AMERICAN UNIVERSITY OF BEIRUT

SAFETY DISSEMINATION MESSAGES IN VANET AND OPTIMIZED RESOURCE MANAGEMENT

by

MOHAMED HUSSEIN ELHAJJ

Approved by:

Dr. Haidar Safa, Full Professor — Advisor — Haidar Safa
Computer Science Department

Dr. Ahmad El Hajj, Assistant Professor — Member of Committee
Electrical and Computer Engineering Department

Dr. Hassan Artail, Full Professor — Member of Committee — Haidar Safa
Electrical and Computer Engineering Department

Date of thesis defense: February 17, 2020

AMERICAN UNIVERSITY OF BEIRUT

THESIS, DISSERTATION, PROJECT RELEASE FORM

Student Name: El Hajj Mohamed Hussein
Last First Middle

☒ Master's Thesis ○ Master's Project ○ Doctoral Dissertation

[x] I authorize the American University of Beirut to: (a) reproduce hard or electronic copies of my thesis, dissertation, or project; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes.

[ ] I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of it; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes after :
One ---- year from the date of submission of my thesis, dissertation, or project.
Two ---- years from the date of submission of my thesis, dissertation, or project.
Three ---- years from the date of submission of my thesis, dissertation, or project.

Signature July 7th, 2020
Date

AMERICAN UNIVERSITY OF BEIRUT

SAFETY DISSEMINATION MESSAGES IN VANET AND OPTIMIZED RESOURCE MANAGEMENT

by
MOHAMED HUSSEIN ELHAJJ

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Sciences
to the Department of Computer Science
of the Faculty of Arts and Sciences
at the American University of Beirut

Beirut, Lebanon
February 2020

AMERICAN UNIVERSITY OF BEIRUT

SAFETY DISSEMINATION MESSAGES IN VANET AND OPTIMIZED RESOURCE MANAGEMENT

by
MOHAMED HUSSEIN ELHAJJ

Approved by:

____

Dr. Haidar Safa, Full Professor — Advisor
Computer Science Department

____

Dr. Ahmad El Hajj, Assistant Professor — Member of Committee
Electrical and Computer Engineering Department

____

Dr. Hassan Artail, Full Professor — Member of Committee
Electrical and Computer Engineering Department

Date of thesis defense: February 17, 2020

AMERICAN UNIVERSITY OF BEIRUT

THESIS, DISSERTATION, PROJECT RELEASE FORM

Student Name: ____
Last First Middle

○ Master's Thesis ○ Master's Project ○ Doctoral Dissertation

☒ I authorize the American University of Beirut to: (a) reproduce hard or electronic copies of my thesis, dissertation, or project; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes.

☐ I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of it; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes
after : **One ---- year from the date of submission of my thesis, dissertation, or project.**
Two ---- years from the date of submission of my thesis, dissertation, or project.
Three ---- years from the date of submission of my thesis, dissertation, or project.

____

Signature Date

ACKNOWLEDGMENTS

Special thanks are for Dr. Haidar Safa who supported me throughout the thesis and was giving effective and valuable feedbacks on a daily basis. Working with Dr. Safa is a pleasure since you feel like working with one of your family members who is caring for you and looking for your success. Dr. Safa is the main reason for feeling happy while working and putting behind our backs all the long nights working on this thesis.

I would also like to thank Dr. Ahmad El Hajj who was thoroughly checking my work and giving important ideas and suggestions. Without his persistent help, the goal of this thesis would not have been realized.

My deep gratitude and appreciation extend to Dr. Hassan Artail for imparting his knowledge and expertise in this study. Dr. Artail's guidance and encouragement were the key factors behind finishing this thesis.

AN ABSTRACT OF THE THESIS OF

<u>Mohamed El Hajj</u> for <u>Master of Science</u>
<u>Major</u>: Computer Science

Title: Safety Dissemination Messages in VANET And Optimized Resource Management

With the recent technological advancements in vehicular communication, vehicular ad-hoc networks (VANET) have been intensively studied for being a promising approach for reliable dissemination of safety-related messages. VANET who became a key component of the intelligent transportation systems (ITS) will provide a safety environment through early vehicle detection/ collision avoidance systems, cooperative driving and periodic updates on road conditions. The timely exchange of safety information among cars in VANET is of utmost importance. In this context, this thesis provides a mechanism for safety information dissemination that takes into consideration the criticality of the exchanged messages and the optimized usage of uplink and downlink resource in a TDD-LTE framework. vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-infrastructure (I2I) are the main communication techniques deployed in VANET. In this thesis, the main idea is to employ V2V and V2I communications where both systems will cooperate in order to reach the goal which is drivers' safety. Based on several criteria the communication might be between: (i) I2I communication only, (ii) V2V only, (iii) V2I only, (iv) adaptive V2V-V2I-I2I communication. The main significance of the proposed work is the reconfigurability of the message dissemination architecture based on the actual VANET configuration, traffic conditions, and criticality of messages being relayed. To improve the message delivery process, we used a dynamic LTE resource allocation in which the number of uplink and downlink slots will be set differently every single time based on the joint consideration of traffic volumes and quality of service requirements (delay, rate) in the uplink and downlink. We implemented the proposed work using python and evaluated its performance measuring different parameters. The obtained results are very promising.

CONTENTS

ILLUSTRATIONS

Figure Page

TABLES

Table Page

ABBREVIATIONS

VANET: Vehicular Ad-hoc Network

ITS: Intelligent Transportation System

V2V: Vehicle-to-Vehicle

V2I: Vehicle-to-Infrastructure

I2I: Infrastructure-to-Infrastructure

V2X: Vehicle-to-Everything

RSU: Roadside Unit

WAVE: Wireless Access in Vehicular Environment

DSRC: Dedicated Short-Range Communication

RN: Relay Nodes

WHO: World Health Organization

YASA: Youth Association for Safety Awareness

3GPP: Third Generation Partnership Project

UMTS: Universal Mobile Telecommunication System

GSM: Global System for Mobile Communications

PLMN: Public Land Mobile Network

CS: Circuit Switched

PS: Packet Switched

PSTN: Public Switched Telephone Network

PDN: Packet Data Network

EDGE: Enhanced Data Rates for GSM Evolution

GERAN: GSM EDGE Radio Access Network

UTRAN: UMTS Terrestrial Radio Access Network

DL: Downlink

UL: Uplink

RAN: Radio Access Network

RNC: Radio Network Controller

BTS: Base Transceiver Station

BSC: Base Station Controller

MGW: Media Gateway

MSC: Mobile Switching Center

GPRS: General Packet Radio Service

GGSN: Gateway GPRS Support Node

SGSN: Serving GPRS Support Node

HSS: Home Subscriber Server

1G: First Generation

2G: Second Generation

3G: Third Generation

HSDPA: High-Speed Downlink Packet Access

HSUPA: High-Speed Uplink Packet Access

WiMAX: Worldwide Interoperability for Microwave Access

EPC: Evolved Packet Core

E-UTRAN: Evolved UMTS Terrestrial Radio Access Network

UE: User Equipment

SAE: System Architecture Evolution

LTE: Long-Term Evolution

EPS: Evolved Packet System

IP: Internet Protocol

ME: Mobile Equipment

MT: Mobile Terminal

TE: Terminal Equipment

UICC: Universal Integrated Circuit Card

USIM: Universal Subscriber Identity Module eNB: evolved Node B

APN: Access Point Name

S-GW: Serving Gateway

MME: Mobility Management Entity

TDD: Time Division Duplex

FDD: Frequency Division Duplex

OFDM: Orthogonal Frequency Division Multiplexing

OFDMA: Orthogonal Frequency Division Multiplexing Access

SSF: Special Subframe

DwPTS: Downlink Plot Time Slot

GP: Guard Period

UpPTS: Uplink Plot Time Slot

SRS: Sounding Reference Signals

M2M: Machine-to-Machine

LTE-A: LTE Advanced

LTE-A Pro: LTE- Advanced Pro

H2H: Human-to-Human

MTC: Machine Type Communication

MTCG: MTC Gateway

MIMO: Multiple Input Multiple Output

RN: Relay Node

S/N ratio: Signal to Noise ratio

R13: Release 13

R14: Release 14

LAA: Licensed Assisted Access

LWA: LTE-Wi-Fi Aggregation

FD-MIMO: Full Dimensional MIMO

3D: 3-Dmensional

CRAN: Centralized RAN

TTI: Transmission Time Interval

RTT: Round Trip Time

5GAA: 5G Automotive Association

LAN: Local Area Network

MANET: Mobile Ad-hoc Network

OBU: On Board Unit

AU: Application Unit

VDTN: Vehicular Delay Tolerant Network

CAM: Cooperative Awareness Messages

DCCH: Dedicated Control Channel

HARQ: Hybrid Automatic Repeat Request

SA: Scheduling Assignment

RB: Resource Block

SPS: Semi Persistent Scheduling

PDR: Packet Delivery Ratio

HVN: Heterogeneous Vehicular Network

WMAN: Wireless Metropolitan Access Network

MV: Moving Vehicle

DV: Destination vehicle

BS: Base Station

MAC: Medium Access Control

CV: Coordinator Vehicle

SV: Sink Vehicle

CSI: Channel State Information

VE: Vehicle Equipment

DF: Decode and Forward

QoS: Quality of Service

RAT: Radio Access Technology

RRM: Radio Resource Management

PF: Proportional Fairness

EXP-PF: Exponential Proportional Fairness

MLWDF: Modified Largest Weight Delay First

PLR: Packet Loss Ratio

ACM/TDM: Adaptive Coding and Modulation/Time Division Multiplexing

SINR: Signal-to-Interference Noise Ratio

MPO: Motion Prediction Optimization

RAP: Road Accident Prevention

VBN: Vehicular Backbone Network

PR: Prediction Report

EWM: Emergency Warning Message

HRZ: High -Risk Zone

RF: Risk Factor

ITS: Intelligent Transportation System

ESPM: Emergency Situation Prediction Mechanism

SR: Status Report

TF: Traffic Flow

GPS: Global Positioning System

MCMF: Moving Cluster Multiple Forward

ACRR: Alternate Cluster Resource Reuse

WCDMA: Wideband Code Division Multiple Access

C-ITS: Cooperative Intelligent Transportation System

VMaSC: Vehicular Multihop Algorithm for Stable Clustering

CH: Cluster Head

CM: Cluster Member

VIB: Vehicle Information Base

NHTSA: National Highway Safety Administration

DOT: Department of Transportation

FCW: Forward Collision Warning

LCW: Lane Change Warning

LTE: Left Turn Assist

IMA: Intersection Management Assist

HCMAC: Hybrid Cooperative MAC

TDMA: Time Division Multiple Access

CSMA: Carrier Sense Multiple Access

CCH: Control Channel

CCWS: Cooperative Collision Warning System

D-CMST: Delay Constrained Minimum Steiner Tree

D2D: Device-to-Device

P_r: Power Received

P_t: Power Transmitted

dBm: Decibels

MHz: Mega Hertz

PRB: Physical Resource Block

NPRB: Number of Physical Resource Block

IMCS: Modulation and Coding Scheme Index

RE: Resource Element

CQI: Chanel Quality Indicator

TBS: Transport Block Size

ITBS_DL: TBS Index Downlink

ITBS_UL: TBS Index Uplink

Mbps: Megabits per second

ECU: Electronic Controlling Units

CHAPTER 1

INTRODUCTION

The newest vehicular technologies will rely on intelligent transportation systems (ITS) applications in order to prevent collision, increase road safety and manage traffic congestion. The complete process will be attenuated through the use of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. In order to limit crashes and critical accidents on the road, safety applications rely on a collaboration between vehicles and roadside units (RSUs): vehicles will periodically send short safety messages among them with the support of RSUs who will keep on sending updated information for all vehicles within their range. ITS is supported by IEEE 802.11p which add wireless access in vehicular environments (WAVE). This technology has a lot of advantages as low cost, easy deployment and support of V2V communications. However; many critical weaknesses as unbounded delays and unguaranteed QoS allowed LTE and its future releases such as LTE-advanced and LTE-pro to be the best alternatives for communications in vehicular networks. The main power of LTE and its successors resides in its low message latency which is the most promising concern in safety applications.

Nowadays, a collision prevention/warning system is mandatory in order to mitigate crash problems. The role of this system is to spread, within a specific time limit, safety messages to other vehicles and thus reducing potential collisions. This system should operate effectively despite congestion, adverse weather conditions or unexpected road events. It is fundamental to say that in case a collision happened; such systems target to diffuse safety messages with minimum delays. Vehicular ad hoc network (VANET) is the best suitable network that can be deployed to disseminate collision warning messages. VANET will support the needed communications between vehicles and RSUs, as well as V2V communications, and RSUs to RSUs communications. The RSU will keep on checking vehicles that are within its range and collecting several information as location, speed, power (transmit power), delays… The RSU will either directly notify the vehicle in danger or send a warning message to another vehicle who will in its turn relay the message to the destination vehicle. The dissemination of safety messages among vehicles has been the focus of many recent research works. In the remaining of this chapter we briefly present some backgrounds, the motivation of our work, the problem statement, our objectives and contributions, and finally the thesis plan.

1.1 Background

Countries all over the world face a serious problem which is road accidents and more specifically car collisions. In a survey [28] related to road accidents, 90% of the participants stated that the "driver behavior" is the main cause of accident. If the driver is notified with the necessary information within a reliable and accurate timing, then accidents could be reduced to a greater extent. Researchers are interested in new and sophisticated VANET or ITS to create a safer driving environment. These networks are called VANET: VANET is composed of vehicular nodes that are in continuous movements. Vehicles in VANET move in regular pattern since traffic regulation determine their movements. We can differentiate between three types of communication in VANET: V2V via dedicated short-range communication (DSRC), V2I via IEEE 802.11p and infrastructure-to-infrastructure (I2I) via IEEE 802.3u.

In a collision warning system, time is a key factor that will determine if the system is reliable or not. For this reason, a multi-hop broadcast protocol is more suitable than a single-hop broadcast protocol since the latter will increase the delay and the warning message might not arrive within the appropriate time and the whole system will fail. RSUs and vehicles are the main constituents in the vehicular network. This system relies on relay nodes (RN) which is one of its power. RNs have somehow the same role of a base station and are dynamically elected based on several criteria as time, location, distance, and power. In some cases, the RSU might not reach the destination vehicle within an appropriate time due to several circumstances as low power, bad signal and network congestion. In this case, RNs will be elected and forward the message to the destination vehicle. RNs are elected based on several criteria as: (i) the vehicle should be within a specific distance from the RSU, (ii) it should have a specific transmit power, (iii) it will be given a time limit after which it will be no more considered a relay node, (iv) if a vehicle passes the distance limit set by the RSU then a new vehicle closer to the RSU will be reelected as RN. This unique network architecture has many advantages that makes it suitable for collision warning delivery. It mainly reduces Source-Destination distance, increases warning message notification, extends the coverage area of RSUs as well as reduces their numbers.

space

1.2 Motivation

According to the world health organization (WHO) [51-52], each year nearly 1.25 million people die in road crashes in addition to 20-50 million injured or disabled in 2019. On average 1000 people under 25 die every day on the world's roads. By 2030, road traffic injuries will jump from being the 9th leading cause to become the 5th unless action is taken. According to the youth association for safety awareness (YASA) [52], around 4 to 5 people out of 100,000 die every year from road accident in Europe whereas around 20 to 25 people out of 100,000 die every year in Lebanon. These statistics show that the death rate in Lebanon is 4 to 5 times greater than Europe which require immediate action to mitigate the problem [52].

A collision prevention/avoidance system implemented in VANET is the best solution to limit accidents and improve a safety environment for drivers. VANET will provide the drivers with various information related to safety, traffic and infotainment. For example, safety information includes collisions/accidents warning or emergency braking. Traffic information includes road under construction, road conditions and traffic jams. Infotainment information includes nearby restaurants, gas station, alternative routes…

Although many approaches were proposed to safety application, none of them support a collaboration between V2V and V2I communications or ensure that all vehicles will receive a warning message within a time limit even when the network is dense and congested.

Studies show that the major drawback of VANET protocols is the degradation of its performance in dense and high traffic conditions. These protocols suffer from one main complication which is the packet size which will lead to communication overheads and increased cryptography. Hence, our main concern in this thesis is to deliver safety warning messages with minimum delay, ensuring a very low message loss and quick actions in case of message loss in addition to satisfaction of the scalability requirements and a sophisticated dynamic allocation between uplink and downlink slots.

1.3 Problem statement

V2X which combines V2V and V2I is the major type of communication used in vehicular networks. Most of the work done so far was related only to V2I mainly because it is simpler, managed easier and less expensive compared to V2V communication. However; depending only on RSUs will not solve the problem especially with the huge increase in the number of vehicles and traffic density. The network will become congested which imposes an increase in communication overhead and results in message loss and high delays. On the other side, many works have tackled the option of only using V2V communication without depending on RSUs. Previous researches show that this system can give an acceptable performance only when the number of cars is low. In this case, vehicles can be clustered into small groups and share reliable information without the need of RSUs. However; it is well known that vehicles are in a continuous high mobility, therefore when the number of vehicles increases, their management and communication will be no longer feasible, and the performance of the system will drastically fall back. In the literature very few works tackled the idea of using both V2V and V2I communications [54].

In this thesis, the main idea is to employ V2V and V2I communications where both systems will cooperate in order to reach the ultimate goal which is drivers' safety. In this system, based on several criteria the communication might be between: (i) I2I communication only, (ii) V2V only, (iii) V2I only, (iv) adaptive V2V-V2I-I2I communication. The main significance of the proposed work is the reconfigurability of the message dissemination architecture based on the actual VANET configuration, traffic conditions, and criticality of messages being relayed. For instance, in normal cases when there is no high risk of collision and simply a message on road conditions should be spread then in this case only I2V communication can be used.

To optimize the message delivery process, there is a need for a dynamic LTE resource allocation approach in which the number of uplink and downlink slots will be set differently every single time based on the joint consideration of traffic volumes and quality of service requirements (delay, rate) in the uplink and downlink. This way, all the slots in an TDD-LTE frame will be used in the most efficient manner. In particular, we will differentiate between three cases:

- Case 1: in case of a collision or accident, the number of uplink timeslots shall be increased to cater for the sudden increase in the number of messages being sent by the vehicles to other vehicles or to the RSUs.
- Case 2: in case of some critical information (such as changing road conditions) the number of downlink slots need to increase to allow the RSUs to send the information to the surrounding cars in the smallest delay possible.
- Case 3: In normal case where, periodic updates are being shared between vehicles and RSUs then the number of slots allocated for uplink and downlink transmission should be done in a way to allow communication between the different entities while satisfying different QoS requirements.

Dynamic resource management in addition to a collaboration between V2V and V2I will ensure that emergency warning messages will reach destination vehicle within a time limit with minimal delays. Moreover, even if the network is dense and congested all type of information can be spread and more importantly critical information will for sure reach the destination with minimum delays.

1.4 Thesis Objectives and Contributions

The main objective of this thesis is to develop a reconfigurable vehicular network model that aims to ensure that safety messages will reach the destination vehicle despite high traffic density or adverse weather conditions or any other unexpected road events. The main objective is to enhance both V2V and V2I communications: this translates to finding the best mapping between the current network configuration and status to the best communication paradigm in terms of V2I, V2V or an adaptive V2V-V2I system. Another fundamental objective is to properly allocate the available resources for uplink or downlink transmission in a dynamic way to accommodate the continuously changing conditions.

The main contributions can be summarized as follows:

- Surveying existing emergency warning messages based on RSUs, and related works based on V2V only and on both RSUs and V2V.
- Proposing a new vehicular communication model with modifications to improve the use of RSUs and V2V communication and at the same time ensure availability of resources and delivery of safety messages with minimum delay.
- Evaluating the performance of the proposed approach and comparing it with baseline while measuring delays, resource allocation, and other parameters, etc.

1.5 Thesis Plan

The remainder of this thesis is as follows. Chapter 2 presents LTE and VANET, their architecture, routing protocols, scheduling techniques as well as their need in a reconfigurable vehicular model for safety messages dissemination. Chapter 3 surveys several existing approaches done in the literature regarding emergency warning message dissemination and management of resources. Chapter 4 presents our proposed information dissemination approach. In chapter 5 we evaluate the proposed work. Finally, we conclude in chapter 6.

CHAPTER 2

LTE and VANET: ARCHITECTURE, ROUTING PROTOCOLS, SCHEDULING TECHNIQUES

In this chapter we present the architecture of LTE and VANET.

2.1 UMTS and GSM (Architectural Review)

2.1.1 High Level Architecture of UMTS and GSM

LTE known as 3GPP long term evolution was designed and developed by the third-generation partnership project (3GPP). 3GPP also developed earlier systems as universal mobile telecommunication system (UMTS) and global system for mobile communications (GSM) which are at the base of the emergence and evolution of LTE [53].

Public land mobile network (PLMN) denotes and represents a mobile phone network who is run by a network operator. GSM and UMTS have the same network architecture which consists of three main components: core network, radio access network and user's device (mobile phone) as shown in figure 2.1.

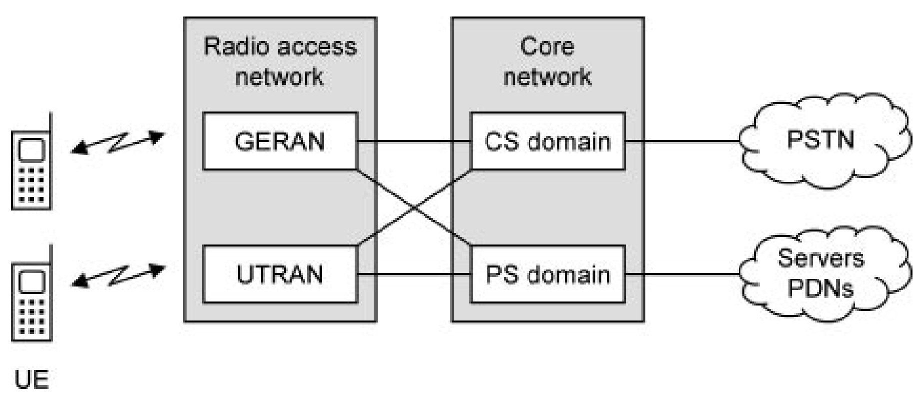

Figure 2.1 High level architecture of UMTS and GSM

The circuit switched (CS) and packet switched (PS) domains are the two main components of the core network. In the CS domain, a network operator covers a specific area for which phone calls can be made. More specifically, the CS domain communicates with the public switched telephone network (PSTN) in order to make calls to land lines and other network operators. On the other hand, the PS domain transfer data streams between the user and the external packet data networks (PDNs). The internet is an example of PDNs.

CS and PS domain differ in the way data is transferred. Circuit switching technique is used in CS domain. This technique implies that for making a phone call we must establish a pre-dedicated two-way connection for each individual phone call. This way, the data is transferred with minimal delay and a constant data rate which is very effective. However, this technique is inefficient and unsuitable for data transfers mainly when there are wide variations in data rate.

It is true that circuit switching is effective even in the worst-case scenario when both users are speaking at the same time but as mentioned earlier that this technique will be ineffective when transferring data rate especially at extensively varying data rate. Packet switching technique is used to solve this issue. This technique is based on dividing the data stream into packets which are labeled with the address of the destination. Packets will pass through several routers and each router will then check the address labels of the packets and forward them to the corresponding destination. The weaknesses of the circuit switched technique are solved using the mentioned technique because all the resources in the network are shared among all users. Delay is one main drawback of this technique which will occur when too many devices are transmitting data at the same time.

The role of radio access network is to handle the communication between the user and the core network. The two-radio access network are (i) GSM EDGE radio access network (GERAN) used for GSM, (ii) UMTS terrestrial radio access network (UTRAN) used from UMTS. GSM and UMTS share a common core network but use different radio communication techniques.

The user equipment (user's device so mobile) will use the air interface to communicate with the radio access network. Downlink (DL) from network to mobile. Uplink (UL) from mobile to network.

2.1.2 Architecture of Radio Access Network (RAN)

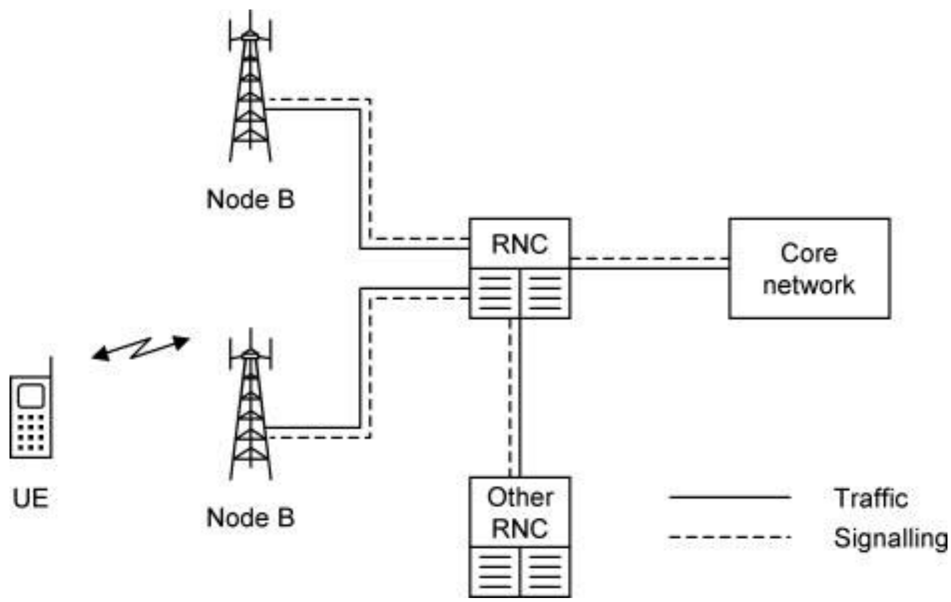

Figure 2.2 Architecture of the UMTS terrestrial radio access network

Figure 2.2 shows the architecture of UMTS and which clearly shows that the base station known as Node B is the key element in the radio access network of UMTS.

Users can be in continuous mobility and change from one region to another. In such cases, a user is leaving a network and joining another one which means it must stop communicating with one network and start communication with a new one. In UMTS, a user can communicate with more than one cell (network).

The radio network controllers (RNCs) group the base stations together. RNCs have two important tasks: First, they constitute a link between the base station and the core network so they can deliver users' data between them. Second, they control several aspects that are invisible to the user as in the case of handover where a mobile move from one cell to another.

GSM radio access network and UMTS radio access network have very similar architecture with few differences as: in GSM we have base transceiver station (BTS) instead of base station and base station controller (BSC) instead of RNC.

2.1.3 Architecture of the Core Network

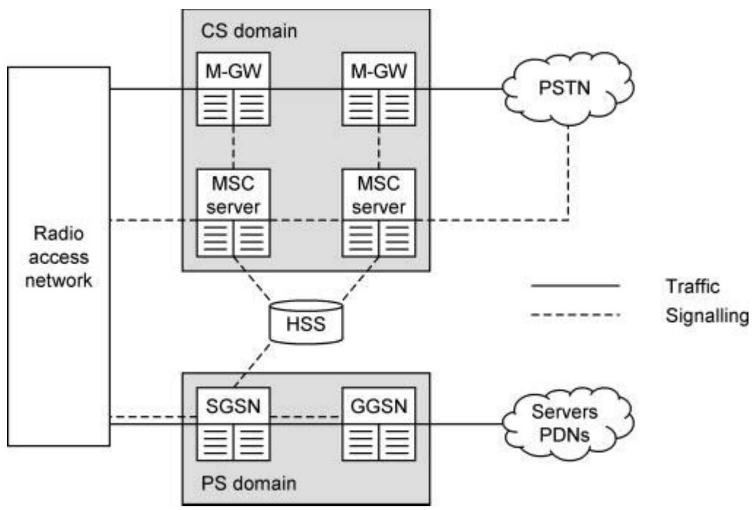

Figure 2.3 Architecture of the core networks of UMTS and GSM

Figure 2.3 shows the internal architecture of the core network. As said before the core network is composed of CS and PS domain. In the CS domain, calls are routed from one part of the network to another through the media gateways (MGWs) and signaling messages is handled by the mobile switching center (MSC).

In PS domain, data are routed and signaling are handled between the base station and gateway GPRS support nodes (GGSNs) through the serving GPRS support nodes (SGSNs). The GGSNs constitute a link with the outside world (Servers PDNs).

All the information about all the subscribers of the network operator are stored in the home subscriber server (HSS) which is a central database and shared between CS and PS domain.

2.2 History of Mobile Telecommunication System

2.2.1 From 1G to 3G

The early 1980s experienced the first introduction of mobile telecommunication systems. The first generation (1G) systems used a similar analogue communication technique as in traditional radio. First generation systems suffer from inefficient use of available radio spectrum and have very large cells that are individual and with minimal characteristics. In this era, mobile devices were only used by business users since they were very expensive and very large in size. In the early 1990s, the second generation (2G) systems took off. Devices are now cheaper and smaller. Global system for mobile telecommunication (GSM) is the most popular 2G system. The emergence and growth of the internet are at the base of the success of 2G systems. 2.5G systems are built on top of 2G systems and introduce new concepts in which users can download data onto mobile devices and introducing the packet switched domain in the core network. Several improvements were made into the 2G systems to enhance its performance as the use of enhanced data rates for GSM evolution (EDGE) techniques. After 2000, the 3rd Generation (3G) was introduced to cope with users' satisfaction and businesses demands. 3G systems were more powerful than 2G because they have a more efficient usage of the available spectrum and increased peak data rates.

2.2.2 Third Generation Systems

UMTS is the most dominant 3G system. UMTS, the successor of GSM, has almost the same core network as GSM but has introduced a totally different technology on the air interface. UMTS has experienced several improvements as the introduction of 3.5G technologies characterized by high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA).

Worldwide interoperability for microwave access (WiMAX) is the final 3G technology and has a different history from other 3G systems. The first version of WiMAX was designed to transfer data over one-to-one links. A later version of WiMAX was designed to support one-to-many communications between a single base station and many fixed devices. A following version supports the same characteristics with more capabilities as devices are not obliged to be fixed and move from one region to another and connect from one base station to another.

2.3 From UMTS to LTE

2.3.1 High Level Architecture of LTE

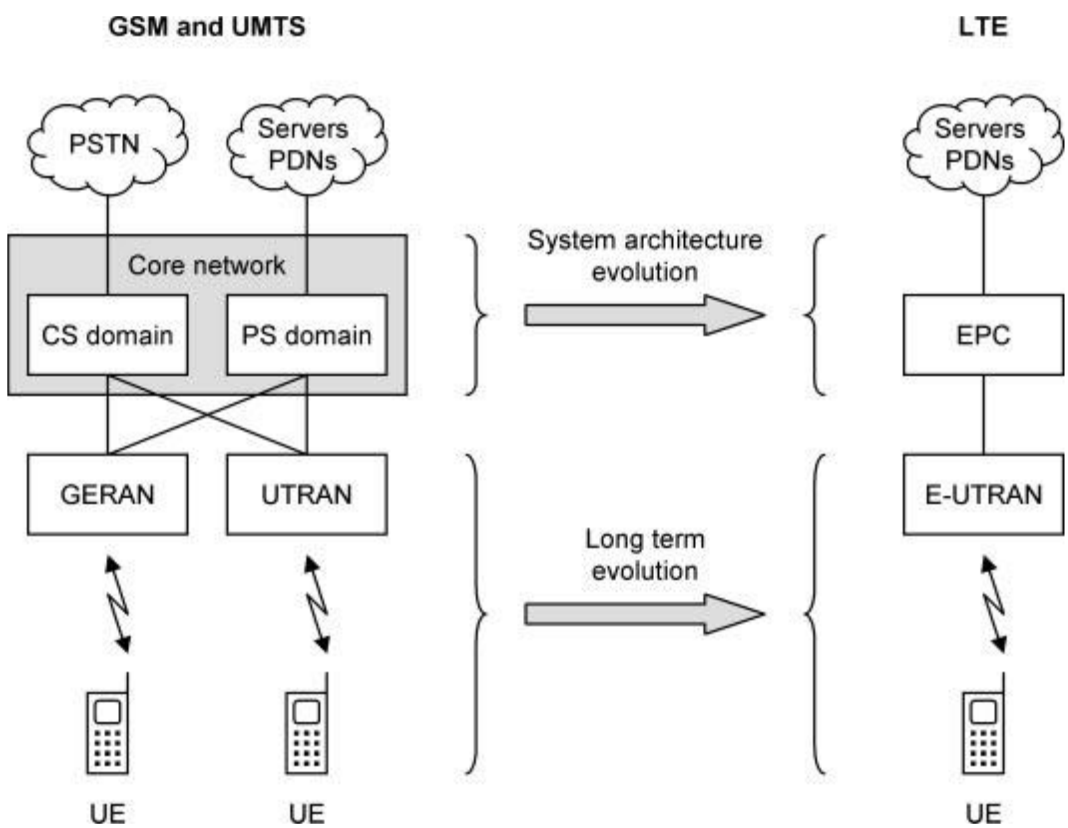

Figure 2.4 Evolution of the system architecture from GSM and UMTS to LTE

The fourth generation (4G) was designed in order to cope with users' satisfaction which are characterized by high data rates and low latencies. Figure 2.4 shows how LTE architecture evolved from GSM and UMTS [57]. The evolved packet core (EPC) in LTE replaces the packet switched domain of GSM and UMTS as shown in figure 2.4. EPC delivers data and voices to the users similarly to the packet switched domain. In LTE, voices are transferred using voice over IP whereas they were delivered using circuit switched domain in GSM and UMTS. The evolved UMTS terrestrial radio access network (E-UTRAN) replaces the UTRAN of UMTS and is responsible for the communication between the EPC and the mobile (UE) [56].

The new architecture of LTE was designed by the work of 3GPP as two categories: The system architecture evolution (SAE) and long-term evolution (LTE). The core network part is covered by the SAE, and the radio access network, air interface and user equipment are covered by LTE. Evolved packet system (EPS) refers to whole system whereas LTE, who is in fact the evolution of the air interface, became the colloquial name for the whole system.

2.3.2 Long Term Evolution

One of the main improvements of LTE is the evolution of the air interface. LTE characteristics are as follows: 100 Mbps and 50 Mbps peak data rate in the downlink and uplink respectively. In the eventual system, these rates have exceeded and can reach 300 Mbps and 75 Mbps respectively. These data rates have almost 10 times exceeded previous versions and that is the main power of LTE [56-57]. LTE stresses on the issue of latency who is fundamental in time-critical applications as road safety, voice and interactive games. LTE provided several characteristics to provide users with low latency even in harsh situations (network congested). Other than latency, LTE focuses on mobility and coverage. LTE can support cell size of up to 100 km; however, it is optimal performance will be for cell size of up to 5 km. moreover, LTE can work with speeds of up to 350 km/hr; however, it is optimal performance will be for speed up to 15 km/hr. LTE uses different bandwidths ranging from 1.4 MHz up to 20 MHz.

2.3.3 System Architecture Evolution

The EPC, who supports Internet Protocol (IP) version 4, version 6 and a mix of version 4 and 6, routes packets using the IP. The EPC is always connected to Servers PDNs (outside world) to provide users with always-on connectivity. A device is given a unique IP when it is connected and will last until the connection is switched off. The main role of the EPC is to deliver information to and from the user. Regarding voice packets, EPC delivers them the same way as any other data stream. EPC specifies several constraints as error rate, data rate, and delay for a data stream to receive its destination. Some systems still use 2G and 3G systems and that is why EPC support functionalities for inter-system usage between LTE and earlier versions as 2G and 3G.

2.4 LTE relevant components to our research

2.4.1 Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) Architecture

The E-UTRAN which is composed of the evolved node B (eNB) control the communication between the UE and the EPC. The eNB is simply a base station communicating with many mobiles in one or more cells. The two main functions of the eNB are: first, eNB receives message from the users on the uplink and sends feedbacks and data back to them on the downlink. Second, the eNB controls other operation as handover commands. eNB evolved from earlier versions of node B and has better performance since it reduces latency. As shown in figure 2.5, the S1 interface connects each eNB to the EPC. Also, the X2 interface connects nearby eNBs to each other. The main role of the X2 interface is to exchange data between eNBs as forwarding data and signaling during handover.

2.4.2 Evolved Packet Core (EPC) Architecture

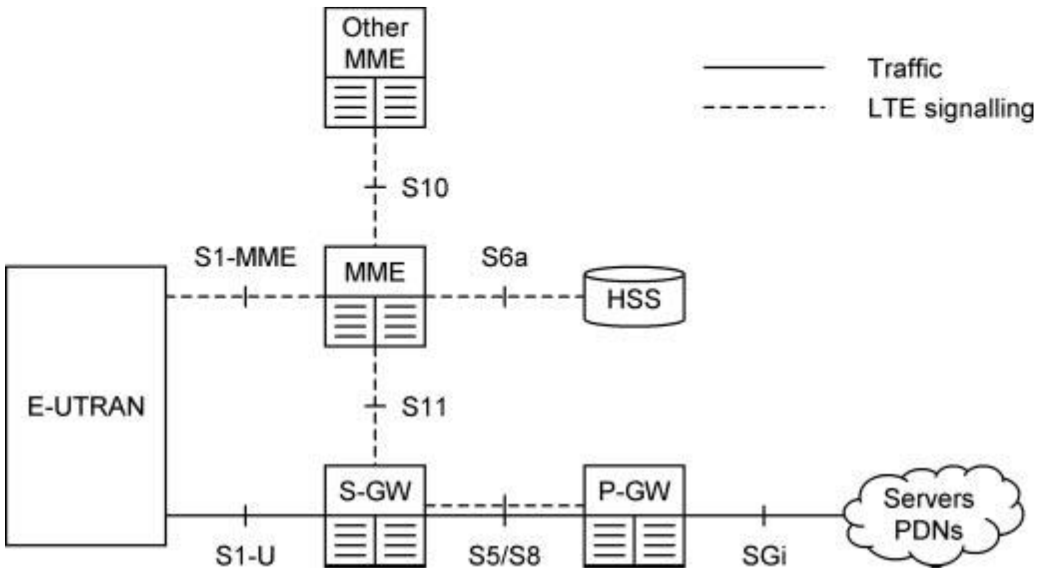

Figure 2.5 Main components of the evolved packet core

As shown in figure 2.5, the home subscriber server (HSS) is one of the components that existed in GSM and UMTS and still available in LTE. As said before, all the information about all the subscribers of the network operator are stored in the HSS.

The point of contact between the EPC and the servers PDNs (outside world) is done through the packet data network (PDN) gateway. This link is done through the SGi interface. Each PDN has a unique access point name (APN) which will be used by the network operator to know each APN is used for which task.

Once a mobile is switched on, it will be automatically assigned to a default PDN gateway, so it has always-on connectivity to a default packet data network such as the internet. Other than the default PDN gateway, a mobile can be assigned to many other gateways as if it wishes to be connected to a private corporate network.

The connection between the base station and the PDN gateway is done through the serving gateway (S-GW). The S-GW receives data and forward them similarly to the job of a router. In a network we have several S-GWs and each user is connected to a single S-GW; however, if the user is moving and become far from the S-GW then in this case he can switch to another S-GW.

The high-level operation of the user equipment is controlled by the mobility management entity (MME). It handles security issues and management of data streams unrelated to radio communications through sending signaling messages. In a network we have several MMEs each one covering a specific area. A serving MME is an MME assigned to a mobile. In a comparison with UMTS and GSM, we can say that PDN gateway and the gateway GPRS support node (GGSN) have the same role, as well the serving MME and the serving GPRS support node (SGSN) have the same routing and signaling functions.

2.4.3 LTE Frame Structure for Time Division Duplex (TDD)

Figure 2.6 shows the LTE frame structure [70]. It can be described as following:

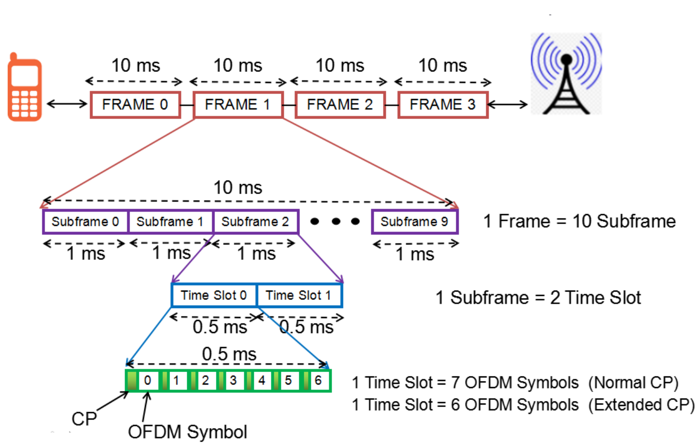

Figure 2.6 LTE Frame Structure

- 1 frame = 10 subframe
- 1 subframe = 2 time slot ➔ 1 frame = 20 time slot
- 1 Time Slot = 7 ODFM (orthogonal frequency division multiplexing) symbols (normal cyclic prefix) or = 6 OFDM symbols (extended CP)

Frames and subframes like in previous cellular systems are used to carry LTE data. We can distinguish between two types of LTE frame structure:

- Type 1: LTE frequency division duplex (FDD) systems,
- Type 2: LTE TDD systems.

2.4.3.1 Type 1 LTE Frame Structure

Type 1 has an LTE frame length of 10 ms divided into 20 individual slots as shown in figure 2.7. Each subframe consists of two slots which means that a frame is composed of 10 subframes.

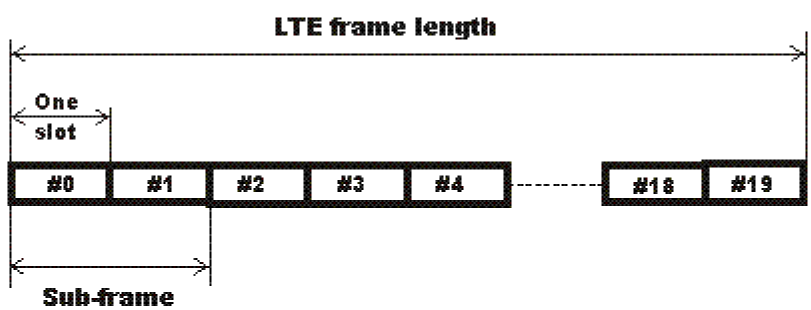

Figure 2.7 Type1 LTE Frame Structure

In an LTE FDD scenario, we have both downlink and uplink transmission that happen at the same time but at different frequencies as shown in figure 2.8.

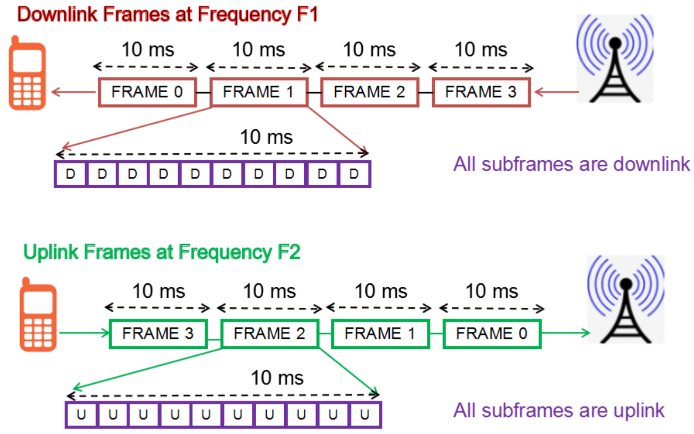

Figure 2.8 FDD Scenario

<u>2.4.3.2 Type 2 LTE Frame Structure</u>

LTE TDD frame structure is different from the previous one. The frame of 10 ms is divided into two half-frames each 5 ms long (frame #0 to frame #4 => 5 ms; frame #5 to frame #9 => 5 ms). One frame is divided into 10 subframes of 1 ms each. Each subframe can be either downlink, uplink or special subframe as shown in figure 2.9.

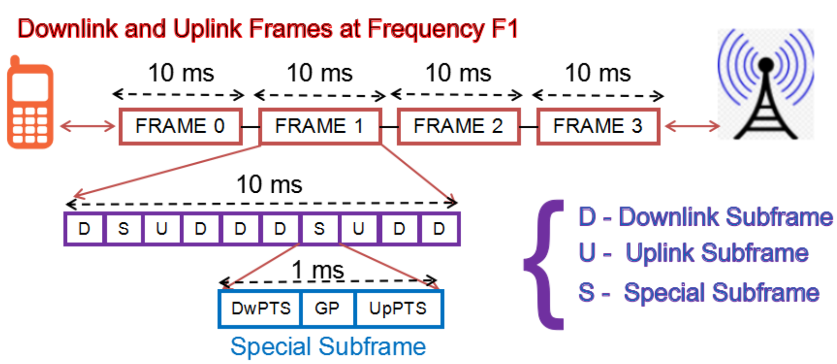

Figure 2.9 TDD Scenario

Based on the 3GPP specifications, we can distinguish between 7 TDD configurations as shown in table 2.1.

Configuration	3GPP release	Downlink to uplink switch point periodicity (ms)	Subframe number												Number of subframes / frame		
			0	1	2	3	4		5	6	7	8	9		D [DL]	U [UL]	S [SSF]
0	8	5	D	S	U	U	U		D	S	U	U	U		2	6	2
1	8	5	D	S	U	U	D		D	S	U	U	D		4	4	2
2	8	5	D	S	U	D	D		D	S	U	D	D		6	2	2
3	8	10	D	S	U	U	U		D	D	D	D	D		6	3	1
4	8	10	D	S	U	U	D		D	D	D	D	D		7	2	1
5	8	10	D	S	U	D	D		D	D	D	D	D		8	1	1
6	8	5	D	S	U	U	U		D	S	U	U	D		3	5	2

Table 2.1 TDD Configurations

As we can see from table 2.1, in addition to downlink and uplink slots we have a special subframe slot (SSF). The latter will be used whenever we need to switch from downlink subframe to uplink subframe. It is important to mention that this special subframe is not needed to be used when we switch from uplink to downlink, so it is only used from downlink to uplink transition. The special subframe is composed of:

- Downlink plot time slot (DwPTS): When enough duration is configured, DwPTS is similar to a downlink frame and carries data, reference signals and control information.
- Guard period (GP): used to control the transition between uplink and downlink transmission. The length of the GP determines the maximum supportable cell size.
- Uplink plot time slot (UpPTS): reserved for uplink transmission and mainly used for the user equipment transmission of SRS (Sounding Reference Signals).

Based on 3GPP specifications, we can distinguish between 10 special subframe configurations as shown in table 2.2:

Configuration	3GPP release	Number of OFDM symbols / subframe		
		DwPTS	GP	UpPTS
0	8	3	10	1
1	8	9	4	1
2	8	10	3	1
3	8	11	2	1
4	8	12	1	1
5	8	3	9	2
6	8	9	3	2
7	8	10	2	2
8	8	11	1	2
9	11	6	6	2

Table 2.2 Special Subframe Configurations

2.4.4 Relay Nodes

Relay nodes (RN) will to a great extent support the role of base stations. They can be identified as low power base station since they will mimic their work. They will increase cell coverage and capacity mainly at hot-spot areas and cell edges. As shown in figure 2.10, RNs can be used in several circumstances: (i) suppose the destination node is outside the coverage area of the base station and hence cannot be reachable through a direct communication. In this case, the base station will deliver the information to the relay node which will in its turn forward them to the destination node. (ii) suppose the destination node is inside the coverage area of the base station; however due to excessive shadowing as tall buildings, the information sent by the base station will not reach the destination node with a good quality. In this case, the relay node will be used to deliver the message received from the base station to the destination node with a good quality. (iii) suppose certain area is considered to be a “hotspot” where there are a high number of users and the relay node is utilized to increase the available throughput to these users.

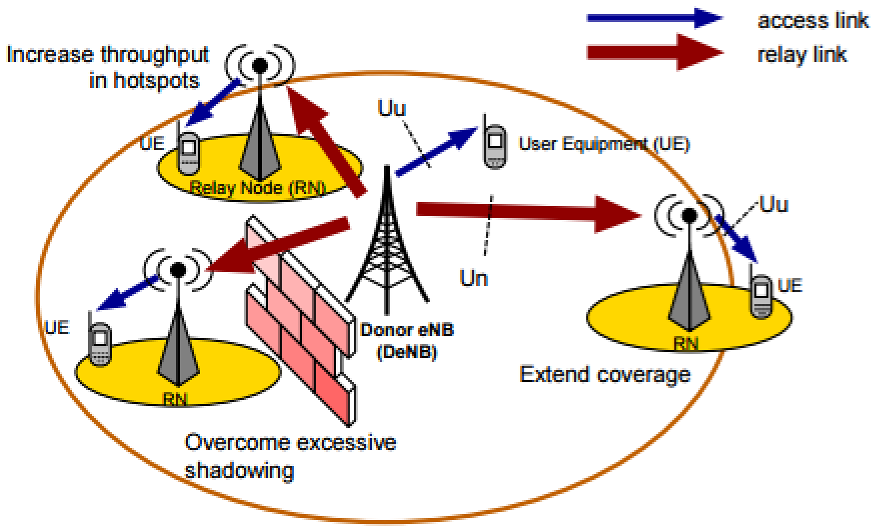

Figure 2.10 Relay Nodes

2.5 VANET

VANET and MANET (mobile ad-hoc network) are very similar for the exception that VANET is composed of vehicular nodes that are in continuous movement. Traffic and traffic regulation determine the movement of vehicles. Therefore, vehicles in VANET move in a regular pattern. We can distinguish between 3 types of communications in VANET:

1- vehicle to vehicle (V2V)
2- vehicle to infrastructure (V2I)
3- infrastructure to infrastructure (I2I)

Dedicated short range communication (DSRC) is used in V2V communication. IEEE 802.11p is used in V2I communication. IEEE 802.3u is used in I2I communication [28].

The three main components employed in VANET communication are: roadside unit (RSU), on board unit (OBU) and application unit (AU). Usually, vehicles are equipped with

OBU and AU, whereas RSUs are fixed on roads. The main functionalities of an RSU is to broadcast emergency warning message to vehicles under its coverage, to provide internet connectivity and many other safety applications. On the other hand, the network communication between vehicles and the RSUs is managed by the OBU. Moreover, the AU is directly related to the OBU and will benefit from the provided services.

2.5.1 Characteristics of VANET

The major characteristics of VANETs are

- *Movement prediction:* Unlike MANET, vehicles in VANET will move in streets, intersections and highways (urban and rural layouts). This indicates that in a VANET architecture, we can predict the future movement of vehicles.
- *No power limitations:* Nowadays, batteries in vehicles are very sophisticated and have a long-life which imply that there are no power limitations in VANETs.
- *Large-scale network:* Mainly in huge dense city, highways and dense urban areas, the number of vehicles is very dense which leads to a very large-scale network.
- *Mutable network density:* The density of the network in VANET will drastically change with respect to location and time. For instance, the density of the network is very high in urban areas whereas it is a very low in rural areas. Similarly, network density is at its peak during rush hours or traffic jam whereas it is low during midnight [28-31].

2.5.2 Challenges of VANET

The main applications of VANET are related to traffic safety applications and can be extended to infotainment ones. VANET imposes several communication protocols in order to meet the applications' requirements. The new resulting challenges of these requirements are:

- *Bandwidth limitations:* Urban areas or highways characterized by a high-density area suffer from network and channel congestion. VANET suffers from a lack of bandwidth management and coordination.
- *Delay constraints:* time is a key factor in VANET and mainly in traffic safety application since we need to guarantee that the emergency warning message should reach its destination within a time limit; otherwise, drivers might not be informed in time and accidents might occur which may result in injuries or deaths. Therefore, time is a fundamental factor in providing an efficient vehicular communication system in VANET.
- *Privacy and accountability rights:* In VANET, there is a tradeoff between privacy and accountability rights: in fact, the privacy of the driver should always be protected and at the same time each vehicle must trust the source of the information it receives
- *Security attacks:* VANET is an open network which made it susceptible to several severe attacks. Therefore, it is critical to find and mitigate the new attacks in order to guarantee that drivers receive warning messages on time and the routing protocol is secured. Otherwise, the whole system might crash, and humans' life is at risk.
- *High dynamic and frequently disconnected topology:* In VANET, vehicles are in continuous mobility and hence the network topology will keep in changing. Therefore, several issues may arise as link disconnection or disruption (crash, car fail,

network error, etc.), connectivity problems (congestion, weather, etc.), as well as the repeated partitioning of the topology. vehicular delay tolerant networks (VDTNs) is an example of research paradigm that can be used to tackle and solve the previously mentioned issues.

2.5.3 What is V2V?

In a V2V communication model, vehicles will share various data as location, direction, speed, braking, and loss of stability among other vehicles. Dedicated short-range communications (DSRC) is a mean used by vehicles to communicate and share essential information. One vehicle can send and receive data from another vehicle up to 300 meters. The goal is to reach the point where all the vehicles in the network can communicate with each other within a certain time limit. V2V communications will help in collision prediction and avoidance as well as mitigating traffic congestion and improving the environment.

A V2V network is a very dense and dynamic network since cars are on continuous movement receiving and sending data. A small network composed of only 10 cars and 3 RSUs will be a mesh network [43-44].

2.5.4 What is V2I?

vehicle-to-infrastructure (V2I) is a mean of communication between the vehicles and infrastructure as RSUs, traffic light, cameras, etc. and vice versa. In this paper, the infrastructure will only consist of RSUs. Same as V2V communication, The RSUs can send/receive data over an ad hoc network using dedicated short-range communication (DSRC) frequencies. The main role of RSUs is to collect information from the different types of infrastructure as well as from vehicles in order to provide drivers with accurate, consistent and valuable information. The collected information as traffic and road conditions, accidents, speed, location and distance between cars, and roads under constructions are disseminated to and among drivers in order to prevent and avoid collision and reach the goal which is increase the safety of drivers [45].

2.5.5 What is V2X?

Vehicle-to-Everything (V2X) is a technology that allows vehicle to communicate with several components in its surrounding using short-range wireless signals. V2X is developed by the 5G Automotive Association (5GAA) which contains several well-known companies as BMW Group, AUDI AG, Nokia, Huawei… For instance, V2V and V2I are part of the V2X network. Similar to other networks, V2X is directed toward safety purposes: In a V2X system, there will be a collaboration between V2V and V2I which means that connected vehicles will communicate with each other and on the same time they will communicate with RSUs which on their turn will share data with other RSUs. All this communication cycle will be geared toward sending fundamental information to drivers in order to avoid collision and increase their safety. In order to communicate in a V2X system, short-range wireless signal will be adapted and might be compatible with the different systems. Unfavorable weather condition will not affect its performance and this signal is unaffected by interference. In this thesis, V2X network is adapted since we must use both networks V2V and V2I which will cooperate in order to reach the goal and save drivers' life [46].

Vehicles are able to communicate indicators such as position and speed through IEEE 802.11p to their surrounding entities; however, this added value is only effective in sparse networks, whereas in dense and high load conditions this performance deteriorates massively. This is due to the fact that data packets are much more likely to collide thus impacting the number of throughputs negatively and increasing delays.

The allocation of radio resources to suitable devices for communication is referred to as scheduling, and there are two modes of doing this in V2X, which are scheduled and autonomous mode. In the scheduled mode, UE requests E-UTRAN for resource allocation under network coverage for Sidelink communication. The E-UTRAN provides the UE with the exact frequency of resources and time that will be used and can allocate resources through semi-persistent scheduling thus further reducing latency. Autonomous mode, on the other hand, is used where there is no network coverage and UEs use pre-configured resource pools to use radio resources, which is provided by the V2X control function or by the pre-configured in the USIM.
Several works show that under low traffic loads and short ranges, the performance of the IEEE 802.11p based WAVE (wireless access in vehicular environments) was effective and met the V2X requirements. However; after increasing the number of vehicles as well as their speed, the performance of WAVE declines and becomes ineffective. This same simulation was run using LTE V2X and its performance was optimal. Moreover, when using long ranges LTE V2X appeared to be more reliable than WAVE. Based on the output in terms of lower delays, better performance in terms of range, reliability, and scaling, LTE V2X is considered to be the best solution for V2X applications and mainly safety related ones [6].

2.5.6 What is DSRC?

Dedicated Short Range Communications (DSRC) is very similar to WiFi and used for wireless communication. The main difference between DSRC and WiFi is that the latter is used for wireless Local Area Networks (LAN) whereas DSRC is a mean of communication between vehicles and the infrastructure ensuring wireless communication at high speed and high security.

The main characteristics of DSRC are:

- Very low latency in the order of 0.02 seconds (delays for opening and closing a connection).
- Very limited interference: due to its short range which almost 1000m DSRC is very strong, powerful in front of radio interference and limits intrusion from remote sources.
- Unfavorable weather condition will not affect its performance.

DSRC operates in the band of 5.9 GHz where 75 MHz where dedicated for it. DSRC was mainly developed for safety purposes. More specifically, they are used to alert drivers in order to prevent and avoid collisions and crashes [47].

CHAPTER 3

EXISTING APPROACHES FOR EMERGENCY WARNING MESSAGE DISSEMINATION AND RESOURCE MANAGEMENT

In this chapter we survey several works [8, 1, 7, 6, 4, 59, 14, 15, 28, 63, 64, 65, 66, 67, 68, 69].

3.1 LTE Resource Scheduling for Vehicular Safety Applications [8]

The research of Tung and Gerla (2013) suggested that the prominence of LTE diverse applications have facilitated the innovative vision of implementing it into new dimensions. Among which the most prevalent and crucial service implementation is highlighted within the vehicular aspects through which LTE can be used for cooperative experience in driving, avoidance of intersection collision. In other words, vehicular applications are one of the important services that LTE resource scheduling has, which includes components such as cooperative driving, intersection collision, avoidance, and other services. Cooperative awareness messages (CAMs), which are also known as beacons, are data packets transmitted by every vehicle. CAMs will provide detailed information each 100ms about the location, speed, and other information related to the cars in the network. So, for intersection collision avoidance, appropriate algorithms are applied by base stations to identify where there are potential collision patterns and hence sending warning messages to vehicles that may potentially be in danger. Therefore, LTE may potentially be better for intersection collision avoidance services considering the good communication, however it needs to be further investigated to see if the traffic of beacon transmissions can be supported factoring in the scarcity of radio resources today.

CAMs can be transmitted through random access or dedicated communication. For random access, the CAMs are accessed by a UE at the base station, which allows channel diversity and thus making it good for adaptive beaconing. However, as a result, there is more signaling overhead. On the other hand, within the dedicated communication approach, the dedicated channel transmits the CAMs through allocated dedicated channel. One of the main benefits of dedicated communication is the fact that it reduces signaling overhead since there isn't any pre-allocation of resources. However; there is not enough information as to how CAM transmissions are scheduled. Therefore, persistent scheduling may be more appropriate if the CAMs are transmitted regularly but if may be more difficult to estimate accurately the number of CAMs generated if adaptive beaconing is used.

The CAM transmission pattern is based on a short time period of 100ms for the transfer of small data packets, similarly this can be noted in the traffic of VoIP where each voice packet requires 20ms to arrive. Accordingly, it is logical to indicate that CAM messages scheduling can be conducted in the same manner of the VoIP traffic. Regarding VoIP, there are three main scheduling approaches which are dynamic, persistent and semi-persistent.

For dynamic scheduling, the requests for all data packets are requested by the UE that can be scheduled by dedicated control channel (DCCH) or L1/L2 signaling through PUSCH. Although it can incur significant signaling overhead, it still can ensure the diversity of the channel through both time and frequency domains.

For persistent scheduling, the sequencing of the resource blocks is set from the beginning, which are reserved for any pending data transmissions or retransmissions. Also, the hybrid automatic repeat request (HARQ) retransmissions are allocated from the beginning. While this means there is less signaling overhead, there are resources wasted to reserve the resources for HARQ. As a result, no retransmissions are needed, and other users cannot be used the reserved resource blocks.

For semi-persistent scheduling, and considering the disadvantages of the above-mentioned methods, both are used. As a result, initial transmissions are done through persistent scheduling while retransmissions are done through dynamic scheduling. This happens through the initial uplink resource request being sent by the UE to a base station. Once the request is received, the predefined sequence of resource blocks is allocated by the base station to the UE. This process can be done every 100ms, which is the inter-arrival time of the CAMs until it is no longer needed such in the case of a car moving out of the intersection. Alternatively, the retransmissions are allocated dynamically using the L1/L2 control channel signaling for the vacant resource blocks. This assumes that the majority of the transmissions are successful for the following method to avoid the drawbacks of persistent and dynamic scheduling.

Reflecting on the above, whenever we have CAMs with adaptive beaconing, we shall use dynamic scheduling whereas for CAMs with fixed beaconing we shall use persistent and semi-persistent scheduling. Therefore, the mechanism of generating beacons should be factored in the development of new resource scheduling methods for vehicular applications as it is heavily dependent on data traffic patterns.

Due to CAM generation being dependent on vehicle movement there are two states that it can be in, either moving or not. In the case that the vehicle is moving, the CAMs are being sent to the base station until it comes to a complete stop at a red light. Once it moves again, the base station would receive a resource request for CAM transmissions. The assumption is that all UEs have global positioning system (GPS) to identify when a vehicle is approaching an intersection, where once it does the initial connection setup is sent via random access so that the UE can send a scheduling request. Once this request is received, the resource blocks are scheduled every 100ms for CAM transmissions and the retransmissions would be scheduled by the dynamic via HARQ since it's a semi-persistent scheduling. The CAMs stop again when the car stops at another red light. Through this the base station can reschedule the resource for other users. This is repeated until the vehicle is no longer in the intersection area.

3.2 System Level Evaluation of LTE-V2V Mode 4 Communications and its Distributed Scheduling [1]

Communications that have reliability requirements and strict latency for transmitting small packets are known as V2V communications. Modes 3 and 4 were designed to meet the requirements of V2V communications by being network scalable, low latency, and high reliability. With that objective, the role of Release 14 is to adjust the management and organization of radio resources, especially when it comes to eliminating data periods, time division of resources into scheduling assignment (SA), and organizing resource blocks (RBs) into frequency sub-channels. Through this, at any point in time vehicles are able to both reserve a resource and transmit a packet, which reduces the latency but not necessarily the energy-efficiency as vehicles would have to permanently be in reception mode.

It is worth noting the innovative aspect to mode 4, which is the fact that vehicles would be able to autonomously select radio resources through the distributed scheduling protocol that can be used when cellular infrastructure cannot be relied on. This is known as sensing-based semi persistent scheduling (SPS). The aim of SPS is to minimize overload of channels with retransmissions and improve V2V communications reliability through exploiting the periodic characteristics of CAM packets or beacons and introducing a semi-persistent reservation of resources. As a result, packet collisions are avoided because vehicles can pick up on previous transmissions and approximating which resources are free.

This work suggested that the packet delivery ratio (PDR) will get a very low error rate while using LTE-V2V mode 4 communications. The distance between the transmitter and the receiver represents the PDR. This work ended up by proving that over a random selection of resources sensing based SPS scheme improves the performance over short and medium distance. Also, whenever packets are transmitted only once, the sensing based SPS scheme can produce even better results [1].

3.3 Weighted Sum-Rate Maximization Resource Scheduling and Optimization for Heterogeneous Vehicular Networks: A Bipartite Graph Method [7]

Heterogeneous vehicular network (HVN) is composed of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) links. There are problems associated with resource scheduling for HVN linking on the selection of the relaying mobile vehicles and the selection of the link between V2V and V2I with the objective of enhancing system performance. Communications between vehicles are supported in an ad hoc way through the V2V mode and is popular within safety related applications such as accident information. V2V mode are found in VANET. On the other hand, the V2I mode allows for wider range information including internet data through access to roadside communication infrastructure. V2I are found in networks called wireless metropolitan area network (WMAN). With the aim of combining the added value of both modes, the HVN was enhanced where users traveling on mobile vehicles are able to access information through the WMAN and VANET, which is why both links exist in the HVN. The implementation of this can be done through different technologies such as dedicated short-range communication (DSRC) systems, cellular communication and other types.

In this work, the aim is to identify moving vehicles whose channel quality is poor and improve their achievable rate. To solve the problem efficiently, they proposed a new efficient algorithm which takes into consideration fairness among moving vehicles (MVs) and at the same time calculating the maximum total information transmission rate of the system. The main idea in this work can be illustrated by the fact that the HVN is represented through a bipartite graph in which nodes can be either moving vehicles, RSUs, and relay nodes. Several information can be generated from the bipartite graph such as calculating V2V and V2I transmit rate, resource allocation and scheduling for HVN. The proposed cooperative transmission will increase the sum throughput of the system compared to a non-cooperative transmission. The proposed algorithm will support moving vehicles with poor channel quality and enhance their rates. Simulating the network as a bipartite graph will for sure generate the optimal case since one of the spanning trees will be the best route to use. However, in practical applications this work is not feasible because based on the proposed formula, there will be 133650 spanning trees for only 10 moving vehicles. It is obvious that it is not optimal to calculate all these spanning trees in order to be able identify the best route and keeping in mind that it is only for 10 cars. Also, this technique is buffer and computation complex [7].

3.4 Joint optimization of link scheduling and resource allocation in cooperative vehicular networks [4]

The objective and concept of cooperative communications in vehicular networks is that vehicles are able to benefit from each other's channel conditions. This can be translated in cases where the destination vehicle (DV) and the base station (BS) have an unreliable channel condition, and thus the destination vehicle will receive the packets from a vehicle with a better channel condition than the BS. As a result, the entire system is able to benefit from each other and enhance communication when forwarding packets to the destination vehicle.

The medium access control (MAC) protocol is a new distributed cooperative relay medium that maximizes the achieved system throughput and service distance of vehicles through the adaptive selection of suitable transmission modes and relay nodes depending on the quality of the channel. However, there is little research focus on cooperative vehicular communications in regard to resource allocation and relay selection. Other related works proposed a V2V-V2I communication systems where both infrastructure and vehicles can transmit multiple data streams at the same time through multiple direction beams supported by smart antennas. However, relay selection was not considered in these researches.

Other research papers did include relay selection and resource allocation where the V2V communication would be used to complement the V2I. The V2V and V2I links are allocated using a bipartite graph-based scheduling scheme for both 1-hop and 2-hop communications. This paper used the Kuhn-Munkres algorithm in order to deal with the issue of maximum weighted matching of the constructed bipartite graph. The results show that the proposed solution achieved better fairness and extremely close to the optimal one. However, the radio resource is not the optimal since all the links will be allocated the same resources [4].

In LTE, lower data rates as a result of poor radio links will impact vehicle equipment that are not close to the BS. This is another instance where cooperative relaying mechanisms amongst neighboring vehicles would be a good approach to tackle this problem. This would be done by establishing V2V communications through orthogonal frequency-division multiple access (OFDMA) based system.

Within the cooperative relaying, assisting vehicles known as coordinator vehicles (CVs) are able to support vehicles that have low data rates through the downlink transmissions of the CVs. Through this roadside units (RSUs) can transmit data via a higher rate to the CVs that then forward the transmission to the destination vehicle (DV), which in this case is known as the sink vehicle (SV). Through this a higher performance is achieved instead of having the low-rate vehicles transmitting data directly to the destinations. Through this there are two types of communication in the vehicular network, which are direct and cooperative communication. In this case, the primary role of the scheduling center is to collect channel state information (CSI) from all users and through it identify the communication mode that should be used and accordingly allocate the radio resource to both V2V and V2I links.

LTE-Advanced specification is used for direct communication. Along the time and/or frequency domain the resource block (RBs) constitute the entire radio resources and thus, through the given scheduling algorithm the vehicle equipment (VE) can share all the RBs, assuming that the number of radio resources available for direct communication are available for the downlink transmission [4].

When V2I and V2V communications are involved, it's called cooperative communication which is designed for SVs. LTE-Advanced system is used for V2I communication while orthogonal frequency-division multiple access (OFDMA)-based system is used for V2V communication. While the specifications of the OFDMA-based system and the LTE-Advanced system are the same, OFDMA-based systems have higher frequency bands and lower transmission power. To further elaborate, one SV can be assisted by one CV, however one CV can forward data to multiple SVs, and the decode and forward (DF) is applied at the CV to be relayed.

There are two binary matrixes 1 and 2 which represents the resource allocation between CVs and SVs respectively. The key aim is to find the best option within limited bandwidths to connect 1s and 2s and therefore maximizing the spectral efficiency. However, it's worth noting that user satisfaction is dependent on multiple factors such as the quality of service (QoS). In regard to the

QoS, there is a Utility theory that supports in the formulation of the relationship to best reflect on the user experience, which includes an effective trade-off between fairness of resource allocation and throughput. Through the mapping of the utility function, real numbers are generated that allows for the quantification of satisfaction, which is the data rate of communication for users. There is an algorithm based on MD-MCKP for a scheduling-scheme that works on finding the optimal solution for establishing V2V links and the distribution of radio resource to both V2I and V2V links for downlink transmissions. Through this, the vehicles that have weak V2I links are identified as SVs and are thus linked with eNB involving both V2I and V2V links. Vehicles with better link in turn become CVs to forward data.

3.5 Dynamic Clustering and Cooperative Scheduling for Vehicle-to-Vehicle Communication in Bidirectional Road Scenarios [14]

Vehicle to vehicle communication (V2V) has recently occupied the interest of the researches in a manner where many efforts have been implemented towards the allocation of the right cooperation that ensures the dissemination of information and data between vehicles within the range of the RSUs communication range Enough evidence has shown that the cooperation of data dissemination through V2V and V2I are efficient and useful, however there was something that has been noted which was not taken into consideration before. Bidirectional scenarios present a new challenge where vehicles traveling at high speeds in opposite directions do not necessarily work optimally for the V2V.

The limitations and problems that have been presented include that the fact that there are vehicles that are able to share data through RSUs and at the same time have requests coming in from other vehicles, that need to be relayed back to the RSUs. In the scenario of high-speed bidirectional vehicles, the time-window for data sharing is very short and thus critically hindering the ability of vehicles to benefit from the V2V communication. Second, in the even that there are multiple vehicles within close vicinity broadcasting data simultaneously the risk of severe interference is high. This raises another key challenge linking to the spatial reusability for V2V communications in such situations. Third, vehicles can send or receive data at a time and not at the same time as a result of the half-duplex of on-board units (OBU) further adding to the challenge of designing an optimal algorithm to factor in V2V data sharing that is cooperative to that level. Last, as a result of potentially sending and requesting different information, the selection of the most appropriate vehicles and data items to be broadcasted is difficult but important if the wireless channel efficiency is to be maximized.

The work in [14] proposed several contributions related to the above-mentioned problems which include the following: first, a system architecture is proposed to assist in data scheduling of bidirectional road scenarios through RSU-assisted data scheduling. This will support in the coordination between vehicles driving in the opposite directions to use V2V communications for cached data items. Second, signal-to-interference-noise-ratio (SINR) analysis of V2V communication provided a potential of successful data sharing between vehicles regularly broadcasting information. This provides insight to potentially exploiting spatial reusability of V2V communication bandwidth. Third, to address the issue of the speed of the vehicles in opposite directions, a clustering mechanism is proposed where a corresponding time division and optimal cluster length policy can be developed in parallel to a cluster association strategy that enables vehicles to either join or leave a cluster dynamically depending on their real-time velocities. Fourth, to address the issue of distributed data sharing, a two-phase back off mechanism is proposed in addition to a scheduling algorithm that determines the set of vehicles in each time slot in addition to the data that would need to be broadcasted.

The assumption is that RSUs are able to collect vehicular information via V2I communications where the vehicles will piggyback and broadcast their real-time status periodically through the control channel. Through this, the RSU is able to better monitor the vehicle statuses. This will also allow the RSU to push scheduling decisions via control channel to the passing vehicles. To focus on the bidirectional V2V communication problem the model assumes an ideal case where V2I communications are with RSUs. Therefore, when the vehicles are out of its range, they are able to share the data through the service channel and thus based on the scheduling of the RSU. This enables the maximization of the spatial reusability and vehicle flexibility in joining or leaving clusters based on their real-time statuses.

The proposed solution in regard to the short window frame of vehicles in clusters within the RSU coverage whom share data via V2I communication, is as follows. The RSUs will be dividing the vehicles into clusters to reduce the V2V communication interference, where a time slot division policy would be developed. This policy would allocate specific time slots for data broadcasting for each vehicle therefore further improving bandwidth efficiency in each cluster. This cache would also be able to identify the most suitable vehicles within the given time slots to broadcast their cached data as well.

3.6 A multiple RSU collaborative scheduling scheme for data services in vehicular ad hoc networks [15]

The work in [15] indicated that in order to intake several service requests, the utilization of RSUs (roadside units) should be set a priority for receiving and transferring data from vehicles and for the schematic scheduling of these data packets. Accordingly, the research of [15] proposed the implementation of multiple RSUs as a new scheduling model through which the RSUs are interconnected through wired networking which facilitates the data packets transfers.

However, prior to the focus on the utilization of RSUs, it is important to understand the context of the VANETs (vehicular ad hoc networks). VANETs are highly crucial for the traffic information, location sharing, file exchange between different mobile vehicles over the wireless communication connections. Whereas, the RSUs have a short communication range through which the requirement of a transfer scheme is essential to ensure that the information distribution is covering different numbers of vehicles within the same time frame. Considerably, RSUs allocation calls for a specific protocol to cover different vehicles within the limited and inadequate bandwidth.

Moreover, this indicated that there should be a systemic information update for the RSUs to ensure the data download for the request of the vehicles. Hence, when the vehicles continuou sly update the data detected, received or uploaded, RSUs will efficiently provide updated information without any problem. This will in turn ensure that safety and non-safety messages are sent to the magnitude of vehicles requesting it within the communication field. In other words, the schemes of scheduling can be implemented by the RSU based on the requests' number, size of the data and the allocated deadlines. Considerably, this indicates that the current schemes cannot provide efficiently the dynamic scheduling considering the progressively and continuously changing environment of the VANETs.

Based on that given problem, D*S, a basic RSU scheduling, was proposed. The two aspects, service deadline and data size, are given in the form of a *DS_value* to the RSU per request, where the scheduling serves those with the minimum a *DS_value*. Through a single broadcast, several requests are served through the D*S/N scheduling, where pending requests are added to the D*S scheduling. To balance between the requests for both download and upload, the scheduling scheme is done in two steps where an RSU would have a queue for each type of request at different bandwidths, thereby allowing different priority scheduling schemes per bandwidth. Therefore, and reflecting on the two-step scheduling scheme, the service queue would be chosen first followed by the service request that is most suitable.

The researchers in [15] who were interested in data transfer schemes looked at potential solutions for the above-mentioned problems. They have proposed a system which would be used to set the priorities for the multiple RSU scheme so that it improves the RSU basic scheduling through the transfer of requests in parts to the RSUs which have lower loads and thus consider the distance between the RSUs.

The scheduling schemes suggested for the multiple RSU schematic transfer of delayed requests from one to other RUSs within the RSUs multiple ad hoc channels. Within this context, the requests are diversified into two distinctive types which are delay tolerant and delay sensitive. The delay sensitive are smaller in size of that of delay tolerant. Hence, when there is an overload of the RSU, the delay tolerant requests can be transferred to the lightly loaded RUSs to determine the direction of the mobile vehicles. However, one of the most significant proposals to this issue has been suggested trough the MPO (motion prediction optimization) which is a part of the cooperative schematic scheduling. Considerably, the MPO requires the D*S/N to select and allocated the small value qualified and critical requests, especially that of which are suggested to miss its deadlines. However, the unqualified or uncritical requests can be moved to other proximal RSUs based on the prediction of the vehicle motion which is based on the probabilistic motion probability.

The added value of RSU scheduling over a VANET environment is that unnecessary requests are removed which allows for improved efficiency which in turn reduces the deadline miss ratio. This system would have three aspects: item queue, scheduler, and a request queue. Under the request queue the downloads and upload queues are found, where the download queues are used to store the requests and the upload queues are used to store safety and non-safety data. Based on what is in the queues the scheduler would then choose the transmission based on the requests as the bandwidth that it operates on is restricted. The transmissions are based on the data transmission policy of an RSU.

3.7 Road Accident Prevention with Instant Emergency Warning Message Dissemination in Vehicular Ad-Hoc Network [28]

The road accident prevention (RAP) scheme is implemented in VANET and based on vehicular backbone network (VBN) structure. This scheme aims to avoid traffic accidents and hence mitigate the rate of injuries and deaths.

The RAP has several activities:

1- Vehicles will continuously send their status to the road side unit (RSU) which will in return construct a prediction report (PR).
2- If the RSU detect abnormal activity in the PR, then RSU generates an emergency warning message (EWM).
3- The role of the RSU is to construct the VBN structure.
4- Vehicles that are moving in the high-risk zone (HRZ) and have high-risk factor (RF) will receive an EWM from the RSU:

a. Vehicles that are moving within the coverage area of the RSU will directly receive EWM from the RSU
b. Vehicles which are moving outside the coverage are of the RSU will be reached using the VBN structure and receive the EWM from a relay node vehicle

The dynamic topology of VANET and the high mobility and dynamic density of vehicles as well as the limited bandwidth are the main challenges in achieving low end-to-end delay and at the same time ensuring that vehicles in danger zone will for sure receive the warning message within a specific time limit. This part is directly related to the main goal of our thesis.

This unique construction of RAP scheme will ensure that all the vehicles will receive a notification message in case of emergency and within a specific time without delay. The use of VBN structure will lead to a decrease in the number of RSUs which will highly reduce the infrastructure cost. Moreover, the main objective of RAP is to improve the intelligent transportation system (ITS) in VANET.

All vehicles characterized by a high-risk factor and moving in the high-risk zone will receive an EWM. These vehicles are either moving within the coverage area of the RSU or outside it (reached using VBN structure). Once a vehicle receives an EWM, it should directly react either by changing lane, slowing down or choosing substitute routes.

VBN is a VANET structure whose main constituents are the RSUs and vehicles in the network. The major power of VBN is the use of relay nodes (RN). Based on criteria as time and location, specific vehicles are dynamically elected as RN that have the same role of a base station. The relay nodes will be elected for a specific period of time and their job is to forward the warning message to the destination vehicle. These RN have explicit path to follow in order to deliver the warning message and in case they detect a path failure due to network congestion or loss of signal for example, then they have the option to follow an alternative path with a totally different set of intermediate nodes keeping in mind that the main target is to deliver the message within the given time. Several criteria are to be used in order to know which vehicle can be elected as a relay node: first, the vehicle should be within a specific distance from the RSU. Second, the vehicle will be given a time limit after which it will be no more considered a relay node. Finally, if a vehicle passes the distance limit set by the RSU then a new vehicle closer to the RSU will be reelected as RN. (The relay node election is discussed in detail later).

The main advantages of using a VBN structure can be summarized as follows: (i) reduction in source-destination distance, (ii) decrease in end-to-end delay, (iii) increase in EWM notification, (iv) extension of the coverage area of RSUs, (v) reduction in number of RSUs. The four phases of the RAP scheme are: (i) construction phase of the prediction report (PR), (ii) generation phase of the EWM, (iii) formation phase of the VBN, (iv) dissemination phase of the EWM.

As said before, the RSU will receive status report (SR) and traffic flow (TF) data from vehicles in the network and based on abnormality in these data a PR is constructed. After the PR construction, the RSU generates an EWM. In the last step, the RSU will form a VBN structure and the EWM will be spread to all vehicles moving in the high-risk zone (HRZ) and having high-risk factor (RF).

3.8 SAI: Safety Application Identifier Algorithm at MAC Layer for Vehicular Safety Message Dissemination Over LTE VANET Networks [65]

Definitely when most of the research addresses the vehicular communications, it is associated to ubiquitous cellular networks which are innovative technologies that doesn’t only govern the progressive elevating traffic but more to ensure the QoS (quality of service) demanded for current and future vehicular applications. Interestingly, operators and service providers utilize several or single schematic technologies to meet up with the requirements and needs of the applications markets. To illustrate the utilization of the service operators, take for instance, the data and voice application which demand low latency that can be attained and retrieved from a WCDMA (wideband code division multiple access) compared to the higher rate demand that can be appealed to through lower latency of LTE.

Significantly, the umbrella of vehicular communications encompasses and include the C-ITS (Cooperative intelligent transportation systems) which offers rigid services in terms of accurate packet delivery and latency. Although two vehicular communications applications have been mentioned earlier which are the safety and commercial applications, currently the research focuses on safety in terms of risk warning, transport efficiency in term of drivers' assistance and entertainment or information application which is needed for remote assessments. The mentioned applications are correlated with the introduction of DSRC which are compliant to the IEEE connection over wireless channels within the wave standards of the vehicular environment. This was introduced to explain the necessity of connecting the vehicles over the range of IEEE 802.11p, multiple hop that requires RSUs and infrastructure adjustments to meet up with the requirements and process of the V2V applications.

3.9 Multihop-Cluster-Based IEEE 802.11p and LTE Hybrid Architecture for VANET Safety Message Dissemination [66]

In the prior sections we have highlighted the concept of multihop and cluster schematic connection for vehicular communication. Considerably, the current research focused on explaining the concept of VMaSC (vehicular multihop algorithm for stable clustering). To better understand VMaSC, the multihop clustering systematic algorithm should be demonstrated and explored in terms of its features. Most importantly, the VMaSC govern the providence of a cluster head (CH) stable selection where the mobility is relatively and metrically calculated based on the average speed relative to the near vehicles within the clustered network.

Moreover, VMaSC is characterized by offering a cluster connection with the minimal overhead requirements since it directly connects to the member of the head of the cluster within the reach instead of needing to connect to the multi hops CH that requires that cluster member (CM) information dissemination throughout the periodic packets or hello packets. Accordingly, it can be suggested that VMaSC operates efficiently through the reactive clustering which an asset to reduce the overhead caused by excessive packet transmission.

In retrospect, the same can be deduced about reducing the interference or minimizing the inter-cluster one through the reduction of overlapping clusters within the connection space and providing priority for the already connected devices on the existing provided clusters. All of this will provide hop aware cluster, efficient size and accurate information exchange among the several CHs.

Considerably, the systemized scheme introduces five states under which individual vehicles operate under. The first is named as INITIAL to represent the state of starting the vehicle, STATE Election which is connected the decision that the vehicle undertakes over the vehicle information base (VIB). Third is the CH where the vehicle is allocated as the cluster head, followed by the ISOLATED cluster head when a certain vehicle takes a certain transition and is no longer connected or neighboring to any cluster. Compared to the final state which is the cluster member as in the connection of the vehicle to an already existing or established cluster.

3.10 A cooperative V2X MAC protocol for vehicular networks [67]

Road safety is critically one of the most pondering and crucial implementations to reduce fatalities and physical injuries caused car accidents. According to recent statistics conducted in 2015, almost an estimate of 35,092 out of 36,973 fatalities in the USA are directly linked to highway accidents. Considerably, NHTSA (national highway safety administration) highlighted that the safety protocols implemented by vehicular communications mainly that of V2V and V2I are able to mitigate and reduce these fatalities up to 80 percent. Based on this proven fact, the DOT (department of transportation) mandated V2V installation on all heavy weight transport vehicles to ensure and promote their and others safety.

In other words, vehicular communications have been receiving more attention from authorities and governments as well as from researchers. This has contributed to the proposal of new approaches of implementing innovative processes within the vehicular networks to widen the road safety parameter of applications among which is the FCW (forward collision warning), LCW (lane change warning), LTA (left turn assist) and IMA (intersection management assist). If these applications were developed in the line with associating V2V along V2I then the transportation vehicles will witness a variety of intelligent services that can control and optimize road traffic.

Aside from the previously introduced new applications, a new protocol has been suggested to mobilize the innovative and practical application of vehicular communication. This innovative protocol has been entitled HCMAC (hybrid cooperative MAC) which corresponds to the VeMAC mechanism but is innovatively optimized for optimal connections of the vehicular networks. The authentic mechanism of HCMAC is characterized through its ability to benefit from the TDMA scheme of channelization along the advantage of utilizing CSMA random access. Accordingly, it can be deduced that HCMAC is mostly efficient in reducing CCH channels collisions over the rate of access and for the assignment of available time slots for contending and mobile vehicles. The importance of HCMAC is in the fact that it has a re rapid response than that of VeMAC which is crucial for high dynamics of communication networks.

Prominently, the advantages of HCMAC can be foreseen through its collection effective detection where it is powered by a new MAC scheme that duplicates the allocation of time slots and fully allow for the time slot distributed reservation. This is further supported by the analytical algorithm that functions efficiently in supporting the reservation of faster slots which is really needed in urban areas and conditions.

In summary, HCMAC out power that of VeMAC through its PDR (packer delivery ratio), throughput, rate of collisions and delays of inter packet

3.11 On vehicular safety message transmissions through LTE-Advanced networks [69]

Safety messages transmission within the vehicular communications can encounter several problems among which the most prominent is the congestion issue which contribute to message delays that are contradictory to the purpose of safety implementations of applications. One of the main assets that must be maintained in the V2V and V2I communication is the information freshness which is correlated to the network latencies and safety transmission generation rate. Accordingly, this indicates that with progression of more generated messaging rates, the accurate provenance of fresh information is ensured.

On the other, more latencies induce lesser fresh information and inaccurate information sharing of location. However, the location sharing problem is the most prominent within the latencies, generation periods and mobile faster vehicles. Therefore, two solutions were proposed to resolve this issue of the server which are the LTE modification and the safety application modification.

The LTE modification indicates that the MAC layer scheduler should be modified. This scheduler will take into consideration vehicle speed in order to allocate resources.

The LTE modification has been introduced through the scheme of D2D direct communication which is a 3GPP (third generation partnership project) or also known as LTE-A. LTE-A promotes the proximal devices connectivity and data transfer directly through the established infrastructure. Nevertheless, D2D alone cannot accomplish this connectivity accuracy for safety messages exchange since it pairs quickly and more rapidly than the vehicles ability to detect and receive these messages. Moreover, it requires more connection initial time to launch safety metrics.

Knowing that vehicles transmit real time location, the cellular communications are always employed for this purpose, and the real time location sharing can be used for pair detection of D2D and at the same time for the allocation of resources for safety messages transmission between vehicles. All of which contribute to the reusability of resources allocated within the subset of vehicles.

CHAPTER 4

PROPOSED INFORMATION DISSEMINATION APPROACH

This chapter presents our proposed information dissemination approach. This approach is effective in case a reliable protocol is considered in VANET that supports both V2V and V2I communications.

4.1 Main idea of the proposed model

The proposed model will mainly consist of several RSUs and cars dispersed in a predefined area. The proposed approach will differentiate between 3 traffic classes:

- Class 1: this class represents event or accident detected which require immediate actions. For instance, this category should get the highest priority and warning messages should be diffused as fast as possible. For example, in case of a car collision nearby vehicles should receive the necessary updates in the shortest delay to allow them to take prompt action such as reducing the vehicle's speed, change lanes, or display appropriate warning messages to alert other cars.
- Class 2: this class represents critical cases which are not due to unexpected event but rather to changing traffic and road conditions. This class is less critical than class 1 but still messages must be disseminated quickly. Class 1 and 2 require direct and immediate delivery of safety messages; however, in this class delays can be slightly higher than the previous class and alternative techniques might be used. Examples of this class include roadwork warning which will alert the drivers about certain work on specific locations which will mitigate the risk of collisions at these points; vehicles driving on opposite

direction; traffic congestion warning; road safety and traffic regulation at intersections, etc.

- Class 3: this class represents normal case in which there is no need to take immediate actions. This class is the least critical and delays can be higher than the previous two classes. This class consists of periodic updates as sharing weather conditions, map download and update, multimedia download, etc.

4.2 V2V for class 1 messages:

As mentioned before, class 1 is the most critical case in which we must ensure reliable delivery of messages as well as lowest delay possible. For this reason, V2V is adapted in this case as shown in figure 4.1. Many reasons can explain why we will use V2V: First, instead of using a 2-way delivery of the message (from vehicle to RSU then from RSU to vehicle), the message will be directly delivered from one vehicle to another one. This way the amount of data transmitted from vehicles to RSU will be reduced as well as delay is reduced, and messages will be spread faster. Second, V2V is considered faster in term of latency compared to other communication models. For instance, WiFi has a latency communication of 151 ms, WiMAX 120 ms whereas V2V has a low latency of approximately 50 ms [58]. Finally, V2V allows high data transmission rate of 3 to 27 Mbps with line of sight is 360º of a span of up to 1000m which will help emergency messages to quickly reach their destination [58].

Figure 4.1 Class 1: V2V Communication

4.3 Adaptive V2V-V2I for class 2 messages:

As mentioned earlier, class 2 messages are of high importance; however, they are less critical and have a slightly lower priority than class 1. In this part, there is no fundamental need of only using V2V, but it is better if we use a collaboration between V2V and V2I as shown in figure 4.2. It is well known that RSUs and vehicles have predefined communication limits. (V2V communication range is ~300m, RSU communication range is ~500m). In this thesis, vehicles and RSUs are grouped into clusters based on the k-means clustering algorithm. Suppose we have three RSUs then in this case, vehicles are grouped into three clusters where each RSU is considered a cluster head. This way, the communication between vehicles is organized and vehicles can only communicate with their appropriate cluster head or other vehicles on the same cluster.

For instance, suppose one of the roads is closed due to sudden manifestations. In this scenario we have two options of distributing the message:

- The closest vehicle to this road can either directly notify its RSU which will in its turn notify all the vehicles in its range. (Vehicle → RSU then RSU → Vehicles in its range)
- In case the vehicle who detected the road-closure was on the edge of the vicinity of the RSU then it will send the message to another vehicle who will in its turn forward this message to the RSU who will spread it to all vehicles nearby. (Vehicle1 → Vehicle2 then Vehicle2 → RSU then RSU → Vehicles in its range). It is important to mention that every vehicle is always receiving information updates from the RSU of its vicinity. These updates will include information as closest vehicles, their transmit power, delays, etc.

On the same side, several scenarios can include a direct communication between vehicles and RSUs. For instance, a vehicle who detects closure of a road can request and receive information from the RSU regarding alternative routes. In this case it is a direct single communication between one vehicle and its RSU and vice versa. This vehicle can later send the data received from the RSU to another vehicle and so on depending on the scenario.

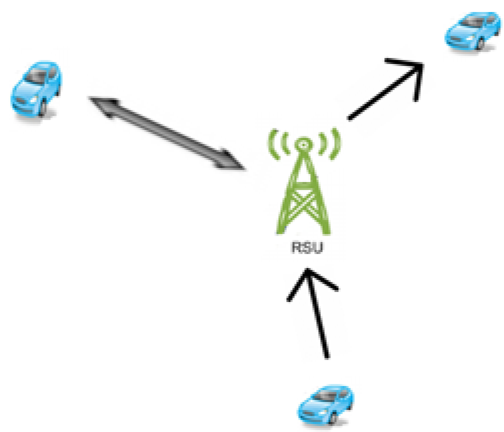

Figure 4.2 Class 2: Adaptive V2V-V2I Communication

4.4 I2V for class 3 messages:

As stated before, class 3 is the least critical and does require any immediate action. This class can be described as regular updates to vehicles' information. After a certain specified time-limit, the RSU will send the updated information to all the vehicles in its range as shown in figure 4.3. This information is collected from vehicles, other RSUs and other components of the ITS as road cameras, traffic lights, etc. The RSU will collect and save all the information and then share them with the vehicles. Examples of such information include weather conditions, number of cars in the same range, speed limit, distance and power between cars, nearest restaurant and hotels, etc.

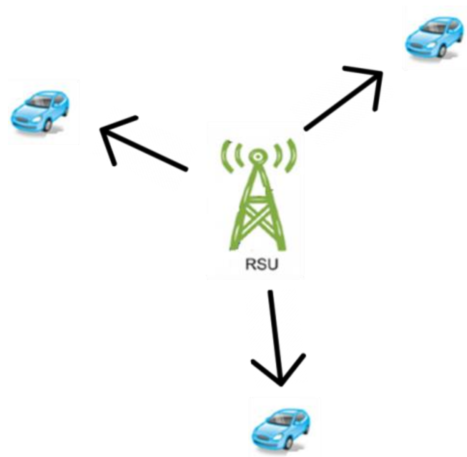

Figure 4.3 Class 3: I2V Communication

4.5 Dynamic Resource Allocation for TDD-LTE frame:

The LTE TDD and FDD frame structures were discussed before in detail (section 2.4.3) and in the scope of our thesis, LTE TDD frame structure will be used. In fact, the latter is used due to the possibility of dynamically changing the number and position of uplink and downlink slots. As said before, 3GPP has defined 7 TDD configurations which are unique and have different number of uplink slots , downlink slots and special subframe slots. This way several options are available, and the best configuration is chosen in order to balance and meet the load conditions of the network.

In this thesis, in order to improve the delay of message delivery process and optimize the throughput of the constituents of the network, a new dynamic LTE resource allocation is needed. Despite the presence of predefined LTE TDD configuration as explained before, the proposed configuration of the LTE TDD frame will be dynamically configured based on several parameters such as traffic volumes and quality of service requirements in the uplink and downlink. This means, all the slots in a TDD-LTE frame will be used in the most efficient manner. This way, in some cases we might increase the uplink slots, in other cases we might increase the downlink slots and in some other cases we need to find the best suitable combination of uplink and downlink slots in order to reach and satisfy QoS requirements. Regarding the special subframe slots, we can distinguish between 10 special subframe configurations as mentioned earlier (section 2.4.3.2). These predefined configurations are unique which means that each subframe will have a different combination of position and number of DwPTS, GP and UpPTS. In this thesis we will adopt the special subframe 7 for the main reason that this configuration is the best suitable for small cells since it has more UpPTS symbols which can be utilized for RACH (Random Access Channel which is the first message from UE to eNB when you power it on) planning and uplink SRS signals. The special subframe 7 is composed of the following: (i) 10 DwPTS, (ii) 2 GP, (iii) 2 UpPTS.

As mentioned before, (i) for a case 1 which is considered to be the most critical case, we shall increase the number of uplink timeslots; (ii) for case 2 which also represents some critical information, we shall increase the number of downlink slots; (iii) for case 3 which represents a normal case, we shall find the best combo of uplink and downlink which ensure communication between entities and at the same time satisfying different QoS requirements. The number of downlink and uplink slots will dynamically change in order to cope with the different mentioned cases and reach the best uplink and downlink throughput.

4.6 K-means Clustering:

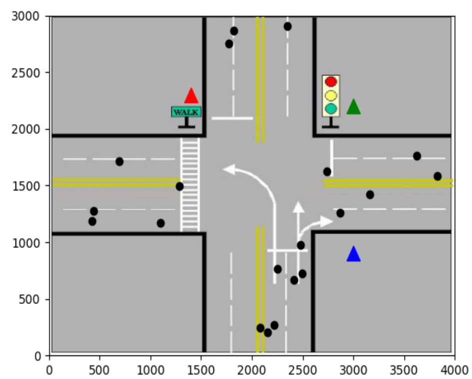

Figure 4.4 Network Topology without k-means

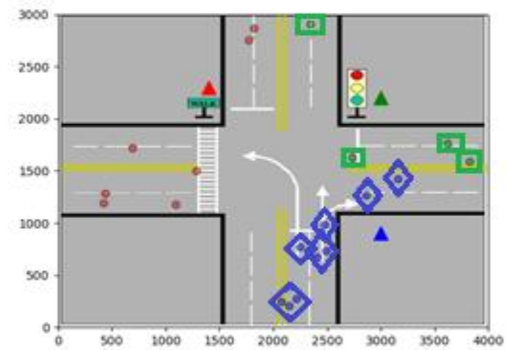

Figure 4.5 Network Topology with K-means

Figure 4.4 shows a VANET topology composed on 3 RSUs and 20 cars. The cars are randomly dispersed in a predefined area (in this case it is a 4 km x 3 km). In figure 4.5, the cars are clustered based on the k-means clustering algorithm. We can infer that each RSU has a group of cars which constitute its vicinity and in which they can share various types on information. For example, cars in red are in direct communication with the red RSU which means all cars in the same group share important information with each other and with the RSU. The red cars for instance cannot have a direct communication with the blue RSU or green cars; however, they can reach them either through: (i) a red car will send the info to its red RSU, then this RSU will do a direct communication with the blue RSU for example which will then deliver the message to blue cars, (ii) or a red car will send the info to its red RSU, then this RSU will forward the info to a red car considered as relay node vehicle who will in its turn forward the message to all the green cars reachable from it. Clustering is fundamental in this case since it will give an intuition about the structure of the data and facilitate its analysis.

In our thesis, k-means algorithm is used in order to partition the dataset into k pre-defined clusters. We have decided to pick k-means for many reasons: (i) the most essential step in k-means is to know “k”. In our case, “k” is the number of RSUs which will be predefined. Therefore, the value of “k” will be known. (ii) k-means uses distance-based measurements to determine similarity between data points and in our case, distance is already calculated. Therefore, knowing the value of “k” and already having the distances calculated imply that k-means is the best suitable algorithm to use.

Clustering the cars into several groups based on the k-means algorithm will highly improve and organize the communication between cars. Since our system is delay sensitive, then transforming the big system into small subsets will efficiently decrease end-to-end delay and reduce in source-destination distance. This way the message delivery process will be controlled, reliable and faster. For example, suppose we have three clusters (red, green, blue) then cars in the red cluster will be able to send warning messages within this cluster only. Thus, the message will be contained within a predefined cluster and not within the whole big system. Moreover, new parameters added to the clustering part will boost the performance of the system. In fact, red cars are grouped within a certain RSU and cars are randomly dispersed over it having different distance and power. In this thesis we can differentiate between two models: (i) in a V2V communication model, cars which are within 500 meters from each other can only communicate together. The rest of the red cars can be reached through other red cars considered as relay nodes. Moreover, as stated before each car has a specific received power. This means that not all the cars have the possibility to send and receive messages. Cars with a received power greater than -110 dBm can receive the messages without being degraded or with a low signal. This way in the V2V communication model, not all the red cars will be senders or receivers. A red car within 500 meters and having a received power greater than -110 dBm will be able to successfully receive the warning message from a red car only. This way clustering the cars in addition to power and distance constraints will improve the V2V communication model where only certain cars can send and receive and not all of them. (ii) In the adaptive V2V-V2I communication model, cars as said before are clustered within RSUs. The red cars can only share information with the red RSU or other red cars. In this scenario, the car which is sending the data has two options: either directly sending the data to the nearest red car (within the predefined distance and power specified) or to its corresponding RSU. Cars can only communicate with their RSU if they are within 750 meters from it. Otherwise, they need to select a car which is a relay node to forward the message to the RSU. Suppose we have the following scenario in an adaptive V2V-V2I model: a red car needs to deliver a message to car which is not in its cluster such as a car in the blue cluster. In this scenario, the red car will send the warning message to its red RSU. This RSU will forward the message to the blue RSU which will forward it to the corresponding blue car. The worst-case scenario can be represented by three stages: (i) the distance between the red car and RSU is the maximum distance which means this car is the farthest car from the RSU, (ii) the blue RSU is the farthest RSU from the red one, (iii) the blue car is the farthest car from its RSU. In this case, the system will fail since it is delay sensitive and in such a case the message delivery process will take too much time. For these reasons we have set several constraints such as cars which are very far from the RSU (distance greater than 750 meters) will not be able to perform a direct communication with it. Only cars within the specified range will perform a direct communication with the RSU which will eliminate the choice of having a very far car undergoing a communication with the RSU. This way the distance between cars and RSUs are reduced and thus delays are improved. Moreover, the RSU will look for the closest RSU to send the messages and thus very far RSUs cannot be directly reached which also implies that delays will be enhanced. Following these rules, we ensure that the worst-case scenario will never be employed, and the adaptive V2V-V2I communication model can be used to obtain low delays that can be used for critical cases.

4.7 Information Index:

The information index is a key element in the network topology. Each car will have an information index (Info Index) which will indicate its status. The information index can be either 1, 2 or 3 based on the criticality of the case: (i) A car which has an info index 1 indicates that it has the highest priority since it has a very critical case that requires immediate action (V2V communication). (ii) A car which has an info index 2 has also a high priority which is somehow slightly lower than case 1 but still requires immediate action (Adaptive V2V-V2I communication). (iii) A car which has an info index 3 indicates a low priority case which symbolizes a normal case that does not require prompt and direct action (I2V communication).

Suppose the network consists of simply 10 cars. Therefore, we must have 10 info indexes (each car has a specific info index). This info index will be periodically updated after a certain period. For instance, a car at time t = 0.4 s had an info index 3, then at t = 0.8 s its info index became 2. This means that based on the topology of the network (dense or light) and based on other parameters such as traffic congestion, road conditions, and weather conditions the info index of the network will keep on changing. Each car will constantly send its status to the RSU via a V2I communication. This status will include several parameters such as location, speed, transmit power in addition to the information index. The role of the RSU is to collect the info indexes of the cars in its vicinity and continuously updating the cars via an I2V communication. In other words, the cars in the same communication range of the RSU will be aware of the info indexes of each other.

Suppose we have the following info index:

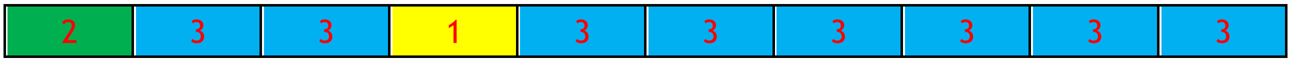

Figure 4.6 Information Index (10 cars)

Based on this info index (figure 4.6) we can know when to use a V2V or V2I communication. For instance, since only car 4 has an info index 1 then it will perform a V2V communication and the rest of the cars will perform a V2I communication.

Figure 4.7 shows the cars which performed a V2V communication. The x-axis shows the car number and the y-axis the V2V value. This V2V value will be incremented by one every single time a V2V occurs.

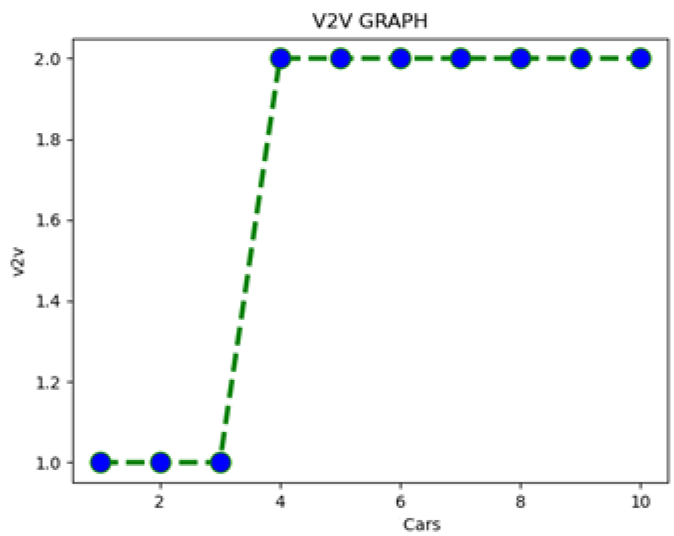

Figure 4.7 V2V-Info Index Relation

We can infer from figure 4.7 that only car 4 performed a V2V scenario. In this figure, whenever a V2V is performed we add a 1. We can clearly see that only car 4 got a plus 1 which indicates that it is the only car who executed a V2V communication. The graph shown in figure 4.7 perfectly matches which the information index shown in figure 4.6. For instance, the fourth slot in figure 4.6 has a 1 as information index which was translated into a clear change in the status of the car number 4 as shown in figure 4.7.

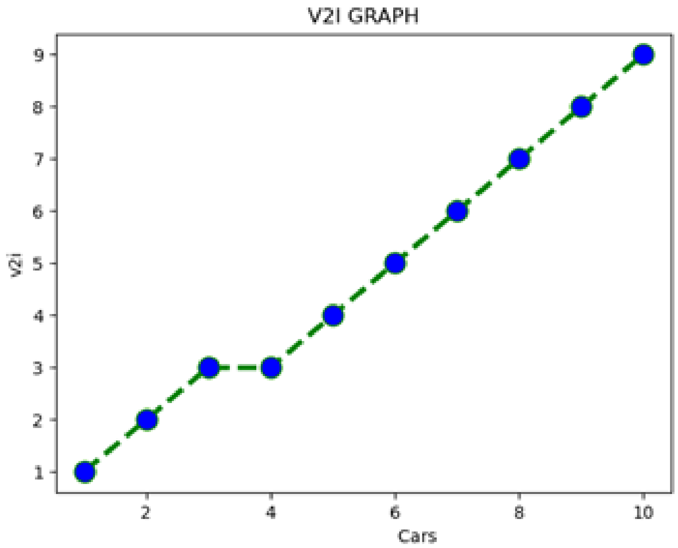

Figure 4.8 V2I-Info Index Relation

Figure 4.8 shows the same work as the one done in figure 4.7 with the only exception that this time, we are studying the cases in which a V2I communication occurs. Same as in figure 4.7, whenever we are going to perform a V2I we are going to add one. We can infer from figure 4.8 that car 1, 2, and 3 performed a V2I communication, then car 4 performed a V2V since we did not add a 1, then the rest of the cars (car 5 → car 10) made a V2I communication since we are adding 1 for each one of them. These two plots are essential visualization tools which will help in identifying when V2V or V2I communications are employed.

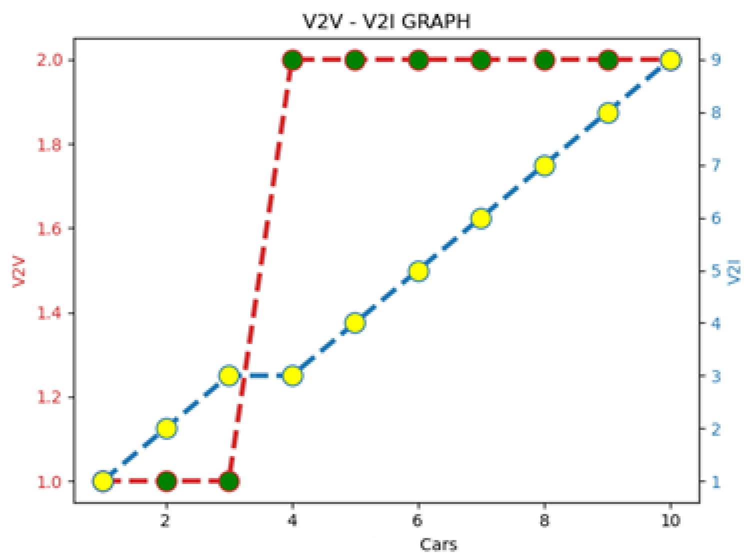

Figure 4.9 V2V-V2I-Info Index Relation

Figure 4.9 combines the two previous figures: In red, we have the relation between V2V and cars and in blue the relation between V2I and the cars. The x-axis represents the cars in the network, the first y-axis represents the V2V communication, and the second y-axis is the V2I communication.

The red and blue lines represent the V2V and V2I communication respectively. For example, a car which witnessed a V2V communication will have the red line increasing since the value will be incremented and the blue one will stay stable and indicating that the V2I value was not changed. From this figure we can say that all cars performed a V2I communication except for car 4 who executed a V2V communication.

Based on the three figures (figure 4.7-4.8-4.9), we can say that the network witnessed very few critical cases and most of the cars had a normal indicator. Therefore, the number of crashes is very minimal, and this is the best scenario to achieve. Whenever the V2V indicator is low this implies that the network environment is safe and on the same side whenever this indicator is high, the network is dense, and we have a lot of crashes. In another scenario we can have a totally different case which represents chaos in the network and a lot of crashes. In a real-life scenario this might happen during adverse weather conditions when roads are frozen, and cars might slide and as a result ten of them will crash and lead to severe accidents. The figures below represent the described scenario.

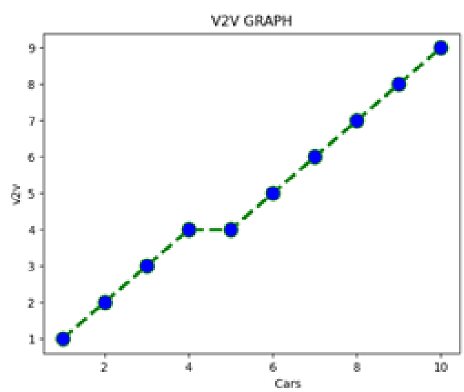

Figure 4.10 V2V-Info Index Relation

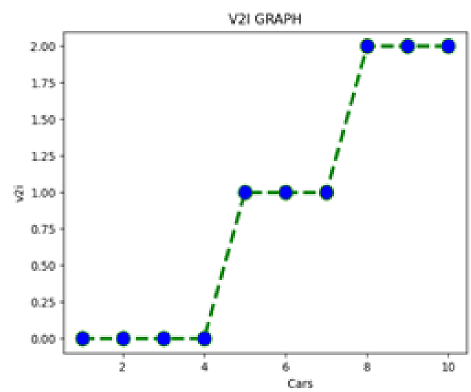

Figure 4.11 V2I-Info Index Relation

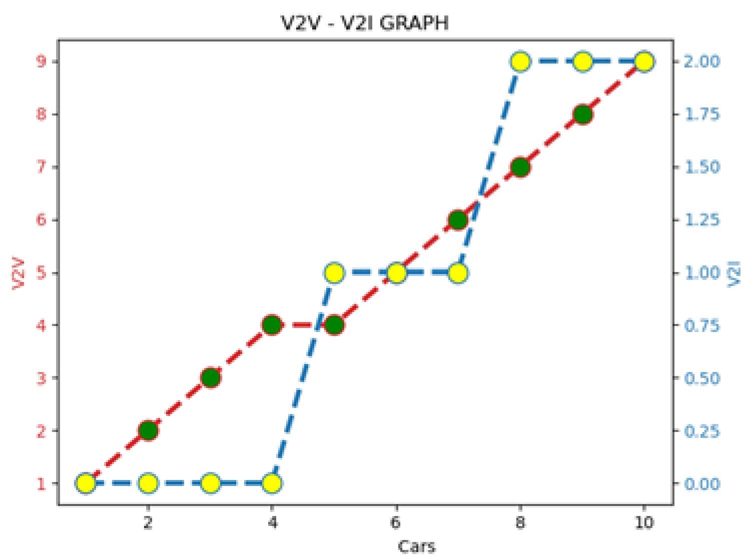

Figure 4.12 V2V-V2I-Info Index Relation

Figure 4.12 combines the two previous figures (4.10 and 4.11): the red dashed line represents the relation between the V2V and cars; the blue dashed line represents the relation between the V2I and the cars. The x-axis represents the cars in the network, the first y-axis represents the V2V communication, and the second y-axis is the V2I communication.

In this figure, we evaluate both the V2V and V2I status of each car. The red and blue lines represent the V2V and V2I communication respectively. For example, a car which witnessed a V2V communication will have the red line increasing since the value will be incremented and the blue one will stay stable and indicating that the V2I value was not changed.

Based on the 3 figures (figure 4.10-4.11-4.12), we can infer that car 5 and 8 only carried out a V2I communication; whereas the rest of the cars (car 1 → car 4, car 6-car 7, car 9-car 10) have conducted a V2V communication. In this scenario, around 80% of the cars where using V2V communication which implies that they had a very critical case. In other words, this network composed of few cars have witnessed a lot of crashes and this is the worst case in a real-life scenario.

CHAPTER 5

EVALUATION

In this chapter we evaluate the performance of the system and discuss the obtained results.

5.1 Implementation, simulation environment, parameters

Our approach was implemented in Python. All the modules, functions, methods, etc. were built from scratch. Python is one of the newest booming programming languages nowadays. The choice of using Python is derived based on several criteria such as: (i) a huge library that covers almost "anything" from machine and deep learning, to data processing and scientific computing, etc. (ii) simple and clean syntax with a lot of documentation and online support. (iii) a great tool to visualize, manage and organize complex data.

The network is composed of RSUs and cars dispersed over a specific area. Several parameters were used in order to derive information such as distance, power, delay, throughput etc. The distance between cars, between cars and RSUs and between RSUs is calculated using the Euclidean distance formula. Suppose we have two RSUs with coordinate (x, y) and (a, b), then the Euclidean distance is given by the following equation:

$$\text{dist}\,((x,y)(a,b)) = \sqrt{(x-a)^2 + (y-b)^2} \tag{5.1}$$

Figure 5.1 shows how the same equation (5.1) is calculated in our code in order to obtain the distance between RSUs:

```
np.sqrt(
    (df13['x_cars'] - centroids1[i][0]) ** 2
    + (df13['y_cars'] - centroids1[i][1]) ** 2
)
```

Figure 5.1 Distance calculation for RSUs

Where x_RSUs and y_RSUs are respectively the x-coordinate and y-coordinate of the RSU. The code is composed of three main functions: (i) RSUs to RSUs which is directly related to I2I communication. In this function, we calculate the *distance* between RSUs, as well as the *power* and *delays*. (ii) Cars to cars is used for V2V communication and is responsible for determining the distance between cars, as well as power and delays. Delays can be defined as being the distance over speed. In this function delays are built using two different techniques and we shall show that our proposed technique performed better than some existing ones. An attribute called closest will be set to allow each car to know which are the closest cars to it. (iii) Cars to RSUs is used for a mix of V2V-V2I communication and calculates the distance from cars to RSUs (and vice versa) , as well as their *power* and *delays*. The closest attribute in addition to another attribute *called* color will allow each car to know its closest cars as well as closest RSUs.

Moreover, *path loss* of the channel is defined as the difference in decibel (dB) between the transmitted and received signal power. In this thesis, we adopted the simplified path loss model as a function of distance that is commonly used for system design as shown in equation (5.2):

$$\mathrm{P_r} = \mathrm{P_t}\mathrm{K}\,[\frac{d_0}{d}]^{\alpha} \qquad (5.2)$$

Where P_r is the received power, P_t is the transmitted power, K is a constant factor $(P_r(d_0)/P_t)$, d_0 is a reference distance, and *ALPHA* is the path loss exponent. *ALPHA* ranges from 2 to 8 and is function of obstructions, environment, and carrier frequency. In our case *ALPHA* is set to 3.7 since we evaluate our model in a typical outdoor environment and this value is considered to be the most suitable one.

Simulation Parameters	
Speed	36 km/h (=10 m/s)
Path loss exponent (ALPHA)	3.7
Path loss constant factor (K)	0
Size of Area	Variable
Number of cars	Variable
Number of RSUs	Variable
Transmit Power of cars	[9-30] dBm
Transmit Power of RSUs	[15-40] dBm
Distance (r)	[1-3] meters
Angle (Theta)	[1-2π]
Bandwidth	20 MHz
RBs	100
MCS Index	[0-28]
TBS index	[0-26]
Special Subframe 7	10 DwPTS, 2 GP, 2 UpPTS

Table 5.1 Simulation parameters

Table 5.1 summarizes the simulation parameters used in our thesis.

5.2 Simulation scenarios:

As said previously, we must ensure that V2V communication has the lowest delay. This case is used whenever a car needs to send very critical sensitive information. For instance, suppose a car needs to inform other cars regarding a certain danger as a sudden crash. This information is delay sensitive which means that if the message was not delivered within a certain time limit, other cars may not have enough time to take control and might agglomerate the situation and cause more damage. Thus, the whole system will fail. For this reason, we must ensure a very low delay in this category.

5.2.1 Scenario 1

This simulation will consist of 20 cars and 3 RSUs randomly dispersed over an area of 4 km x 3 km

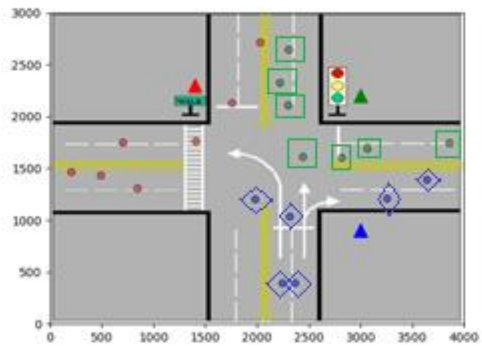

Figure 5.2 network topology scenario 1

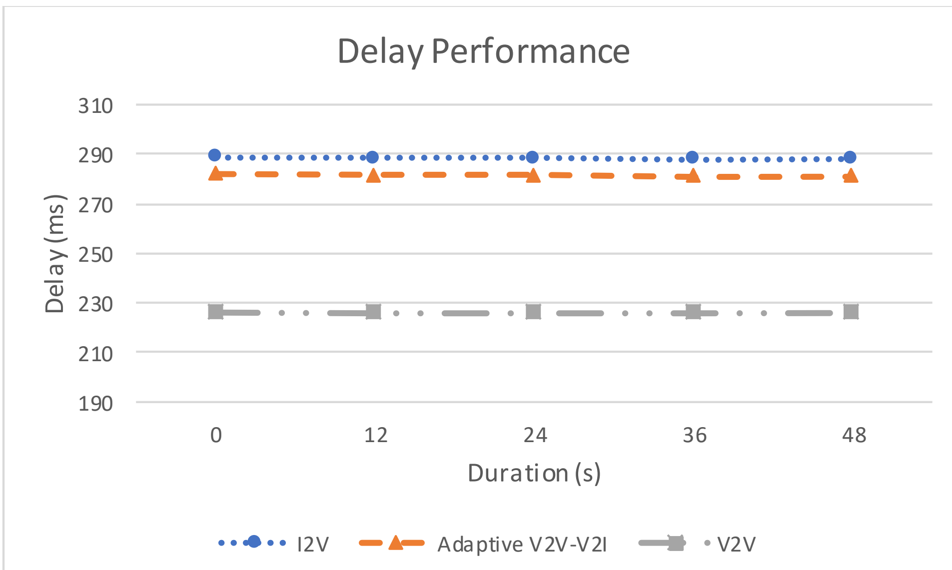

Figure 5.3 Delay over time (20 cars – 3 RSUs)

Figure 5.3 represents the maximum delay between the difference cases. Case 1 which represents a V2V communication has the lowest maximum delays. For example, at time t=24s (or t=0.4 min) the maximum delay is 226.01 ms and at t=48s (or t=0.8 min) the maximum delay is 225.91 ms. Case 2 which represents an adaptive V2V-V2I communication has a maximum delay greater than the one in case 1. For example, at t=24 s the maximum delay for case 2 is 281.41 ms and at t=48 s the maximum delay is 280.92 ms. Case 3 which represents an I2V communication has the highest maximum delays. For example, at t = 24 s (t=0.4 min) the maximum delay for case 3 is 288.34 ms and at t=48 s the maximum delay is 288.05ms. in this scenario, the delay in case 1 is lesser than the ones in case 2 and 3 which enforces our idea that V2V should be deployed in case of high critical cases such as road accident in order to deliver safety messages within minimal time limit.

Figure 5.4-5.5-5.6 are in deep and more detailed representation of the figure 5.3. These figures are presented in order to show that the lines in figure 5.3 are not straight lines and are changing over time. In all the next simulations, the blue, orange and grey lines are not straight lines and are varying over time. These lines are changing in all the simulations and for simplicity purposes, we will show that these variations only in simulation 1 and 4.

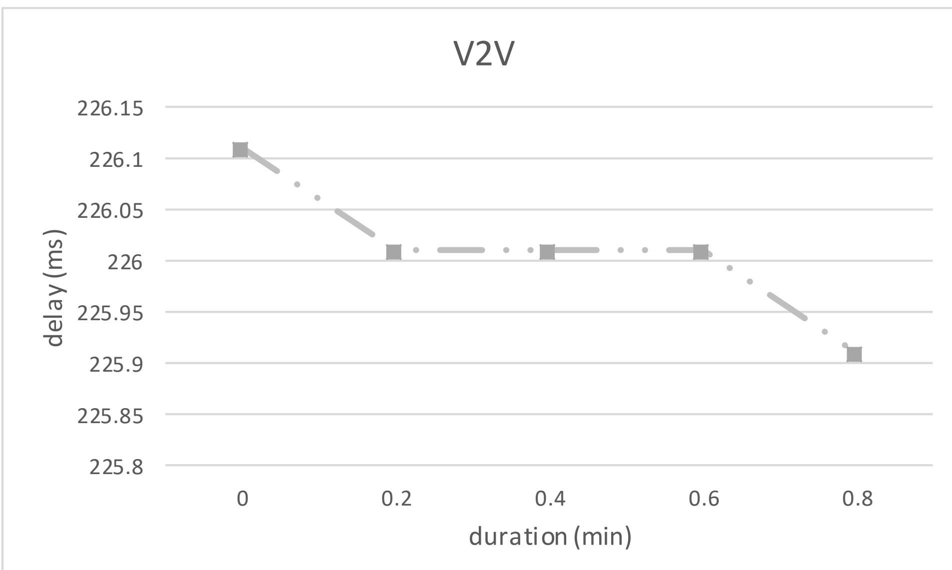

Figure 5.4 V2V Max Delay

Figure 5.4 shows the maximum delay for case 1 which is the V2V communication. This figure is the same as the grey line in figure 5.3. Based on this figure, we can infer that the maximum delay in this case started to be 226.1 ms and then after certain period of time this value became almost

225.9 ms. This shows that V2V communication not only achieved the lowest delays among the other two cases, but its performance is even getter better with time.

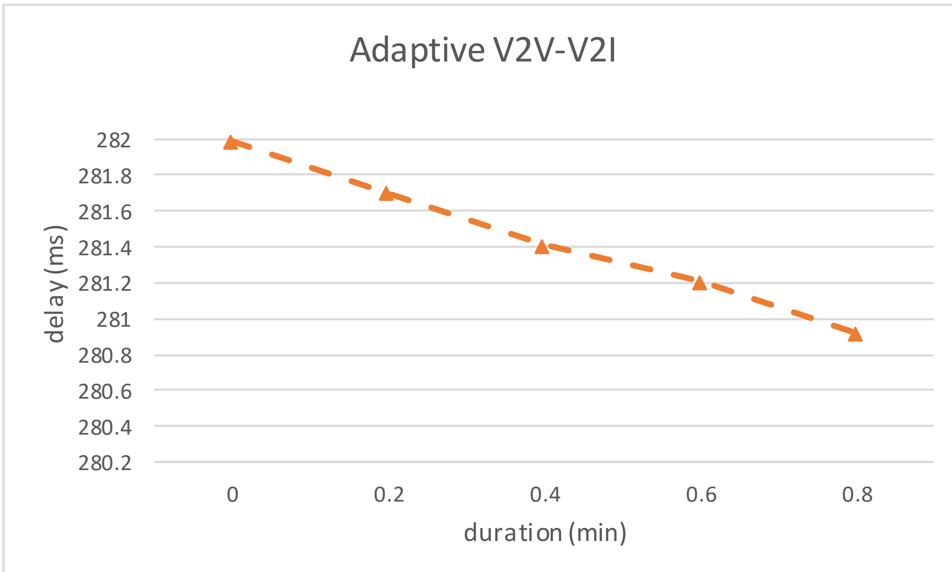

Figure 5.5 Adaptive V2V-V2I Max Delay

Figure 5.5 shows the maximum delay for case 2 which represents the adaptive V2V-V2I communication. This figure is the same as the orange line in figure 5.3. Based on this figure, at t=0.4 min the maximum delay is 281.4 and at t=0.8 min this delay is 280.9. This enforces the idea that case 2 has low delays which are improving over time. This delay is enhanced but still higher than case 1. This indicates that case 1 is still better than case 2.

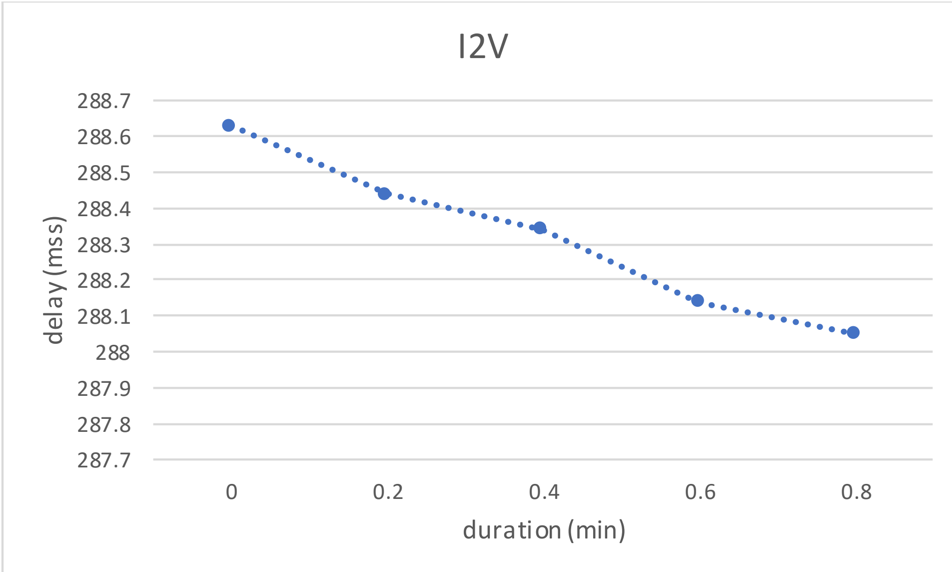

Figure 5.6 I2V Max Delay

Figure 5.6 shows the maximum delay for case 3 which represents the I2V communication. This figure is the same as the blue line in figure 5.3. At t=0.4 min the maximum delay is 288.35 ms and at t=0.8 min this delay is 288.05 ms. Still in case 3 the maximum delay is improving over time; however, this delay is higher than case 1 and case 2. In the next simulations, we will show that the V2V communication will have the best results in terms of delays, then the adaptive V2V-V2I and finally the I2V communication. We will show that in most of the simulations, the V2V communication will improve and reach better delays over time. The adaptive V2V-V2I and the I2V communication will in some cases reach better results and in some other cases their performance will decline; however, they will never be better than the delays reached by the V2V model.

5.2.2 Scenario 2

This simulation will consist of 45cars and 3 RSUs randomly dispersed over an area of 4 km x 3 km

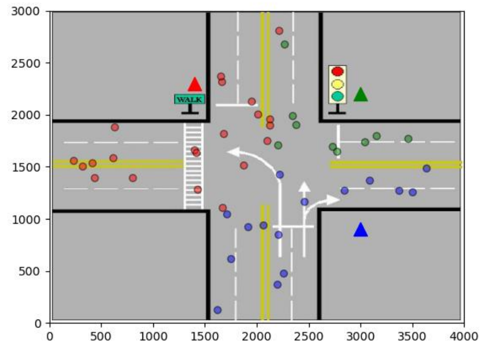

Figure 5.7 network topology scenario 2

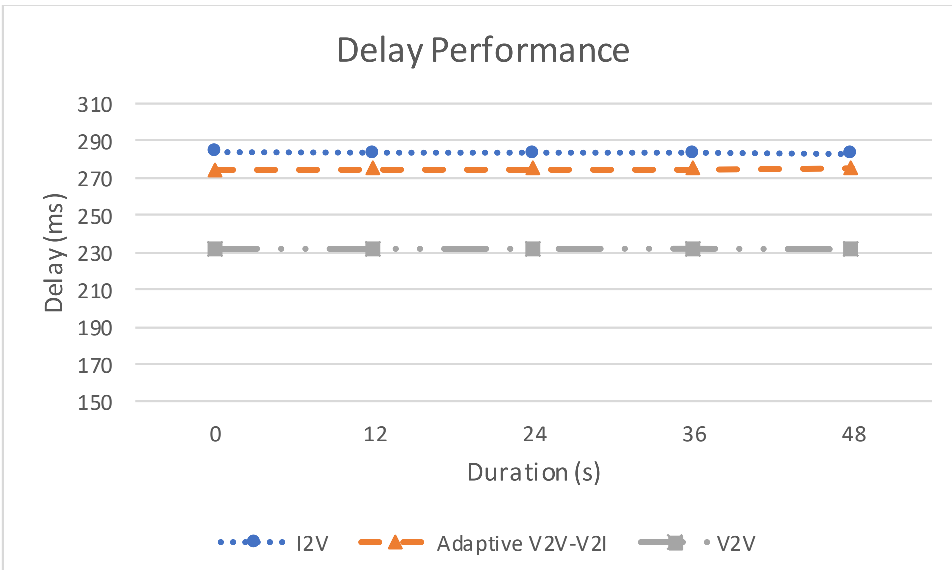

Figure 5.8 Delay over time (45 cars – 3 RSUs)

In this case we have increased the number of cars and still using the same number of RSUs. We can say that even after applying these changes, V2V still have the best results in terms of delays as shown in figure 5.8. For instance, at t=36s the maximum delay for case 1 is 231.81 ms. Also, case 2 and 3 come in the second and third places with maximum delays 274.91 and 283.02 at t=36s respectively. This indicates that even after increasing the number of cars, V2V communication remains the best alternative for delivering high critical information.

5.2.3 Scenario 3

This simulation will consist of 100 cars and 3 RSUs randomly dispersed over an area of 4 km x 3 km

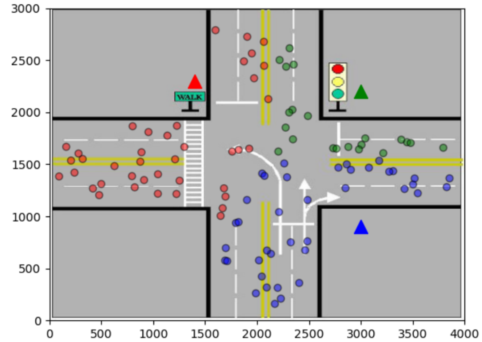

Figure 5.9 network topology scenario 3

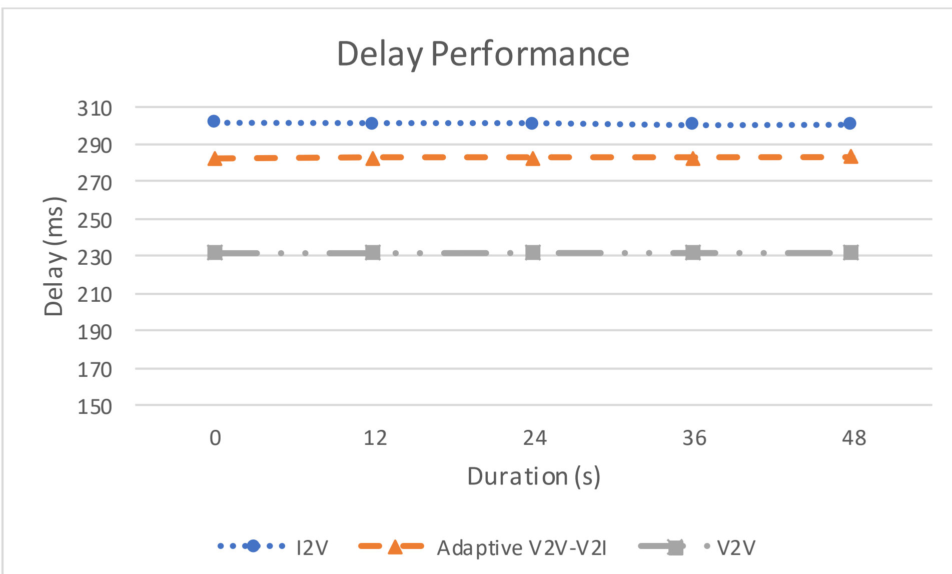

Figure 5.10 Delay over time (100 cars – 3 RSUs)

After highly increasing the number of vehicles, we still got the same results with V2V having the lowest delays as shown in figure 5.10. It is important to mention that in this case the performance of case 3 was drastically affected and leading to even to more delays which worsen the case. For example, in the previous case using 45 cars and 3 RSUs the maximum delay for case 3 was around 283 ms whereas in this case this delay is around 300 ms. This can be explained by the fact that increasing the number of cars and still deploying 3 fixed RUSs implies that more spaces are covered which can lead to higher distance as well as higher delays.

5.2.4 Scenario 4

This simulation will consist of 100 cars and 9 RSUs randomly dispersed over an area of 4 km x 3 km

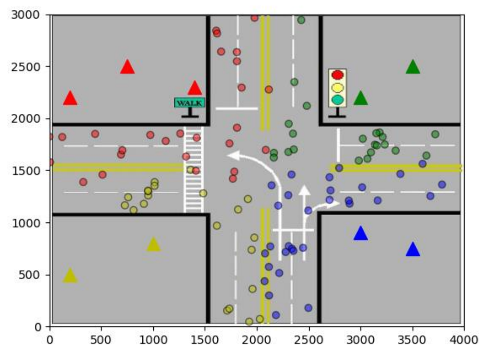

Figure 5.11 network topology scenario 4

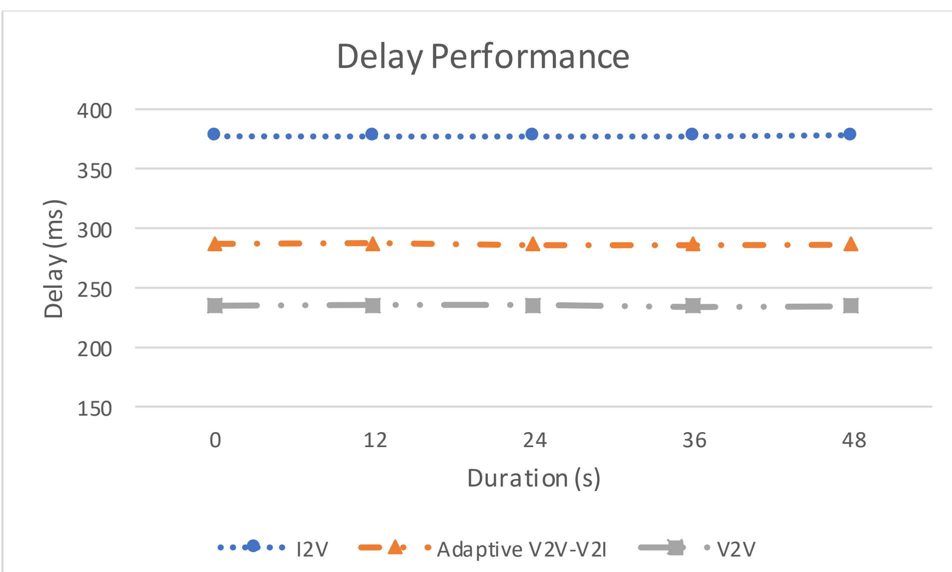

Figure 5.12 Delay over time (100 cars – 9 RSUs)

In this scenario the number of RSUs is three times greater than the ones in previous simulations. In terms of delay, increasing the number of RSUs has not affected the maximum delays in case 1 and case 2. For example, in a comparison with the previous simulation (100 cars and 3 RSUs), after 60 seconds we had a maximum delay of around 231 ms and 282 ms for V2V and adaptive V2V-V2I communication respectively whereas in this case this delay is around 234 ms ad 286 ms for case 1 and 2 respectively as shown in figure 5.12. This indicates that delays for case 1 and 2 are higher than the one in the previous simulation; however, this increase is slightly higher and will not affect the overall performance of the system. On the other side, the maximum delay of case 3 has highly increased in this scenario compared to the previous one. For instance, in the previous scenario case 3 had a maximum delay of around 300 ms and in this scenario it is around 377 ms. This shows that increasing the number of RSUs has negatively affected the performance of the system. This implies that not always having a high number of RSUs will provide more connectivity, coverage areas and lower delays. In this case for instance adding new RSUs has no benefit on the performance of the system and will eventually cost more money.

Figures 5.13-5.14 and 5.15 give specific and more detailed representation of the figure 5.12. These figures are presented to give a more zoomed image of the delays and that these delays showed in figure 5.12 are not fixed line but are varying over time.

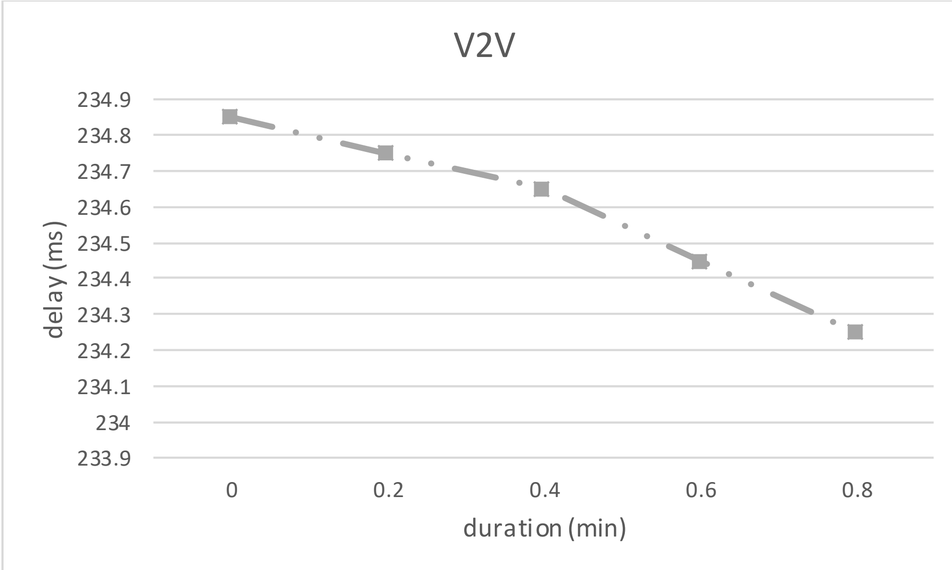

Figure 5.13 V2V Max Delay

Figure 5.13 shows the maximum delay for case 1 which is the V2V communication. This figure is the same as the grey line in figure 5.12. Based on this figure, we can infer that the maximum delay in this case started to be 234.85 ms and then after certain period of time this value became almost 234.25 ms. This shows that V2V communication not only achieved the lowest delays among the other two cases, but its performance is even getter better with time.

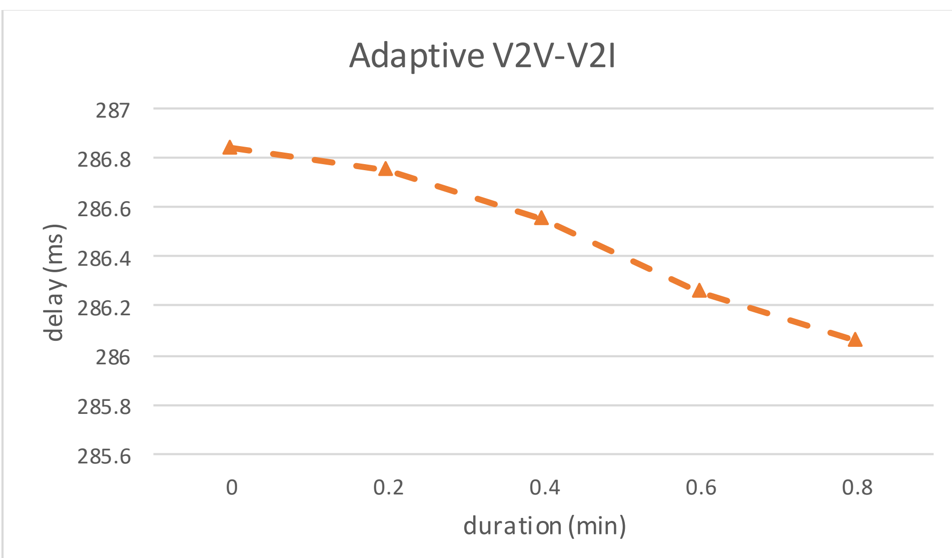

Figure 5.14 Adaptive V2V-V2I Max Delay

Figure 5.14 shows the maximum delay for case 2 which represents the adaptive V2V-V2I communication. This figure is the same as the orange line in figure 5.12. Based on this figure, at t=0.4 min the maximum delay is almost 286.6 and at t=0.8 min this delay is 286.1. This enforces the idea that case 2 has low delays which are improving over time. This delay is enhanced but still higher than case 1. This indicates that case 1 is still better than case 2 and must be used for the highest critical cases.

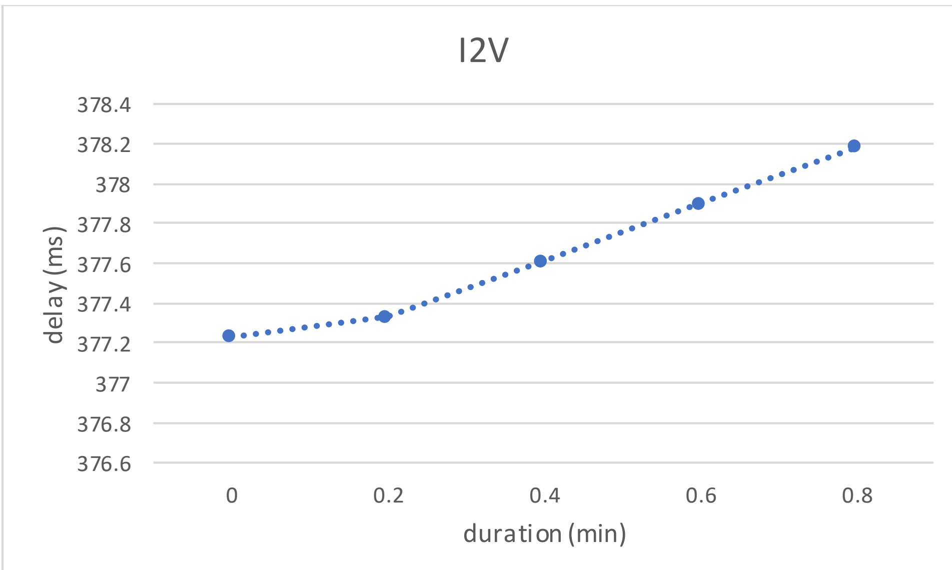

Figure 5.15 I2V Max Delay

Figure 5.15 shows the maximum delay for case 3 which represents the I2V communication. This figure is the same as the blue line in figure 5.12. At t=0.2 the maximum delay is 377.3 ms, at t=0.4 min this delay is 377.6 ms and at t=0.8 min this delay is 378.2 ms. In this case we see that not only case 3 had the highest delays but still its performance is declining over time. This shows that changing the simulation parameter has affected case 3 and reduced its performance. Despite the fact that the performance of case 2 will improve in some scenarios, all the simulations showed that they will never be better than case 1.

5.2.5 Scenario 5

This simulation will consist of 300 cars and 3 RSUs randomly dispersed over an area of 4 km x 3 km

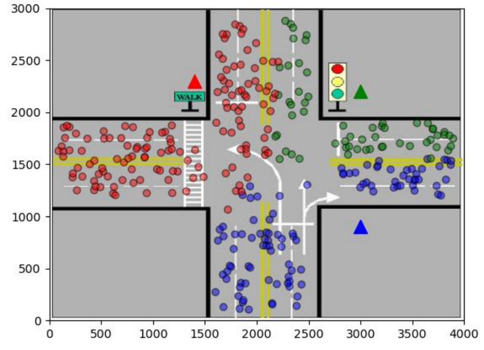

Figure 5.16 network topology scenario 5

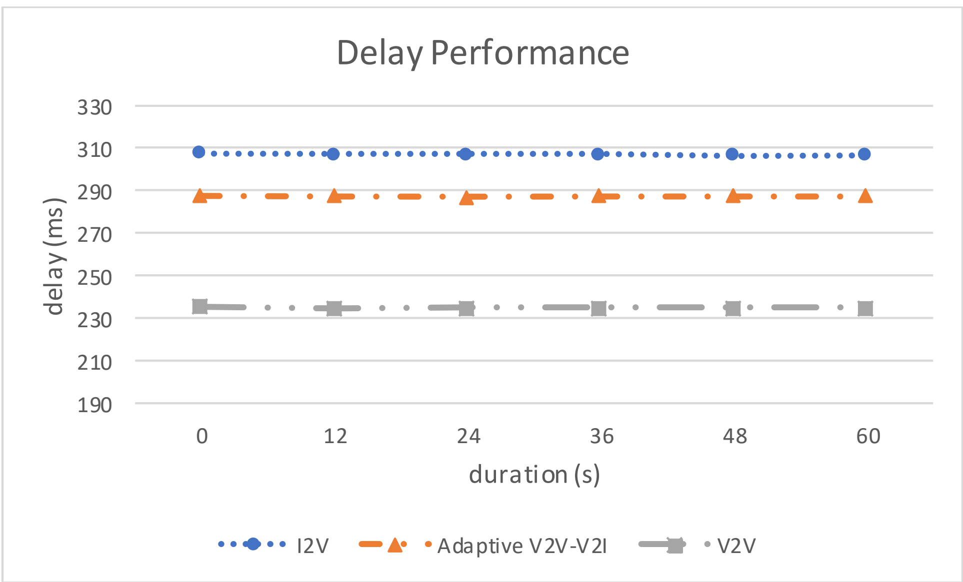

Figure 5.17 Delay over time (300 cars – 3 RSUs)

In this scenario, we have highly increased the number of vehicles (3 times greater) while using simply 3 RSUs. Increasing the number of cars as well as pertaining a moderate number of RSUs with a considerable coverage area as in this scenario led to improvements in the maximum delay of I2V communication with for example a maxim delay of 307.21 ms and 306.65 ms at t=12s and t=60s respectively as shown in figure 5.17. The delay values of V2V and adaptive V2V-V2I communication remained stable and enforcing our proposed idea of using a V2V communication in case of a high emergency warning message since after several combination of the number of cars and RSUs and after many test cases V2V communication is always getting the lowest delay value.

We have implemented several other test cases as a combination of either increasing or decreasing the number of cars and RSUs, as well as changing the coverage area and duration of the simulation. Table 5.2 summarizes the different test cases.

Number of cars	Number of RSUs	Area (km)	Duration (s)
20	9	4*3	60
45	9	4*3	60
100	3	4*3	180
100	3	4*3	300
100	2	4*3	60
100	9	2*1	60
300	3	4*3	60
100	3	2*1	180

Table 5.2 Simulation Test Cases

In all test cases, V2V communication was giving the best output in term of delays, then the adaptive V2V-V2I communication comes in second place and finally the I2V communication has the highest delays. In some cases, case 2 and 3 were giving improved delay results; however, they were never better than the ones of case 1. Despite the fact of having a congested network or not, and despite the fact of having few of excess RSUs, and despite the fact of having a wide or narrow area, V2V is the best way to deliver safety messages with minimal delays. Critical messages that come with a slightly higher delays should be delivered using the adaptive V2V-

V2I communication. Finally, messages with high delays are distributed using I2V communication.

5.3 Comparison between proposed V2V, adaptive V2V-V2I communication and normal ones (without any tweaking):

Suppose we have 20 cars and 3 RSU covering an area of 4x3 km. In this scenario we are going to display a comparison between the proposed V2V communication model and an existing approach which does not take into consideration the criticality of the message. On the same side we are going to display the same comparison while applying an adaptive V2V-V2I communication and an ordinary one.

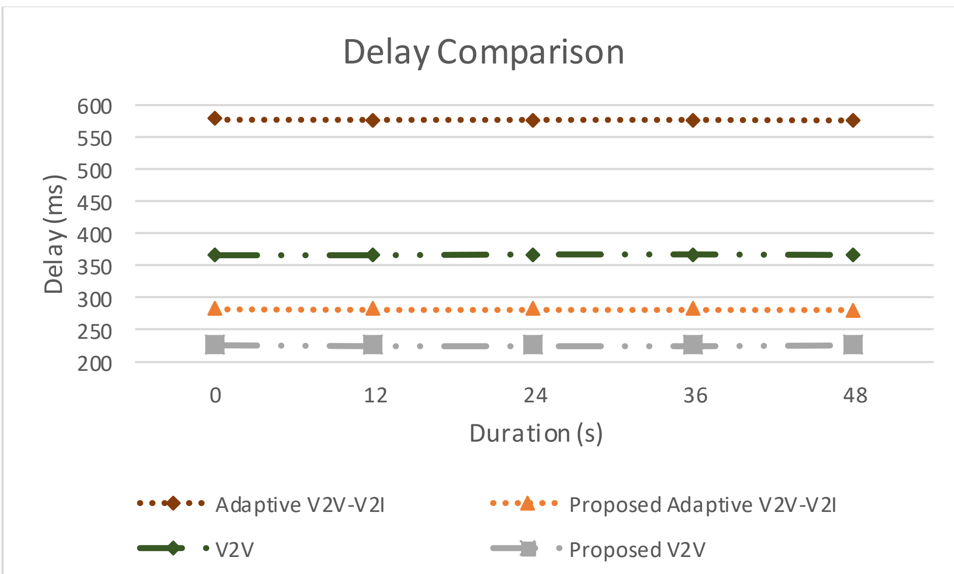

Figure 5.18 Delay comparison (20 cars – 3 RSUs)

Based on this scenario, we can infer that at t=24s the maximum delay for our proposed V2V is around 226 ms and for an ordinary V2V which does not take into consideration safety information this delay is around 366 ms as shown in figure 5.18. Similarly, this delay for our proposed adaptive V2V-V2I communication is around 281 ms compared to a delay of 576 ms in an ordinary case. The parameters we tweaked in our simulation led to great improvements in terms of delays for both V2V and adaptive V2V-V2I communications. Regarding the proposed V2V communication model, the received power is a key factor in determining whether cars can communicate with each other or not. For instance, cars who have a received power greater than -110 dBm will be able to perform a V2V communication. To be more specific and create a more robust safety environment, the cars are clustered using the k-means algorithm based on the number of RSUs. This way, cars within the same cluster and having a received power more than -110 dBm will only execute a V2V communication. After applying these changes, we can infer that delays related to V2V communication were highly improved. In a normal case which does not take into consideration the criticality of messages, delays are higher for the main reason that there are no boundaries or restrictions whether the message will reach its destination within a specific time limit or not. Also, there are no boundaries on the quality of the received message as well as message loss. The adaptive V2V-V2I communication model can be summarized in three stages:

1. Communication between car and RSU
2. Communication between RSUs
3. Communication between RSU and car

Each car is grouped within a specified cluster head (RSU) using the k-means algorithm as specified before. For the first stage, the red cars which are within 700 meters from their red RSU will be in direct communication. The rest of cars are reachable through relay nodes. Also, all the red cars which are within 500 meters will be able to communicate with each other. To this point we have settled the environment in which cars within the same cluster can communicate with each other and with their RSU. In the second stage, the communication is between RSUs. This stage is needed when one red car for example needs to send a warning message to a green car. As mentioned before, in the adaptive model we have eliminated the choice of allowing one RSU having a direct communication with a very far RSU. Therefore, the delay between RSUs is improved. The last stage is very similar to the first stage with the single difference is that the communication now is from the RSU to the car and not from the car to the RSU. Each of the proposed phases as discussed has several metrics which will improve it in term of delays. For this reason, the adaptive V2V-V2I communication is overpassing the ordinary one which does not have any constraints on the different stages.

Suppose the test case consists of 100 cars and 9 RSUs covering the same area. So, in this case both the number of cars and RSUs were highly increased.

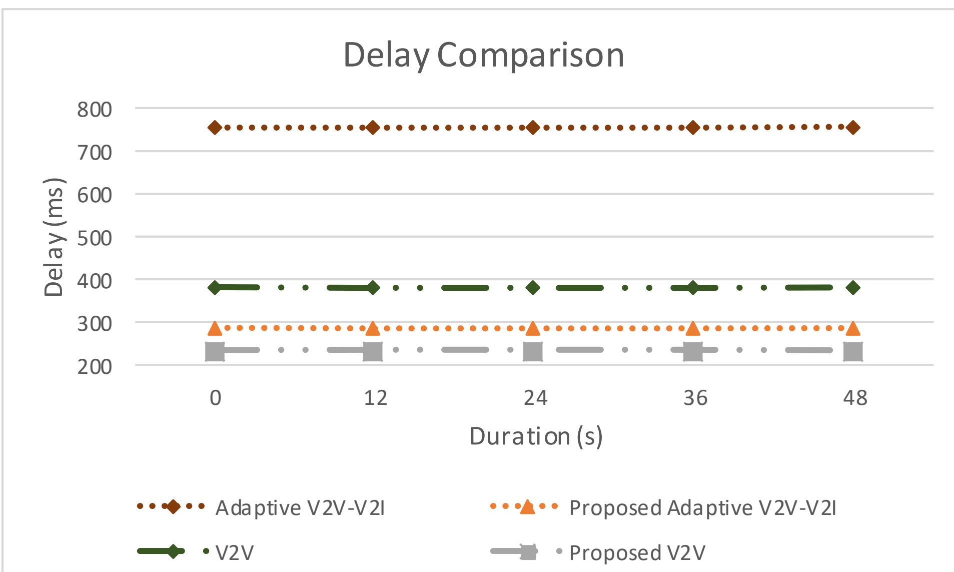

Figure 5.19 Delay comparison (100 cars – 9 RSUs)

The same results we got in the previous scenario remain applicable here as shown in figure 5.19. In fact, the proposed V2V model is way better than the normal one with a maximum delay of around 234 ms and 381 ms respectively. Similarly, the proposed adaptive V2V-V2I model is extremely better in term of delays than the original case with maximum delays of around 286 ms and 755 ms respectively. We can infer that increasing the number of cars and RSUs has negatively affected the performance of the original V2V and adaptive V2V-V2I model, and more specifically a drastic performance for the adaptive V2V-V2I one, whereas our proposed approaches remained stable and generated similar delay to previous scenarios. Based on these two scenarios, the proposed adaptive V2V-V2I communication was outperforming the original V2V. In other words, the proposed adaptive V2V-V2I communication approach can be better than a normal V2V communication unless several parameters are added to it.

5.4 Resource Allocation Based on Information Index:

In a heterogeneous network the whole system will be improved as a result of proper resource allocation. Also, the different kinds of transient bottlenecks involved in the network will be avoided. Since our system is delay sensitive, we must ensure that in a high critical case we have the sufficient resources always available. This means that the standard quality of service must be met through fairness in resource allocation. Several fairness strategies were discussed before in the literature review part such as proportional fairness, exponential proportional fairness, and modified largest weight delay first. On the same side, as mentioned before the 3GPP specification has set 7 configurations in which the number of uplink and downlink slots are specified and fixed. These configurations might be very useful in several scenarios; however, in our case none of the defined configurations will be suitable for our network. For instance, configuration 0 of the 3GPP specification is composed of 2 DL slots, 6 UL slots, and 2 SSF slots. This configuration has the highest number of uplink slots among all the other configurations, and still this number is not the sufficient for a high critical case as accidents in the network. For this reason, in this thesis we are going to define new configurations for the uplink and downlink slots in a way to balance and meet the load conditions of the network and boost its performance. This way, the number of uplink and downlink slots will dynamically change based on the criticality of the case. For instance, in a high critical case, since most of the communication is between cars then the number of uplink slots will be more than 6 slots.

The number of downlink and uplink slots will dynamically change in order to cope with the three mentioned cases and reach the best uplink and downlink throughput. Suppose in a network we have 10 cars and as shown in the figure 5.20 each car has a certain information index. 1 represents case 1, 2 case 2 and so on.

5.4.1 Scenario 1:

1	1	1	1	1	1	1	1	2	3

Figure 5.20 Information Index->80% (10 cars)

Based on figure 5.20 we can say that car 1 has an information index 1 which means car 1 has a very critical case and needs to perform a direct V2V communication. Similarly, from this figure we can infer that car 10 has an information index 3 which means car 10 has no need to perform any immediate action and will just be able to receive periodic updates from its appropriate RSU. Also, we can say that 80% of the cars have an information index 1. For this reason, we will tweak the LTE TDD frame and change its configuration to the following: 1 downlink slots, 1 special subframe slots and 8 uplink slots. This way, the majority of the slots are reserved for the uplink which is fundamental and obvious since we need to cater for the sudden increase in the number of messages being sent by the vehicles to other vehicles. After this new frame configuration, we need to evaluate the downlink and uplink throughput (discussed later).

5.4.2 Scenario 2:

1	1	2	1	2	1	1	1	2	3

Figure 5.21 Information Index- 30-80% (10 cars)

Based on figure 5.21 we can deduce that the percentage of cars having info index equals to 1 is between 30%-80% of the cars. This case is less critical compared to the previous one in which 80% of the cars had an info index 1. In this scenario since we will use both a mix of V2V and V2I communication then we will adjust the LTE TDD frame configuration into the following: 3 downlink slots, 2 special subframe, 5 uplink slots. The number of uplink slots is slightly higher than the number of downlink slots for the main reason that V2V is still needed and which requires more uplink slots. The number of downlink slots is higher than the one in scenario 1 since V2I was not needed and in that scenario, and now it is needed.

5.4.3 Scenario 3:

2	3	3	1	3	3	1	3	2	3

Figure 5.22 Information Index- <30% (10 cars)

Based on figure 5.22 we can infer that the percentage of cars having info index 1 is less than 30% of the cars. This case is the least critical compared to the previous scenarios. In this scenario V2V communication is not used at all and simply it consists of an I2V communication. For this reason, we will adjust the LTE TDD frame configuration into the following: 8 downlink slots, 1 special subframe, 1 uplink slot. It is obvious that most of the time slots are reserved for the downlink since in this scenario the main job is allocated to the RSU and not the cars. The RSUs will keep on sending periodic updates to cars in their vicinity and that is explain why we have 8 downlink slots.

5.5 Downlink and Uplink Throughput Calculation:

	Channel Bandwidth (MHz)					
	1.4	3	5	10	15	20
Number of Resource Blocks	6	15	25	50	75	100

Table 5.3 LTE Channel Bandwidth

Based on the specification set by the 3GPP, the LTE channel bandwidth as shown in table 5.3 can be 1.4, 3, 5, 10, 15, 20 MHz. In this thesis we will use 20 MHz bandwidth for the main reason that wider bandwidth will automatically imply higher throughput.

MCS Index (IMCS)	TBS Index Downlink (ITBS_DL)	NPRB (100)	TBS Index Uplink (ITBS_UL)
0	0	2792	0
1	1	3624	1
2	2	4584	2
3	3	5736	3
4	4	7224	4
5	5	8760	5
6	6	10296	6
7	7	12216	7
8	8	14112	8
9	9	15840	9
10	9	15840	10
11	10	17568	10
12	11	19848	11
13	12	22920	12
14	13	25456	13
15	14	28336	14
16	15	30576	15
17	15	30576	16
18	16	32856	17
19	17	36696	18
20	18	39232	19
21	19	43816	19
22	20	46888	20
23	21	51024	21
24	22	55056	22
25	23	57336	23
26	24	61664	24
27	25	63776	25
28	26	75376	26
29	Reserved		Reserved
30			
31			

Table 5.4 Transport Block Size Table

The essential steps to calculate the LTE downlink-uplink throughput are:

1. Choose one of the available bandwidths. In our case we decided to choose 20 MHz to get higher throughput.
2. Map the bandwidth to the appropriate number of resource blocks (RBs). So, in our case it is 100 Physical Resource Blocks (PRBs) since bandwidth is 20 MHz.
3. Choose a Modulation and Coding Scheme Index (IMCS) value. In our case each car will randomly get an IMCS value which is between 0 and 28. MCS defines how many useful bits can be transmitted per Resource Element (RE). Whenever we have a better radio link quality, we have higher MCS which implies more useful data transmitted. It is important to mention that MCS is directly related and depend on the Channel Quality Indicator (CQI). However, mapping between CQI and MCS values is vendor specific. For the scope of this thesis we will base our work on the MCS values specified in the 3GPP specifications.
4. The obtained MCS Index (IMCS) will be mapped to its corresponding Transport Block Size (TBS) Index. TBS refers to the number of bits which can be transmitted per 1 TTI (=1ms)
5. Map the ITBS value with its corresponding number of physical resource block (NPRB).

After getting all the needed information, the downlink and uplink throughput can be calculated as following:

- *DL_throughput = Number of chains * NPRB_DL * (Contribution by DL Subframe + Contribution by DwPTS in SSF)*

- *UL_throughput = Number of chains * NPRB_UL * (Contribution by UL Subframe + Contribution by UpPTS in SSF)*

For example, as said we have 200 MHz bandwidth which is 100 PRB:

- Suppose the LTE TDD frame configuration is as follows (DL = 1, SSF = 1, UL = 8). As mentioned earlier the special subframe 7 will be used (DwPTS = 10, GP = 2, UpPTS = 2).
- Suppose the MCS index is equals to 20. Based on table 5.4:
  - MCS Index = 20 ➔ TBS index Downlink = 18 (based on table 5.4)
  - MCS Index = 20 ➔ TBS index Uplink = 19 (based on table 5.4)

Since we have 100 PRBS, then also from the same table we induce that:

- TBS Index Downlink 18 = 39232 NPRB (based on table 5.4)
- TBS Index Uplink 19 = 43816 NPRB (based on table 5.4)

Therefore, we have:

*DL_throughput = 2 * 39232 * (1/10 + ((1/10)*(10/14))) = 13450.97 = 13.45097 Mbps ~ 13 Mbps*

*UL_throughput = 1 * 43816 * (8/10 + ((1/10)*(2/14))) = 35678.74 = 35.67874 Mbps ~ 36 Mbps*

5.5.1 Downlink-Uplink Throughput for Case 1 (V2V):

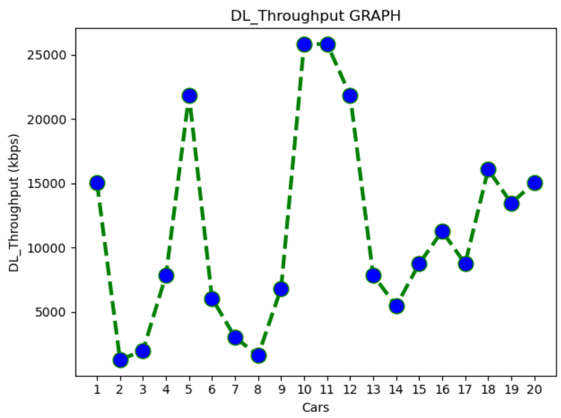

Figure 5.23 Downlink throughput

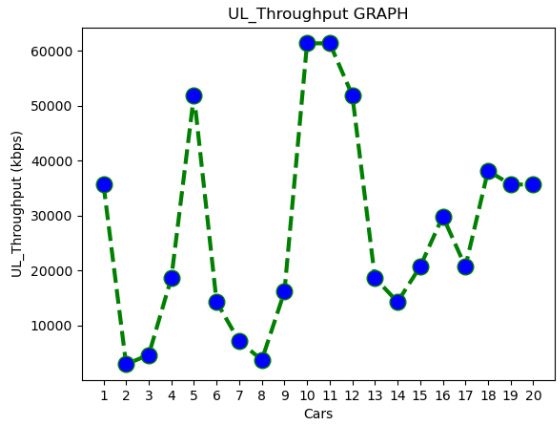

Figure 5.24 Downlink throughput

Figure 5.23 and 5.24 shows respectively the downlink and uplink throughput for 20 cars. The calculation of the uplink and downlink throughput was explained in the previous section, and in this section as shown in figure 5.23 and 5.24 we have calculated the downlink and uplink throughput for each car. It is important to notice that these two figures are different since the y-axis in the two graphs is totally different with maximum values around 25000 kbps (25 Mbps) and 60000 kbps (60 Mbps) respectively in figure 5.23 and 5.24. Based on the performed simulation satisfying the parameters of case 1, it is clear that the uplink throughput is much higher than the downlink one. In fact, the highest downlink throughput is 25000 (25 Mbps) whereas the highest uplink throughput is 60000 (60 Mbps). Case 1 represents critical event detected as car accident and a V2V communication model is proposed for this category of events. Since V2V is excessive and directly employed in case of emergency as accident then this explains why the uplink throughput is much higher than the downlink one. Based on the simulation, car 4 has for example around 8 Mbps (8000 kbps) and 19 Mbps (19000 kbps) as downlink and uplink throughput respectively. For example, car 10 has 25 Mbps (25000 kbps) and 60 Mbps (60000kbps) as downlink and uplink throughput respectively which represent the peak throughput values in uplink and downlink.

5.5.2 Downlink-Uplink Throughput for Case 3 (I2V):

In another simulation satisfying the parameters of case 3, the maximum downlink throughput is around 120000 (120 Mbps) and the maximum uplink throughput is 8000 (8 Mbps). This reveals that the downlink throughput is more than 10 times greater than the uplink one. This support our proposed configuration in which we gave the advantage for the downlink slots since it is case 3 in which cars are somehow passive and the main role is for the RSU. The flow of messages will mainly be from the RSUs to cars and this explains why downlink throughputs are much higher than the uplink ones.

CHAPTER 6

CONCLUSION

In this thesis we aim to introduce a new traffic safety application and that is why VANET is used. The main challenges can be summarized in delay constraints and bandwidth limitations. In other words, time is a fundamental factor in providing an efficient vehicular communication system in VANET. This implicates that we must guarantee that the emergency warning message will reach its destination within a time limit; otherwise, the whole system will fail which can result in drastic consequences as severe injuries and deaths. On the other side, VANET suffers from a lack of bandwidth management and coordination mainly in high-density areas. The LTE-TDD frame configuration as specified by the 3GPP specifications have fixed uplink and downlink slots. These static configurations limit users' choices of dynamically allocating the resources and creating the frame that suits the current event in the network.

The proposed approach is based on a dual communication between V2V and V2I where both systems will cooperate in order to reach the ultimate goal which is drivers' safety. In this system, based on several criteria the communication might be between: (i) I2I communication only, (ii) V2V only, (iii) V2I only, (iv) adaptive V2V-V2I-I2I communication. The main significance of the proposed work is the reconfigurability of the message dissemination architecture based on the actual VANET configuration, traffic conditions, and criticality of messages being relayed. Moreover, a dynamic LTE resource allocation is needed in order to optimize the message delivery process. Every single time, the number of uplink and downlink slots will be set differently based on several different metrics such as traffic volumes and quality of service requirements (delay, rate) in the uplink and downlink. This way, the available resources in a TDD-LTE frame will not be wasted and will be used efficiently. The proposed system based on dynamic resource management in addition to a collaboration between V2V and V2I will ensure that emergency warning messages will reach destination vehicle within a time limit with minimal delays.

We have evaluated the performance of the proposed approach using Python. Several simulation scenarios were derived and performed. Likewise, we implemented the same algorithm without tweaking any elements or adding new functionalities in order to compare them with the proposed approach. We gathered several results such as the maximum delays for the different approaches such as V2V (case1), adaptive V2V-V2I (case2), I2V (case3); the resource allocation based on the different information index; the downlink-uplink throughput calculation for the different cases.

The obtained results show that despite changing the simulation environment (varying the number of cars, number of RSUs, coverage areas) V2V communication (case1) had the best performance in terms of delays, then in the second place with a slightly higher delay comes the adaptive V2V-V2I communication, and finally the I2V communication has the worst delays. It is worth to mention that tweaking certain parameters as power, distance, and clustering has extremely improved the performance of the system and led to have the lowest delays for V2V communication and being best suitable for the delivery of critical messages. The results validate our hypothesis in which we suggested to use V2V communication for the most critical cases. In fact, in all the scenarios V2V was extremely performing well and reaching the lowest delays which implicates that it must be used for high-critical cases as road accidents. Deploying V2V will assure that the destination will receive the information message within a minimal reliable time limit, and which will lead to the ultimate goal in which drivers are alerted and have enough time to take precaution steps that will limit crashes and deaths. On the same side, another hypothesis is validated when deploying the adaptive V2V-V2I communication for less critical cases. In fact, the adaptive V2V-V2I had delays higher than the V2V communication and this explains why they must be used for cases that are still critical but not to the degree of being dangerous accidents and crashes. The last hypothesis suggested to use I2V communication for cases that are not critical. This validates our work in which this category had the highest delays since these cases are not critical and not delay-sensitive. The other part of our work is related to resource allocation and downlink and uplink throughput calculation. The obtained results show that: (i) in high critical cases, the uplink throughput is way higher than the downlink one, (ii) in critical cases; however, not considered extremely critical, the uplink throughput is slightly higher than the downlink one, (iii) in normal cases such as periodic updates on weather, the downlink throughput is way higher than the uplink one. These results support our suggestions: for high critical cases, it is essential to give the majority of the slots reserved for the uplink since all the communications are between cars in absence of any communication with RSUs. For lesser critical cases, the uplink throughput is not way higher than the downlink one for the main reason that the direction of communication is not only between cars but also with RSUs. For the normal case, the downlink throughput is way higher than the uplink one since the direction of communication is from RSUs to cars only.

REFERENCES

[1] R. Molina-Masegosa and J. Gozalvez, "System level evaluation of LTE-V2V mode 4 communications and its distributed scheduling," in 2017, . DOI: 10.1109/VTCSpring.2017.8108463.

[2] K. C. Dey *et al*, "Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication in a heterogeneous wireless network – Performance evaluation," *Transportation Research Part C,* vol. 68, pp. 168-184, 2016.

[3] M. R. Jabbarpour *et al*, "Performance analysis of V2V dynamic anchor position-based routing protocols," *Wireless Networks,* vol. 21, *(3),* pp. 911-929, 2015.

[4] Q. Zheng *et al*, "Joint optimization of link scheduling and resource allocation in cooperative vehicular networks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2015, *(1),* pp. 1-14, 2015.

[5] T. Chen *et al*, "A novel downlink scheduling strategy for traffic communication system based on TD-LTE technology," *Springerplus,* vol. 5, *(1),* pp. 1-16, 2016.

[6] P. Panchapakesan, "Overview of LTE Based Cellular V2X Communication," *Telecom Business Review,* vol. 10, *(1),* pp. 23, 2017.

[7] Y. Lu *et al*, "Weighted sum-rate maximization resource scheduling and optimization for heterogeneous vehicular networks: A bipartite graph method," in 2014, . DOI: 10.1145/2684103.2684149.

[8] L. Tung and M. Gerla, "LTE resource scheduling for vehicular safety applications," in 2013, . DOI: 10.1109/WONS.2013.6578333.

[9] H. Soleimani and A. Boukerche, "SLA: Speed and location aware LTE scheduler for vehicular safety applications," in 2015, . DOI: 10.1145/2810362.2810366.

[10] Y. Tseng, "LTE-Advanced enhancement for vehicular communication," *IEEE Wireless Communications,* vol. 22, *(6),* pp. 4-7, 2015.

[11] T. Zhou *et al*, "A Novel Adaptive Distributed Cooperative Relaying MAC Protocol for Vehicular Networks," *IEEE Journal on Selected Areas in Communications,* vol. 29, *(1),* pp. 72-82, 2011.

[12] W. Lee and D. Cho, "Downlink power control scheme for smart antenna based wireless systems," in 2010, . DOI: 10.1109/VETECS.2010.5493740.

[13] P. Thienthong *et al*, "Comparative study of scheduling algorithms and almost blank subframe for LTE HetNets," in 2019, .

[14] J. Wang *et al*, "Dynamic Clustering and Cooperative Scheduling for Vehicle-to-Vehicle Communication in Bidirectional Road Scenarios," *IEEE Transactions on Intelligent Transportation Systems,* vol. 19, *(6),* pp. 1913-1924, 2018.

[15] K. Bok *et al*, "A multiple RSU collaborative scheduling scheme for data services in vehicular ad hoc networks," *Cluster Computing,* vol. 20, *(2),* pp. 1167-1178, 2017.

[16] S. Joerer *et al*, "A Vehicular Networking Perspective on Estimating Vehicle Collision Probability at Intersections," *IEEE Transactions on Vehicular Technology,* vol. 63, *(4),* pp. 1802-1812, 2014.

[17] Rakhshan, Ali, Hossein Pishro-Nik, Donald L. Fisher, et al. 'Tuning Collision Warning Algorithms to Individual Drivers for Design of Active Safety Systems', *2013 IEEE Globecom Workshops (GC Wkshps),* (2013), pp. 1333-1337.

[18] B. Djamel, G. Nacira and T. Cherif, "Forecasting approach in VANET based on vehicle collision alert," in 2012, . DOI: 10.1109/ICMCS.2012.6320231.

[19] S. Tsugawa, "Inter-vehicle communications and their applications to intelligent vehicles: An overview," in 2002, . DOI: 10.1109/IVS.2002.1188011.

[20] H. Suzuki, H. Murata and K. Araki, "Performance of inter-vehicle communication technique for intersection collision warning," in 2005, . DOI: 10.1109/ICICS.2005.1689118.

[21] C. Huang and S. Lin, "Cooperative vehicle collision warning system using the vector-based approach with dedicated short range communication data transmission," *IET Intelligent Transport Systems,* vol. 8, *(2),* pp. 124-134, 2014.

[22] X. Fan *et al*, "Road side unit assisted stochastic multi-hop broadcast scheme for instant emergency message propagation," in 2015, . DOI: 10.1109/ICACT.2015.7224909.

[23] S. B. Raut and L. G. Malik, “Survey on vehicle collision prediction in VANET,” *2014 IEEE International Conference on Computational Intelligence and Computing Research*, 2014.

[24] C. Bila *et al*, "Vehicles of the Future: A Survey of Research on Safety Issues," *IEEE Transactions on Intelligent Transportation Systems,* vol. 18, *(5),* pp. 1046-1065, 2017.

[25] Raut, S. B., Bajaj, P. R., & Malik, L. G. (2015). Prediction of vehicle collision probablity at intersection using V2V communication. *Int. J. Sci. Eng. Res*, *6*(5), 295-300.

[26] I. Abbasi and A. Shahid Khan, "A Review of Vehicle to Vehicle Communication Protocols for VANETs in the Urban Environment," *Future Internet,* vol. 10, *(2),* pp. 14, 2018.

[27] F. Domingos Da Cunha *et al*, "Data Communication in VANETs: Survey, Applications and Challenges," *Ad Hoc Networks,* vol. 44, *(C),* pp. 90-103, 2016.

[28] P. Gokulakrishnan and P. Ganeshkumar, "Road Accident Prevention with Instant Emergency Warning Message Dissemination in Vehicular Ad-Hoc Network," *PloS One,* vol. 10, *(12),* pp. e0143383, 2015.

[29] G. Yan *et al*, "Cooperative collision warning through mobility and probability prediction," in 2010, . DOI: 10.1109/IVS.2010.5547990.

[30] Z. Peng *et al*, "Vehicle Safety Improvement through Deep Learning and Mobile Sensing," *IEEE Network,* vol. 32, *(4),* pp. 28-33, 2018.

[31] I. T. Abdel-Halim and H. M. A. Fahmy, "Prediction-based protocols for vehicular Ad Hoc Networks: Survey and taxonomy," *Computer Networks,* vol. 130, pp. 34-50, 2018.

[32] “The MobileBroadband Standard,” *LTE-Advanced*. [Online]. Available: http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced.

[33] “What is LTE-Advanced Pro?,” *5G.co.uk - UK's Premier 5G Resource*. [Online]. Available: https://5g.co.uk-pro/.

[34] H. Ji *et al*, "Overview of Full-Dimension MIMO in LTE-Advanced Pro," *IEEE Communications Magazine,* vol. 55, *(2),* pp. 176-184, 2017;2015;.

[35] M. Hasan, E. Hossain and D. Niyato, "Random access for machine-to-machine communication in LTE-advanced networks: issues and approaches," *IEEE Communications Magazine,* vol. 51, *(6),* pp. 86-93, 2013.

[36] K. Zheng *et al*, "Radio resource allocation in LTE-advanced cellular networks with M2M communications," *IEEE Communications Magazine,* vol. 50, *(7),* pp. 184-192, 2012.

[37] N. Abu-Ali *et al*, "Uplink Scheduling in LTE and LTE-Advanced: Tutorial, Survey and Evaluation Framework," *IEEE Communications Surveys & Tutorials,* vol. 16, *(3),* pp. 1239-1265, 2014.

[38] A. S. Lioumpas and A. Alexiou, "Uplink scheduling for machine-to-machine communications in LTE-based cellular systems," in 2011, . DOI: 10.1109/GLOCOMW.2011.6162470.

[39] S. Lien, K. Chen and Y. Lin, "Toward ubiquitous massive accesses in 3GPP machine-to-machine communications," *IEEE Communications Magazine,* vol. 49, *(4),* pp. 66-74, 2011.

[40] S. Lien and K. Chen, "Massive Access Management for QoS Guarantees in 3GPP Machine-to-Machine Communications," *IEEE Communications Letters,* vol. 15, *(3),* pp. 311-313, 2011.

[41] A. G. Gotsis, A. S. Lioumpas and A. Alexiou, "M2M Scheduling over LTE: Challenges and New Perspectives," *IEEE Vehicular Technology Magazine,* vol. 7, *(3),* pp. 34-39, 2012.

[42] S. Y. Shin and D. Triwicaksono, "Radio resource control scheme for machine-to-machine communication in LTE infrastructure," in 2012, . DOI: 10.1109/ICTC.2012.6386765.

[43] B. Howard, "V2V: What are vehicle-to-vehicle communications and how do they work?," *ExtremeTech*, 06-Feb-2014. [Online]. Available: https://www.extremetech.com/extreme/176093-v2v-what-are-vehicle-to-vehicle-communications-and-how-does-it-work.

[44] Jean.yoder.ctr@dot.gov, "Vehicle-to-Vehicle Communication," *NHTSA*, 18-Jun-2019. [Online]. Available: https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication.

[45] M. Rouse and M. Rouse, “What is vehicle to infrastructure (V2I or v2i)? - Definition from WhatIs.com,” *WhatIs.com*. [Online]. Available: https://whatis.techtarget.com/definition/vehicle-to-infrastructure-V2I-or-V2X.

[46] W. K. and T. Segal, “V2X (Vehicle-to-Everything),” *Investopedia*, 09-Dec-2019. [Online]. Available: https://www.investopedia.com/terms/v/v2x-vehicletovehicle-or-vehicletoinfrastructure.asp.

[47] *Connected Vehicle Technology Challenge*. [Online]. Available: https://connectedvehicle.devpost.com/details/understanding-dsrc.

[48] G. Araniti *et al*, "LTE for vehicular networking: a survey," *IEEE Communications Magazine,* vol. 51, *(5),* pp. 148-157, 2013.

[49] F. Ye, S. Roy and H. Wang, "Efficient Data Dissemination in Vehicular Ad Hoc Networks," *IEEE Journal on Selected Areas in Communications,* vol. 30, *(4),* pp. 769-779, 2012.

[50] K. Liu *et al*, "Cooperative Data Scheduling in Hybrid Vehicular Ad Hoc Networks: VANET as a Software Defined Network," *IEEE/ACM Transactions on Networking,* vol. 24, *(3),* pp. 1759-1773, 2016.

[51] “Road Safety Facts,” *Association for Safe International Road Travel*. [Online]. Available: https://www.asirt.org/safe-travel/road-safety-facts/.

[52] H. Mezher, Annahar, and A. Date, “Number of fatal road accidents increasing in Lebanon - Hala Mezher,” *An*, 13-Sep-2019. [Online]. Available: https://en.annahar.com/article/1028236-number-of-fatal-road-accidents-increasing-in-lebanon.

[53] C. Cox and I. Books24x7, *An Introduction to LTE: LTE, LTE-Advanced, SAE and 4G Mobile Communications.* 2012.

[54] J. Nzouonta-Domgang, "Road-Based Routing in Vehicular Ad Hoc Networks." , ProQuest Dissertations Publishing, 2009.

[55] “LTE Tutorial,” *Tutorialspoint*. [Online]. Available: https://www.tutorialspoint.com/lte/index.htm.

[56] “LTE Network Architecture: Basic,” *Network Manias*. [Online]. Available: https://www.netmanias.com/en/post/techdocs/5904/lte-network-architecture/lte-network-architecture-basic.

[57] H. Chan, “The Architecture of LTE Network and Working Principle,” *The Architecture of LTE Network and Working Principle*, 01-Jan-1970. [Online]. Available: http://hershenq.blogspot.com/2012/03/architecture-of-lte-network-and-working.html.

[58] A. Demba and D. P. F. Moller, “Vehicle-to-Vehicle Communication Technology,” *2018 IEEE International Conference on Electro/Information Technology (EIT)*, 2018.

[59] S. Dardouri and R. Bouallegue, "Comparative Study of Downlink Packet Scheduling for LTE Networks," *Wireless Personal Communications,* vol. 82, *(3),* pp. 1405-1418, 2015.

[60] S. Sou and O. K. Tonguz, "Enhancing VANET Connectivity Through Roadside Units on Highways," *IEEE Transactions on Vehicular Technology,* vol. 60, *(8),* pp. 3586-3602, 2011.

[61] P. Salvo *et al*, "Road side unit coverage extension for data dissemination in VANETs," in 2012, . DOI: 10.1109/WONS.2012.6152235.

[62] Naito, K., Ono, A., Mori, K., & Kobayashi, H. Road side unit coverage extension with OFDM Cooperative Transmission.

[63] J. A. Sanguesa *et al*, "A Survey and Comparative Study of Broadcast Warning Message Dissemination Schemes for VANETs," *Mobile Information Systems,* vol. 2016, pp. 1-18, 2016.

[64] H. Venkataraman, R. Delcelier and G. Muntean, "A moving cluster architecture and an intelligent resource reuse protocol for vehicular networks," *Wireless Networks,* vol. 19, *(8),* pp. 1881-1900, 2013.

[65] S. Ansari *et al*, "SAI: Safety Application Identifier Algorithm at MAC Layer for Vehicular Safety Message Dissemination Over LTE VANET Networks," *Wireless Communications and Mobile Computing,* vol. 2018, pp. 1-17, 2018.

[66] S. Ucar, S. C. Ergen and O. Ozkasap, "Multihop-Cluster-Based IEEE 802.11p and LTE Hybrid Architecture for VANET Safety Message Dissemination," *IEEE Transactions on Vehicular Technology,* vol. 65, *(4),* pp. 2621-2636, 2016.

[67] M. A. Abd El-Gawad, M. Elsharief and H. Kim, "A cooperative V2X MAC protocol for vehicular networks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2019, *(1),* pp. 1-24, 2019.

[68] A. Sebastian *et al*, "A multicast routing scheme for efficient safety message dissemination in VANET," in 2010, . DOI: 10.1109/WCNC.2010.5506245.

[69] H. Soleimani and A. Boukerche, "On vehicular safety message transmissions through LTE-Advanced networks," *Ad Hoc Networks,* vol. 79, pp. 133-145, 2018.

[70] Techplayon. 2020. *Explain LTE Frame Structure Both For FDD And TDD - Techplayon*. [online] Available at: <http://www.techplayon.com/explain-lte-frame-structure-both-for-fdd-and-tdd/>