/Nakagami set use_nakagami_dist_ false
Propagation/Nakagami set gamma0_ 2.0
Propagation/Nakagami set gamma1_ 2.0
Propagation/Nakagami set gamma2_ 2.0

Propagation/Nakagami set d0_gamma_ 200
Propagation/Nakagami set d1_gamma_ 500

Propagation/Nakagami set m0_ 1.0
Propagation/Nakagami set m1_ 1.0
```

```
Propagation/Nakagami set m2_ 1.0

Propagation/Nakagami set d0_m_ 80
Propagation/Nakagami set d1_m_ 200

#====================================
#Main Program
#====================================
#====================================
#Initialization
#====================================
global defaultRNG
$defaultRNG seed $val(seed)

#Create a ns simulator
set ns_ [new Simulator]

#Setup topography object
set topo [new Topography]
$topo load_flatgrid $val(x) $val(y)

#Create god
set god_ [create-god $val(nn)]

#Open the NS trace file
set tracefile [open scenario1.tr w]
$ns_ use-newtrace
$ns_ trace-all $tracefile


#Open the NAM trace file
set namfile [open scenario1.nam w]
$ns_ namtrace-all-wireless $namfile $val(x) $val(y)
$ns_ use-newtrace
#Open the output files
set f0 [open throughput1.tr w]
set f1 [open delivryratio1.tr w]
set f2 [open lost1.tr w]
set f3 [open delay1.tr w]
set f4 [open overhead1.tr w]

#set color
$ns_ color 0 blue
$ns_ color 1 darkgreen
$ns_ color 2 red
$ns_ color 3 brown
$ns_ color 4 gray
$ns_ color 5 black
$ns_ color 6 blue
$ns_ color 7 skyblue
```

```
$ns_ color 8 pink


#------------------------------------------------------
#Agent AODV as gateway. 2=reactive 1=hybrid 0=proactive
#------------------------------------------------------
Agent/AODV set gw_discovery 1

#===================================
#Configure node objects
#===================================
proc create_common_node {} {
	global val ns_ node_ contador_nodos topo

	$ns_ node-config -adhocRouting $val(rp) \
	-llType $val(ll) \
	-macType $val(mac) \
	-ifqType $val(ifq) \
	-ifqLen $val(ifqlen) \
	-antType $val(ant) \
	-propType $val(prop) \
	-phyType $val(netif) \
	-channelType $val(chan) \
	-topoInstance $topo \
	-agentTrace ON \
	-routerTrace ON \
      -macTrace ON \
      -initialweight 0.5 \
      -phyTrace OFF

set node_($contador_nodos) [$ns_ node]
	$node_($contador_nodos) random-motion 0

	incr contador_nodos

}

# ========================================
# Procedure to create a gate way node
# ========================================
proc create_gate_way_node {} {

	global val ns_ node_ contador_nodos topo


	$ns_ node-config -adhocRouting $val(rp) \
	-llType $val(ll) \
	-macType $val(mac) \
	-ifqType $val(ifq) \
	-ifqLen $val(ifqlen) \
```

```
        -antType $val(ant) \
        -propType $val(prop) \
        -phyType $val(netif) \
        -channelType $val(chan) \
        -topoInstance $topo \
        -agentTrace ON \
        -routerTrace ON \
        -macTrace ON \
      -initialweight 1 \
      -phyTrace OFF

        set node_($contador_nodos) [$ns_ node]
        $node_($contador_nodos) random-motion 0
        incr contador_nodos

}

# ==========================================
# Procedure to create a base station node
# ==========================================
proc create_ENodeB_node {} {

global val ns_ node_ contador_nodos topo

        $ns_ node-config -adhocRouting $val(rp) \
        -llType $val(ll) \
        -macType $val(mac) \
        -ifqType $val(ifq) \
        -ifqLen $val(ifqlen) \
        -antType $val(ant) \
        -propType $val(prop) \
        -phyType $val(netif) \
        -channelType $val(chan) \
        -topoInstance $topo \
        -agentTrace ON \
        -routerTrace ON \
        -macTrace ON \
      -phyTrace OFF

      set node_($contador_nodos) [$ns_ node]
        $node_($contador_nodos) random-motion 0 ;
        incr contador_nodos

}

proc updateNodeWeight {} {
 global val node_
set w [open weight.tr "w"]
for {set i 0} {$i < 10 } { incr i } {
set max_weight [$node_($i) weight]
```

```
puts $w "$max_weight"
puts "max_weight of [$node_($i) node-addr] is $max_weight"
}
close $w
}
proc nodechlabel {} {
global ns_ node_ t
set t [$ns_ now]
$ns_ at $t "$ns_ trace-annotate \"All the nodes declare themselves as gateway
candidate\" "
for {set i 0} {$i < 10} {incr i} {
$ns_ at $t "$node_($i) label GWc"
}
}
proc noderesetlabel {} {
global ns_ node_ t
set t [$ns_ now]
for {set i 0} {$i < 10} {incr i} {
$ns_ at $t "$node_($i) label \" \""
}
}

#================================
# Define traffic model
#===============================
puts "Loading scenario file..."
source $val(sc)


   $node_(10) set X_ 4000.0
   $node_(10) set Y_ 1500.0
   $node_(10) set Z_ 0.0

#====================================

# Define node initial position in nam

#====================================
for {set i 0} {$i < $val(nn) } { incr i } {
$ns_ initial_node_pos $node_($i) 30 ;#30 difines the node size in nam.
}

# Initialize Flags

set holdtime  0
set holdseq   0
set holdtime1 0
set holdseq1  0

set holdrate1 0
```

```
set holdrate2 0


#===================================
#Defining Communication Between node0 and node2
#===================================
# only one UDP connection at very high bitrate (>saturation throughput)
# the results on different nodes are obtained by setting sink0 at each node
set udp1 [new Agent/UDP]
set sink0 [new Agent/LossMonitor]
$ns_ attach-agent $node_(0) $udp1
$ns_ attach-agent $node_(2) $sink0
$ns_ connect $udp1 $sink0
set cbr1 [new Application/Traffic/CBR]
$cbr1 set packetSize_ 1024          ;# Set Packet Size to 1024 bytes
$cbr1 set interval_ 0.05            ;# in seconds
$cbr1 set random_ 1                 ;# intrdouce random "noise" in the scheduled
departure times
#$cbr1 set maxpkts_ 10000
$cbr1 attach-agent $udp1
# UDP2 connections from node_(2) to node_(0)
set udp2 [new Agent/UDP]
set sink1 [new Agent/LossMonitor]
$ns_ attach-agent $node_(2) $udp2
$ns_ attach-agent $node_(0) $sink1
$ns_ connect $udp2 $sink1
set cbr2 [new Application/Traffic/CBR]
#I add tunable parameters for CBR
$cbr2 set packetSize_ 1024          ;# Set Packet Size to 1024 bytes
$cbr2 set interval_ 0.05            ;# in seconds
$cbr2 set random_ 2                 ;# intrdouce random "noise" in the scheduled
departure times
#$cbr2 set maxpkts_ 10000
$cbr2 attach-agent $udp2


set threshold 500

for {set i 0} {$i <= 0  } { incr i } {
for {set j 0} {$j < 5 } { incr j } {
set x1 [$node_($i) set X_]
set y1 [$node_($i) set Y_]
set x2 [$node_($j) set X_]
set y2 [$node_($j) set Y_]
set distance [expr "sqrt(($x2-$x1)*($x2-$x1)+($y2-$y1)*($y2-$y1)+5)"]
}
}

for {set k 5} {$k <= 5  } { incr k } {
for {set l 5} {$l < 10 } { incr l } {
```

```
set x1 [$node_($k) set X_]
set y1 [$node_($k) set Y_]
set x2 [$node_($l) set X_]
set y2 [$node_($l) set Y_]
set distance1 [expr "sqrt(($x2-$x1)*($x2-$x1)+($y2-$y1)*($y2-$y1)+4)"]
}
}

# install a procedure to print out the received data
Application/Traffic/CBR instproc app-recv {data} {
        global ns_
        $ns_ trace-annotate "$self received data \"$data\""
}

Application/Traffic/CBR instproc app-send {data} {
        global ns_
        $ns_ trace-annotate "$self sent data \"$data\""
}


# Function To record Statistcis (Bit Rate, Delay, Drop, delivryratio, overhead )
proc record {} {

      global sink0 sink1  f0  f1  f2 f3 f4  holdtime holdseq holdtime1 holdseq1
holdrate1 holdrate2


set ns [Simulator instance]
   set time 0.9 ;#Set Sampling Time to 0.9 Sec
  set bw0 [$sink0 set bytes_]
  set bw1 [$sink1 set bytes_]

  set bw4 [$sink0 set nlost_]
  set bw5 [$sink1 set nlost_]

  set bw8 [$sink0 set lastPktTime_]
  set bw9 [$sink0 set npkts_]

  set bw10 [$sink1 set lastPktTime_]
  set bw11 [$sink1 set npkts_]



  puts "No of Packets in 0th node: $bw9"
  puts "No of Packets in 02th node: $bw11"


  puts " ***********************************************"

  set membernodes1 0_1_2_3_4
```

```
  set membernodes2 5_6_7_8_9


proc cluster {} {

        if (ClusterHead())
        {
           set $nsmsg*data=(msg*)pkt.data udp;
           set $nsmember_node = node_rep;
           set $cluster1.node_rep[5]=[0,1,2,3,4]
           set $cluster2.node_rep[5]=[5,6,7,8,9]
           set int weight;
           set int routecapacity = 0.33;
           set int linkstability = 0.33;
           set int signalstrength = 0.33;
           set $clusterhead1=max_weight.cluster1.node_rep;
           set $clusterhead2=max_weight.cluster2.node_rep;
           set threshold_value= 500

                config_.rp_aodv;
           set rt_upd=routing table_updation



max_weight=(msg*data)*linkstability+(msg*data)*routecapacity+(msg*data)*signals
trength;

        }
        else
        {
           begin()
         {
                int max_weight;

           cluster1.node_rep[5]= max_weight;

                if (cluster1.node_rep[5]= max_weight)
                {

                        select clusterhead1=cluster1.node_rep->max_weight;

                cluster1.node_rep++;
                }

           if (cluster2.node_rep[5]=max_weight)
                {

                        select clusterhead2=cluster2.node_rep->max_weight;

                cluster2.node_rep++;
```

```
                    }
            else

                 {
                      clusterhead();
                }

}
}
};

 puts " ***********************************************"
  puts " GROUPING TABLE INFORMATION OF EACH CLUSTER "
  puts " ***********************************************"
  puts " GROUPING TABLE INFORMATION OF FIRST CLUSTER "
  puts "  cluster id_no: 1  "
  puts " MEMBER NODES OF CLUSTER1 id_no:$membernodes1 "
  puts " HIGHEST weight VALUE OF NODE IN CLUSTER1:  selected as cluster
head "

  puts " ***********************************************"
  puts " GROUPING TABLE INFORMATION OF SECOND CLUSTER "
  puts " ***********************************************"
  puts " cluster id_no: 2 "
  puts " MEMBER NODES OF CLUSTER2 id_no:$membernodes2 "
  puts " HIGHEST weight VALUE OF NODE IN CLUSTER2:  selected as cluster
head "
set now [$ns now]
# Record throughput in Trace Files
      puts $f0 "$now [expr (($bw9)*8/$time)/1000]"

# Record Packet Loss Rate in File
      puts $f2 "$now [expr $bw4/$time]"

# Record Packet Delay in File
         if { $bw11 > $holdseq } {
             puts $f3 "$now [ expr ($bw8 - $holdtime )/($bw9 - $holdseq)]"
      } else {

             puts $f3 "$now [expr ($bw9 - $holdseq)]"

      }


# Record control packet overhead in File
      puts $f4 "$now [expr ($holdtime * 8)/($bw9 + $bw4 + $time )]"

# Record packet delivry ratio in File
      puts $f1 "$now [expr ($bw9)/($bw9 + $bw4 + $time)]"
```

```
# Reset Variables

        $sink0 set bytes_ 0
        $sink1 set bytes_ 0

       $sink0 set nlost_ 0
       $sink1 set nlost_ 0

       set holdtime $bw8
       set holdseq $bw9

         set  holdrate1 $bw0
        set  holdrate2 $bw1


$ns at [expr $now+$time] "record"   ;# Schedule Record after $time interval sec

}

$ns_ at 199.00 "$ns_ trace-annotate \" Now the clustering process starts\""
$ns_ at 199.10 "$ns_ trace-annotate \" cluster_head  node id_4first cluster distance
range $distance \""
$ns_ at 300.11 "$ns_ trace-annotate \" cluster_head  node id_9second cluster distance
range $distance1 \""
$ns_ at 400.10 "$ns_ trace-annotate \" cluster_head  node id_7second cluster distance
range $distance \""
$ns_ at 199.12 "$ns_ trace-annotate \" Gateway Advertisement are sended to all nodes
of the cluster in order to update their HWMP table .....\""
$ns_ at 300.12 "$ns_ trace-annotate \" Gateway Advertisement are sended to all nodes
of the cluster in order to update their HWMP table .....\""
$ns_ at 400.12 "$ns_ trace-annotate \" Gateway Advertisement are sended to all nodes
of the cluster in order to update their HWMP table .....\""
$ns_ at 200.01 "$ns_ trace-annotate \" source send CH_request.....\""

$ns_ at 199.03 "$node_(4)  label  CH"
$ns_ at 300.0 "$node_(9)  label  CH"

$node_(4) color green
$ns_ at 199.03 "$node_(4) color green"
$node_(9) color green
$ns_ at 300.0 "$node_(9) color green"

$node_(4) color black
$ns_ at 300.01 "$node_(4) color black"
$node_(9) color black
$ns_ at 400.01 "$node_(9) color black"

$ns_ at 300.01 "$node_(4)  label  N"
$ns_ at 400.01 "$node_(9)  label  N"
```

```
$ns_ at 400.0 "$node_(7)  label  CH"

$node_(7) color green
$ns_ at 400.0 "$node_(7) color green"

$ns_ at 200.00 "$node_(0)  label  source"

$node_(0) color brown
$ns_ at 200.00 "$node_(0) color brown"

$node_(10) color red
$ns_ at 0.0 "$node_(10) color red"

$ns_ at 0.0 "$node_(10)  label  ENodeB"

# Start Recording at Time 0

$ns_ at 0.0 "record"
$ns_ at 200.0 "$cbr1 start"             ;# Start transmission at time t = 200.0 Sec
$ns_ at 210.0 "$cbr2 start"           ;# Start transmission at time t = 210.0 Sec

# Stop Simulation at Time 500 sec
$ns_ at 500.0 "finish"

# Reset Nodes at time 500.0 sec
for {set i 0} {$i < $val(nn) } {incr i} {
   $ns_ at 500.0 "$node_($i) reset";
}
$ns_ at 0.0 "$ns_ trace-annotate \" $t working\""

$ns_ at 500 "stop"
# Exit Simulatoion at Time 500.01 sec
$ns_ at 500.01 "puts \"NS EXITING...\" ; $ns_ halt"

#===================================
# Termination
#===================================
#Define a 'finish' procedure
#the simulation results can be shown by xgraph
proc finish {} {
global f0 f1 f2 f3 f4 ns_ tracefd namtrace t
#Close the output files
close $f0
close $f1
close $f2
close $f3
close $f4
```

```
# Plot Recorded Statistics
	exec xgraph throughput1.tr  -geometry 800x400 -t "Throughput" -x "Time" -y "Throughput" -bg white &
	exec xgraph lost1.tr  -geometry 800x400 -t " Packet Loss" -x "Time" -y "Packet Drop" -bg white &
	exec xgraph delay1.tr  -geometry 800x400 -t "Delay" -x "Time" -y "Cluste Head Selection Delay" -bg white &
	exec xgraph delivryratio1.tr  -geometry 800x400 -t "delivryratio" -x "Time" -y "Packet Delivery Ratio" -bg white &
	exec xgraph overhead1.tr  -geometry 800x400 -t "overhead" -x "Time" -y "Control Packet Overhead" -bg white &
#execute nam
exec nam scenario1.nam &
exit 0
}
puts "Starting Simulation..."

$ns_ run
```

Appendix C

AWK Scripts

Average End to End Delay

```
BEGIN {
for (i in send) {
send[i] = 0
}
for (i in recv) {
recv[i] = 0
}
counter= delay = avg_delay = 0
}
{
event = $1
time = $3
node_id = $5
level = $19
pkt_id = $41
# Store packets send time
if (level == "MAC" && node_id == src && send[pkt_id] == 0 &&
(event == "s")) {
send[pkt_id] = time
counter= pkt_id
}
# Store packets arrival time
if (level == "MAC" && node_id == dst && event == "r") {
recv[pkt_id] = time
}
}
END {
# Compute average delay
processed = 0
for (i=0; processed<counter; i++) {
if(send[i] != 0 && recv[i] != 0) {
num++
delay += recv[i] - send[i]
}
processed++
}
if (num != 0) {
avg_delay = delay / num
} else {
avg_delay = 0
}
printf(" Average End to End Delay between vehicle %d %d %10g\n", src, dst,
avg_delay*1000)
}
```

Average Packet receive

```
BEGIN {
for (i in send) {
send[i] = 0
}
for (i in recv) {
recv[i] = 0
}
tx = 0
drop = 0
pkt_receive = 0
printf(" %30s %30s %30s", "Total sent packets","Total received packets","The
percentage of Packet received")
}
{
event = $1
time = $3
node_id = $5
level = $19
pkt_id = $41
# Store packets send time
if (level == "AGT" && node_id == src && send[pkt_id] == 0 && event == "s") {
send[pkt_id] = 1
}
# Store packets arrival time
if (level == "AGT" && node_id == dst && event == "r") {
recv[pkt_id] = 1
}
}
END {
for (i in send) {
if (send[i] == 1) {
i ++
if (recv[i] == 0) {
drop ++
}
}
tx ++
}
if (tx != 0) {
pkt_receive = (tx - drop) / tx
} else {
pkt_receive = 0
}
printf("%30s %5d %5d\n","between vehicle", src, dst)
printf("%30g %30g %30g\n",tx,(tx -drop),pkt_receive*100)
}
```

Average Packet loss

```
BEGIN {
for (i in send) {
send[i] = 0
}
for (i in recv) {
recv[i] = 0
}
tx = 0
drop = 0
pkt_loss = 0
printf(" %30s %30s %30s", "Total sent packets","Total dropped packets","The
percentage of Packet Loss")
}
{
event = $1
time = $3
node_id = $5
level = $19
pkt_id = $41
# Store packets send time
if (level == "AGT" && node_id == src && send[pkt_id] == 0 && event == "s") {
send[pkt_id] = 1
}
# Store packets arrival time
if (level == "AGT" && node_id == dst && event == "r") {
recv[pkt_id] = 1
}
}
END {
for (i in send) {
if (send[i] == 1) {
i ++
if (recv[i] == 0) {
drop ++
}
}
tx ++
}
if (tx != 0) {
pkt_loss = drop / tx
} else {
pkt_loss = 0
}
printf("%30s %5d %5d\n","between vehicle", src, dst)
printf("%30g %30g %30g\n",tx,drop,pkt_loss*100)
}
```

Average throughput

```
BEGIN {
startTime = 1e6
stoptime = recv = 0
printf(" %10s %25s\n", "Node","Average Throughput")
}
{
event = $1
time = $3
node_id = $5
pkt_size = $37
level = $19
pkt=1024
# Calculate total received packets' size
if (level == "AGT" && node_id == dst &&
event == "r" && pkt_size >= pkt) {
if (time < starttime) {
starttime = time
}
if (time > stoptime) {
stoptime = time
}
# Rip off the header
hdr_size = pkt_size % pkt
pkt_size -= hdr_size
# Store received packet's size
recv += pkt_size
}
}
END {
printf(" %10d %25g\n", dst,(recv/(stoptime-starttime))*(8/1000))
}
```