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Jimma Institute of Technology

School of Computing

A Performance Optimization of VANET Communications by Integrating UAV System with LTE/4G and WAVE Technologies

By

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A THESIS SUBMITTED TO THE SCHOOL OF COMPUTING IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN COMPUTER NETWORKING

October, 2017

Approval Sheet

This Independent Research entitled as “A Performance Optimization of VANET Communications by integrating UAV System with LTE/4G and WAVE Technologies” has been read and approved as meeting the preliminary research requirements of the School of Computing in partial fulfillment for the award of the degree of Master in Computer Networking, Jimma University, Jimma, Ethiopia.

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Dedicated to:

My beloved mother, Sewalem Gebeyehu Haile

Acknowledgment

This work would not have been possible without the endless support of son of St. Merry, Almighty God, thus I praise always the name of him and his mother. And, I would like to give my genuine thanks to my advisor, Dr. Dereje Yohannes, for his advice, supervision, respect, and moral support throughout this thesis work. I would like also to give my honest and special thanks to Mr. Kebebew Ababu for his great and ceaseless supervision, encouragement and comment. As well as, thanks to all my beloved and delightful classmates for everything. Finally, my gorgeous family deserves a very special thanks for their unconditional love, inspiration, patience, and support throughout the whole my life.

Table of Contents

List of Figures

List of Algorithms

List of Tables

Abbreviations and Acronyms

AU	–	Application Unit
BTS	–	Base Transceiver Station
CALM	–	Continuous Air interface for Long and Medium range
DSRC	–	Dedicated for Short Range Communication
eNB/eNodeB	–	evolved Node Base
EPC	–	Evolved Packet Core
EPS	–	Evolved Packet System
ETSI	–	European Telecommunications Standards Institute
E-UTRAN	–	Evolved Universal Terrestrial Radio Access Network
FANET	–	Flying Ad hoc Network
GW	–	Gateway
LTE/4G	–	Long Term Evolution/4th Generation
MANET	–	Mobile Ad hoc Network
MAVLink	–	Micro Air Vehicle Link
OBU	–	On Board Unit
PCAP	–	Packet Capture
PDN-GW	–	Packet Data Network Gateway
PDSCH	–	Physical Downlink Shared Channel
RRC	–	Radio Resource Control
RSUs	–	Road Side Units
S-GW	–	Serving Gateway
UAV	–	Unmanned Aerial Vehicle
U2V	–	UAV to Vehicle
V2I	–	Vehicle to Infrastructure
V2U	–	Vehicle to UAV
V2V	–	Vehicle to Vehicle
VANET	–	Vehicular Ad hoc Network
WAVE	–	Wireless Access in Vehicular Environment

Abstract

With the bulky intensification of conventional vehicles on roads presently, driving has become more challenging and dangerous issue. Roads are filled up with vehicles, safety distance and acceptable speeds are rarely obeyed to, and travelers frequently lack sufficient concentration. As such, leading automobile fabricators to cooperatively work with government administrations to come out with pretty solutions geared toward helping travelers on highways by anticipating dangerous scenario or abstain from severe traffic areas. Hence, Vehicular communication systems have come to existence.

Vehicular communication systems are networks in which WAVE-enabled vehicles and roadside units are the major interactive nodes, offering each other with info, for instance, traffic information and safety warning systems. Besides, there are two basic kinds of communication approaches, V2V and V2I respectively. Even though, both approaches have their own constraints within various scenarios. For instance, a direct V2V communication in highway scenario, to broadcast a delay-sensitive information such traffic accident warnings, it has entirely depended on the sparseness and swiftness of smart ground vehicles. Thus, it will be difficult to achieve the goal of safety applications due to intermittent connectivity. Additionally, each vehicle periodically broadcasts a beacon or Hello message to each other that used to exchange their current states and surrounding info, consequently this, they have consumed a bandwidth from the limited VANETs spectrum (75 MHz). Whereas, V2I communication in urban and highway scenarios, the effectiveness of the communication between smart ground vehicles and roadside infrastructures mostly depends on the capability of roadside infrastructures. Therefore, it will be expected from VANETs technologists and authors to bring out pretty solutions for improvement of VANET communications and applications incorporate with the existing ones. In this thesis, based on reviewed the various literature and related works, I selected and integrated UAV System, LTE/4G and WAVE wireless access network technologies to optimize the VANET communications and satisfy the demands of its basic applications, particularly safety and traffic.

This work proposed an integrated novel architecture of UAV System, LTE/4G and WAVE technologies with its forwarding schemes in highway scenario to enhance the VANET communications and achieve the requirements of its basic applications, particularly safety and traffic. Algorithms for UAV's sensing, tagging (based on the proposed safety and traffic info model) and broadcasting operations, and forwarding of safety or traffic info to respective infrastructures and then smart ground vehicles are designed, particularly to minimize intermittent connectivity and bandwidth usage, and as well as to satisfy the requirements of VANET applications.

I have evaluated the performance of the integrated novel architecture with its forwarding schemes/algorithms through integrated and simulated VANETs and wireless access technologies (LTE/4G and UAV System) environment. Within 12 smart ground vehicles, simulation experiment shows that the proposed integrated architecture with its forwarding schemes results is 66% packet delivery ratio, 0.0193086 seconds mean delay, and 10.3705Mbps throughput, whereas existing work results is 40% packet delivery ratio, 0.0435663 seconds mean delay and 2.49405Mbps throughput. Hence, deploying the integrated architecture of UAV System, LTE/4G, and WAVE with its forwarding schemes in highway scenario enhances the VANET communications and satisfies the requirements of safety and traffic applications.

Keywords: VANET, UAV System, LTE/4G, WAVE, Integrated Wireless Technologies in VANETs

Chapter One: Introduction

1.1 Background

The rapid Internet growth has made communication extremely important and an integrated factor of computing. In today's society with the advent of mobile devices, it has become vital to stay on-line all the time.

Ad hoc is a special purpose network established on the fly. A well-known ad hoc networks are MANETs, FANETs and VANETs. MANET [1] is a kind of wireless ad-hoc network and a self-configuring network of mobile routers connected by wireless links with no access point. Every mobile device in a network is autonomous. The mobile devices are free to move haphazardly and organize themselves arbitrarily. FANET [6] is a form of ad-hoc networks like VANET and MANET. However, certain variations exist between FANET and the other ad hoc networks in existence. FANET has very high mobility and dynamic topology, and its nodes are aerial vehicles. Whereas, VANET [6] is a kind of MANET in which nodes are vehicles that follow particular mobility patterns regulated by vial normative. Mostly, VANET architecture has OBU and RSU. OBU is mounted usually on-board of a vehicle and a WAVE device used for an exchange of information with other OBUs or with RSUs. RSU is a WAVE device that is fixed in locations like near parking areas, junctions and on the road segment.

The concept of using radio communications [2] to communicate from a vehicle in order to improve the safety has been around well before the advent of the digital radio communications we are familiar with today. One example is the patent "Radio Warning Systems for use on Vehicles" submitted on 1922 and issued in 1925, based on the concept of peer-to-peer radio communication between equal devices installed on two different vehicles; RDS is a communication protocol standard for embedding small amounts of digital information in conventional Frequency Modulation (FM) radio broadcasts, in 1984, became the first digital V2I communication, and was introduced in the USA as radio broadcast data system (RBDS) a few years later. In 1990, RDS became a European Standard.

Nowadays, car traffic accident is one of the leading causes of fatalities in our world. The statistics given in [24] show that about 25,700 people lost their lives and 200,000 were injured due to traffic accidents across the European countries in 2014. Thus, most of the industrialized countries have been centered on the vehicular communication systems. Vehicular communication systems [18] are networks in which smart ground vehicles and roadside units are the communicating nodes, providing each other with information, such as safety warnings and traffic information. They can be effective in avoiding accidents and traffic congestion. Both types of nodes are DSRC devices.

DSRC works in 5.9 GHz operational frequency band with a bandwidth of 75 MHz and approximate range of 1000m. Besides, vehicular communication is usually developed as a part of ITS and governing by the ISO/ETSI reference communications stack [3].

Generally, the communication mode of VANET classified into two, V2V and V2I respectively [6]. V2V uses the OBU to communicate with one another, which enables distributed pattern of communication among vehicles with decentralized coordination. While V2I has vehicles communicate to RSU so as to enhance communication range by sending and receiving information from a vehicle to another vehicle. However, these two types of VANET communications have their own constraints within various scenarios. For instance, V2V communication in highway scenario, to broadcast a time-critical information like traffic accident warnings, it has completely depended on the sparseness and swiftness of vehicles. Thus, it will be difficult to achieve the goal of safety applications due to intermittent connectivity. Additionally, each vehicle periodically broadcasts a beacon or Hello message to each other that used to exchange their current states and surrounding info, consequently, they have consumed a bandwidth from the limited VANETs spectrum (75 MHz). Whereas, V2I communication in urban and highway scenarios, the effectiveness of the communication between smart ground vehicles and roadside infrastructures mostly depends on the capability of roadside infrastructures. Thus, it will be expected from VANETs technologists and scholars to bring out pretty solutions for these types of constraints incorporate with the existing ones.

Hence, to overcome these limitations, some authors [15], [16], [17] have carried out different works by integrating heterogeneous vehicular networks (HetVNETs) and other mechanisms. Although the work is completely different from the previous ones due to the integrating architecture of the UAV System, LTE/4G and WAVE wireless access network technologies together with its forwarding schemes, it is a novel architecture.

In this thesis, to provide the performance enhancement of VANET communications and satisfy the requirements of its basic applications (safety and traffic) in highway scenario, an integrated novel architecture with its forwarding schemes will be designed. The architecture will be designed based on making an integration of UAV System with LTE/4G and WAVE wireless access technologies. I will also develop algorithms for UAV System operations for sensing, tagging and broadcasting the current states of vehicles information either safety or traffic, and forwarding schemes to respective infrastructures and smart ground vehicles. Therefore, at the end of this work, an optimized VANET communications and satisfied the requirements of its basic applications will be expected by achieving high packet/information delivers and throughput, and as well as minimizing end-to-end delay.

1.2 Statement of the Problem

In VANETs highway scenario, the smart ground vehicles have a high mobility nature and dynamic traffic density; Due to this, high intermittent connectivity will be faced as a hinder of vehicular communication objectives. For example, to broadcast a delay-sensitive information via V2V communication like CCW, it has completely depended on the swiftness and sparseness of vehicles. To solve this trouble, some papers have been encouraged opportunistic networking (DTN) [22]. However, the nature of DTN does not provide a full warranty of validness and secureness for delay sensitive applications. Simply, if there is a safety-message latency, it might bring out negative consequences. Similarly, in highway scenario, each smart ground vehicle has periodically sense and broadcast its current states and surrounding environment information to nearest vehicles and RSUs though it might also lead to bandwidth consumption with the above mentioned problem that intermittent connectivity (high packet loss). Even to overcome this problem, most scholars of VANETs have carried out a CR-VANETs technology research [25]. Although this technology needs a complex setup and requirements to perform an experiment while there is a lack of suitable simulators with features such as spectrum database, spectrum sensing & management and so on.

Hence, to overcome all of these problems as much as possible or to optimize VANET communications and satisfy the demands of its basic applications (safety and traffic) in highway scenario, I will design and implement an integrated novel architecture with its forwarding schemes/algorithms.

1.3 Objectives

General Objective

The general objective of this thesis is to propose an integrated novel architecture with its forwarding schemes in highway scenario via UAV System, LTE/4G, and WAVE wireless access technologies for performance enhancement of VANET communications and satisfy the requirements of its basic applications.

Specific Objectives

In order to accomplish the general objective, the following specific objectives are set.

- Probe and recognize the current communications enhancement in VANETs, LTE/4G, and FANETs in highway scenario.
- Design an integrated novel architecture via UAV System, LTE/4G and WAVE wireless access network technologies in highway scenario. Consequently, I will attempt to replace the direct V2V communication via integrated architecture of V2I downlink communication to minimize the intermittent connectivity of V2V communication in highway scenario.

- Develop an algorithm for UAV's sensing, tagging and broadcasting of the current states of smart ground vehicles info within UAV transmission range, due to this, I will try to minimize a bandwidth usage of periodically broadcast a beacon or Hello message by smart ground vehicles.
- Develop an algorithm for forwarding schemes of whether safety or traffic information to respective wireless access infrastructures and then smart ground vehicles. Consequently, I will satisfy the requirements of VANET basic applications.
- Develop a model of safety and traffic information for UAV's tagging operation of a sensed info in MAVLink packets.
- Implement an integrated novel architecture with its forwarding schemes in highway scenario under an integrated VANET and wireless access technologies (LTE/4G and UAV System) simulation environment.
- Testing and evaluating the performance of the integrated novel architecture with its algorithms through simulations to prove that the architecture with its algorithms do enhance VANET communications and satisfy the demands of its basic applications in highway scenario.

1.4 Scope and Limitations of the Study

The scope of this thesis is limited to designing and implementing an integrated novel architecture with its forwarding schemes via UAV System, LTE/4G, and WAVE wireless access network technologies. A few algorithms for UAV's sensing, tagging and broadcasting of the current states of smart ground vehicles info within UAV transmission range, and forwarding schemes of whether safety or traffic information to respective wireless access infrastructures and then smart ground vehicles effectively will be designed. The integrated architecture and its forwarding schemes will optimize the performance of VANET communications and satisfy some demands of its basic applications (safety and traffic) in highway scenario. The study will take attention on providing lower end-to-end high packet delivery for safety and traffic information/application by addressing like delay and throughput.

The proposed work will not cover the following operations:

- Any security mechanism of the integrated architecture with its forwarding schemes to protect against attack.
- Load balancing for the communication of the wireless access network technologies.
- Develop any routing protocol for the proposed integrated novel architecture.
- Signal fading and multi-path propagation matters.

- A series issues of UAV System, such as power resource, monitoring the states of internal components, GCS uplink communication, launching and landing operations, and also terrain and weather conditions.
- Frequency reuse of LTE/4G network.
- Handoff mechanisms.
- The expense of a real deployment of the proposed architecture.

1.5 Methods

Literature Review

In order to achieve the objectives of this thesis various resources that related to the work such as published international journals, conferences, workshops, articles, books, related web sites and other vital documents are explored for the purpose of fully understanding the performance of VANET communications and requirements of its applications in general as well as the nature of FANETs and LTE/4G in particular.

Design and Implementation

In the design phase, proposed integrated novel architecture with its forwarding schemes and algorithms in highway scenario which are specified in the objectives of this thesis are designed. Due to prohibitive costs of employing VANETs and different wireless access technologies in real-world testbeds, I implement the proposed architecture using an integrated and simulated VANETs and wireless access technologies (LTE/4G and UAV System) environment.

Evaluation of the Proposed Work

The Experiment is conducted to test the usefulness of the proposed integrated architecture with its forwarding schemes in highway scenario and evaluated in terms of its objective and contributions in comparison to what is already done using an integration of VANETs and wireless access technologies simulation environment. Moreover, the evaluation is carried out by considering different parameters.

1.6 Significances of the Study

With the large increase of ordinary vehicles on roads recently, driving has become more challenging and dangerous. Streets are filled up with vehicles, safety distance and reasonable speeds are rarely obeyed to, and travelers frequently lack adequate attention. As such, leading automobile manufacturers decided to cooperatively work with government administrations to come out with pretty solutions geared toward helping travelers on highways by anticipating dangerous scenario or abstain from harsh traffic areas.

Meanwhile, the main objective is clearly to enhance the safety of car traffic, on board amusement applications and traffic management solutions are also anticipated by the various bodies (CALM) and projects (CarTALK 2000 [12], VICS4 [13], FleetNet [14], CarNet [20]).

Hence, the contribution of this work will optimize the VANET communications and satisfy the demands of its basic applications (safety and traffic) in highway scenario via an integrated novel architecture of UAV System, LTE/4G, and WAVE wireless access technologies with its forwarding schemes.

Additionally, as I have discussed about the problems those faced in highway scenario in Section 1.2, the proposed work will minimize the intermittent connectivity and bandwidth consumption of vehicles broadcasting scheme, as well as realize the requirements of VANETs basic applications by attaining high throughput and packet/information delivery, and low end-to-end delay.

1.7 Thesis Organization

The remaining Chapters are organized as follows. Chapter 2, presents a literature about nature of VANETs and different wireless access network technologies. Chapter 3, introduces related works which are carried out for improvement of VANET communications and its basic applications via heterogeneous wireless access network technologies. Chapter 4, presents the detail of the proposed integrated novel architecture with its forwarding schemes and algorithms. Chapter 5, provides an extensive simulation study and evaluation of the proposed integrated architecture with its forwarding schemes and some algorithms. Finally, the conclusions of the research and recommendations of future works are presented in Chapter 6.

Chapter Two: Literature Review

2.1 Overview

VANET [6] is a form of ad hoc network whereby its nodes are denoted by smart ground vehicles. It initiated from the wish to ensure drivers comfort and safety in road transportation so as to reduce the risk of accidents on the roads. VANETs have some sole features that make it distinguished from MANETs in terms of architecture, characteristics, applications, and challenges. Generally, the communication mode of VANETs classified into three, V2V, V2I and V2X respectively. V2V communication has used the OBU to communicate with one another, which enables distributed pattern of communication among smart ground vehicles with decentralized coordination. Whereas, V2I communication has smart ground vehicles communicate to RSU and vice versa so as to enhance communication range by sending and receiving information from a vehicle to another vehicle. And V2X communication has a very general term that includes all possible forms of communications involving a smart ground vehicle and the external environment. It is the natural extension of the VANET concept, where the vehicle it is not anymore the only communication node involved, but the vehicle becomes part of a larger system where many elements are involved together. It belongs to the family of the Cooperative Intelligent Transport Systems (C-ITS) communications.

Researchers from a diverse field of studies are attracted to develop applications, simulation tools, and even various protocols for VANETs. However, many challenges have been faced by them and they try to deal with those problems. At this time, the popular research issues in VANETs are routing, safety and traffic management, security and privacy, different radio interfaces, medium access control, signal fading and multi-path propagation, connectivity and IP mobility, handover, QoS, driver unwillingness of broadcasting info, and bandwidth management. Hence, finding efficient solutions to these fundamental issues could significantly increase the applicability of VANETs.

2.2 Characteristics of VANETs

VANET has grown into an important research area over the past decades. It has its own distinctive features compared with MANETs and FANETs as follows:

- **High Computational Ability:** Owing to the fact that the nodes in VANETs are smart ground vehicles, they are supplied with adequate sensors and resources for computation such as advanced antenna technology, global position system (GPS), processors, and large memory capacity. Computational capabilities of smart ground vehicles are increased by these resources, which assist in achieving reliable communication, obtaining correct message concerning its current position, direction and speed [4], [5].

- **Predictable Mobility:** The mobility in VANETs is different from MANETs. Nodes in VANETs move randomly, because vehicles are usually restricted by the topology of the road and layout, and they are also required to obey traffic lights, and road signs [7], [8], [9] resulting in their movements being predictable.
- **No Power Constraints:** In VANETs, power is not a serious issue as in MANETs and FANETs, due to the fact that smart ground vehicles can supply power continuously to OBU through the use of long life battery [8], [4], [10].
- **Providing Safe Driving:** This is achieved by improving traveler satisfaction and improving traffic efficiency. The direct communications between mobile nodes are ensured by VANETs, hence enabling the usage of a set of applications that require direct communication between vehicles over the network. These applications offer warning information to passengers moving in the same direction concerning the urgency for swift hard breaking or about accidents, thus the driver needs to create a larger image of road topology ahead. Furthermore, VANETs can also improve traveler satisfaction and improve traffic efficiency by providing information such as shopping malls, gas station, weather, traffic flow, and fast food [8].
- **Variable Network Density:** This depends on the density of traffic, which can be low, as in suburban traffic or high during traffic jam [10].
- **Large Network Size:** The size of the network might be large in VANETs such as urban center, and when entering large cities [10], [11].
- **Swift Distortions in the Topology of the Network:** Vehicles moving on the highway, at a high speed, results in a swift adjustment in the topology of the network. In addition, the information received can influence the behavior of the driver, as such results to changes in the topology of the network [9], [10], [11].

2.3 VANETs Network Architecture

Generally, VANETs network architecture has classified into three, OBU, AU and RSU as follows.

2.3.1 On Board Unit (OBU)

OBU is mounted usually on-board of a smart ground vehicle and a WAVE device that used for the exchange of information with other OBUs or with Road Side Unit (RSUs). Normally, OBU is composed of a user interface, memory used for storing and retrieving a message, a processor, an interface which serves as a link to different OBUs and/or RSUs, wireless device for short communication range based on IEEE 802.11p. OBU connects to different OBUs or to the RSU via a wireless channel which is based on the IEEE 802.11p and it ensures the exchange of messages with RSUs or with different OBUs.

The major tasks of OBU include ad hoc and geographical routing, wireless radio access, information security, IP mobility, reliable message transfer, and network congestion control [5].

2.3.2 Application Unit (AU)

AUs [6] are devices equipped inside the vehicle which uses the services supplied by the provider by exploiting OBU capabilities. AU can be a PDA to connect to the Internet or a device dedicated for safety applications. A wired or wireless connection is used to connect the AU to the OBU and may be kept in one physical unit with the OBU. The difference between OBU and the AU is logical.

2.3.3 Road Side Unit (RSU)

RSUs [6] are WAVE devices that are fixed in locations like near parking areas, junctions and on the road segment. The RSU is furnished with a device that is dedicated for short-range communication based on the radio technology such as IEEE 802.11p, and for the aim of communication within the network infrastructure. RSU may be equipped also with different network devices as shown in Figure 2.1 up to Figure 2.3. The major functions related to RSU according to C.C. Communication Consortium are:

- The range of ad hoc network communication is extended by redistributing the messages to different OBUs and by relaying messages to different RSUs so as to transmit it to different OBUs.
- It runs applications for safety such as work zone or accident warning, a low bridge warning, using V2I communication and it serves as a source of information.
- It provides connections of OBUs with Internet.

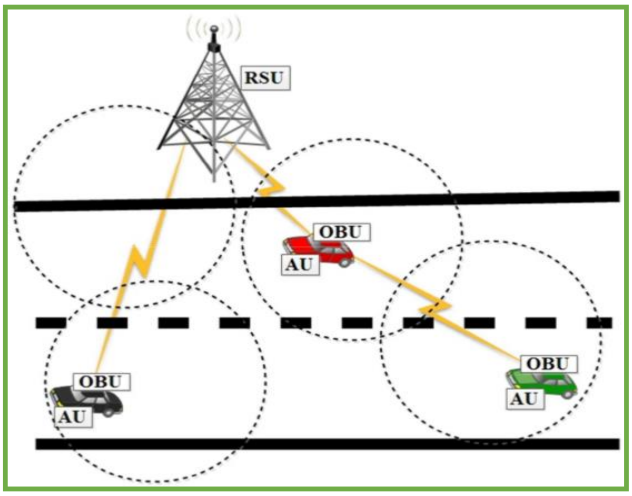


Figure 2.1: The Ad hoc network communication range is extended to other OBUs by redistributing the messages [21]

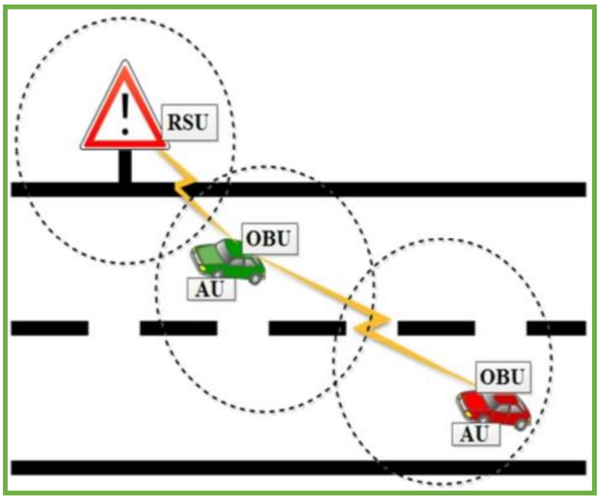


Figure 2.2: RSU runs applications for safety [21]

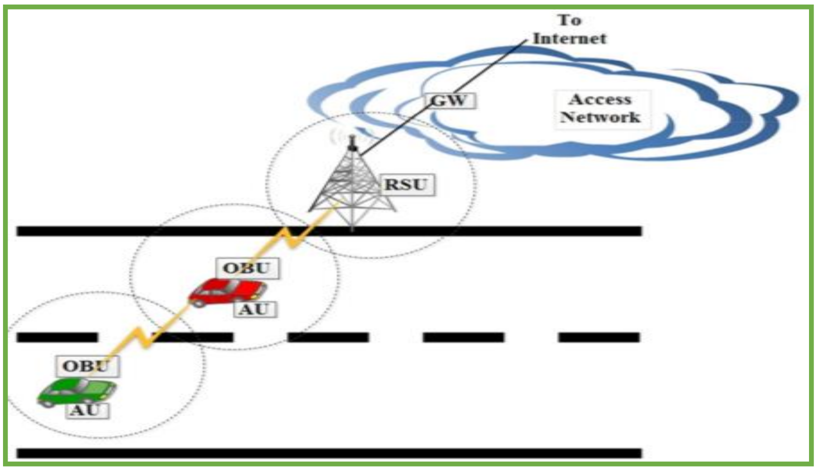


Figure 2.3: RSU provides OBUs with Internet connections [21]

2.4 VANETs ISO/ETSI Communication Architecture

The global ITS community granted on the definition of a common ITS communication architecture suitable for a variety of communication scenarios (vehicle-based, roadside-based and Internet-based) through a variety of wireless access network technologies such as infra-red, IEEE 802.11p, 3G/4G and GPS, and for a variety of application types like road safety, traffic efficiency and comfort/infotainment deployed in various continents or countries governed by distinct policies. This common communication architecture is known as ISO/ETSI reference communications stack as shown in Figure 2.4.

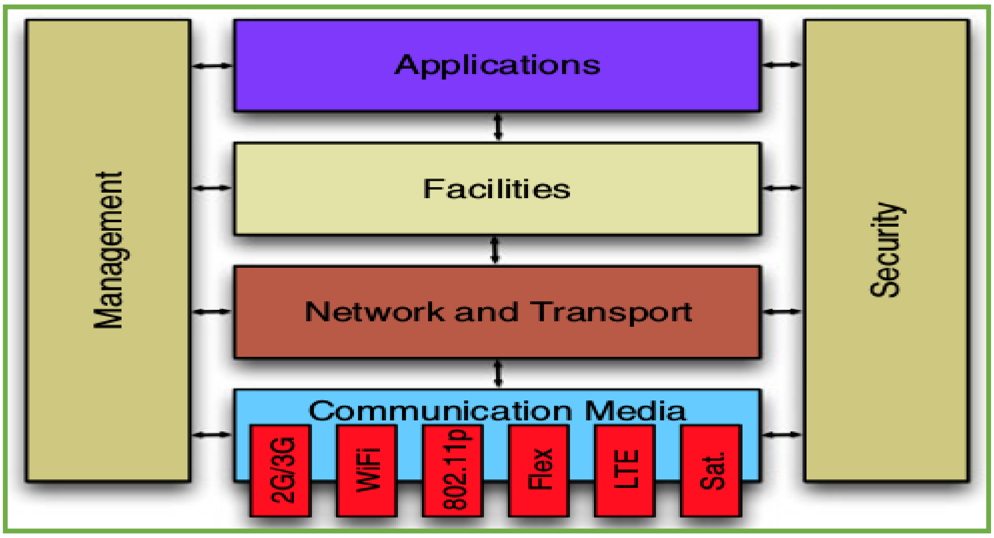


Figure 2.4: ISO/ETSI reference communications stack [3]

2.5 VANETs Communication Domains

As shown in Figure 2.5, three types of VANETs Communication domains are found.

2.5.1 In-vehicle domain

Includes OBU with one or several AUs. A wired or wireless connection is used to connect the AU to the OBU and may be kept in one physical unit with the OBU. OBU provides a channel for communication to the AUs so as to execute some application by exploiting OBU communication capabilities [5], [21].

2.5.2 Ad hoc domain

It has consisted of smart ground vehicles and RSUs [5]. Two types of communications are obtainable as follows:

- Due to its ability to enhance traffic safety on road, and efficient driving, vehicles use the OBU to communicate with one another, which enables distributed pattern of communication among vehicles with decentralized coordination.
- The RSU is used by vehicles so as to enhance communication range by sending and receiving information from a vehicle to another vehicle.

2.5.3 Infrastructural domain

RSU connects to the Internet, enabling the network infrastructure to be accessed by the OBU. As such, for the AUs to be connected to the Internet, it must be registered with the OBU.

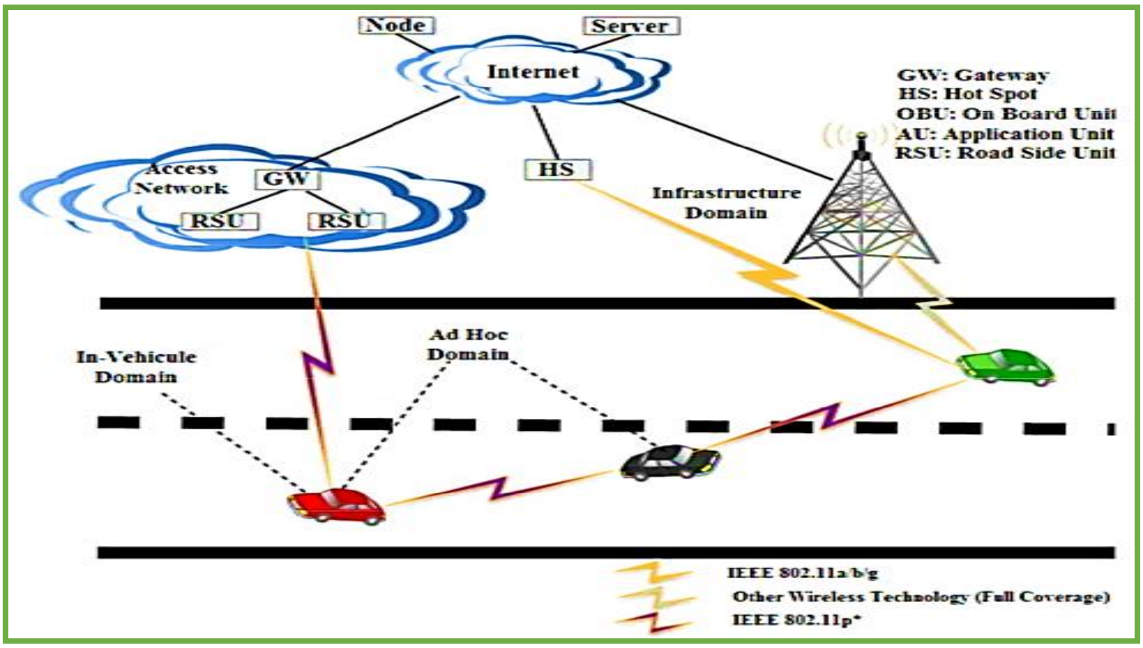


Figure 2.5: Communication Domains in VANETs [5]

2.6 Communication Technologies in VANETs

Presently, a lot of wireless access network technologies are available, which provide different radio interfaces for direct communication between smart ground vehicles and RSUs (V2I communication) and/or indirect communication between smart ground vehicles (V2V communication). Such wireless access network technologies are intended to enhance the comfort of drivers and passengers, traffic efficiency, and road safety. I have discussed the various wireless access technologies in VANETs as follows:

2.6.1 Cellular Systems

To reuse the available limited frequency is the idea behind cellular system [23]. Global system for mobile (GSM) communication is described as a second generation (2G), and provides data at the rate of 9.6 Kbps [5]. GSM is seen to be a cellular system standard. GSM uses both FDMA (frequency division multiple access) and TDMA (time division multiple access) schemes.

In GSM, the available frequency bands are 935 - 960 MHz and 890 - 915 MHz for downlink communication that the communication from a larger network to a smaller network (devices) and uplink communication that the communication from a smaller network (devices) to a larger network respectively.

GPRS (General Packet Radio Service) is referred to as 2.5G and derived from GSM [8]. EDGE (Enhanced Data rates for GSM Evolution) is derived from GPRS [26].

3G/UMTS (Universal Mobile Telecommunications System) [6] operates in the band from 1.8 GHz to 2.5 GHz. It uses more advanced adaptive modulation techniques such as Quadrature Phase Shift keying, or 64 QAM (QPSK), Differential phase shift keying (DPSK), Bipolar Phase Shift Keying (BPSK) and Pulse Modulation (PM). It provides data transfer speeds up to 2 Mbps.

LTE (Long Term Evolution) [15] is a standard of 4G that is described by 3rd Generation Partnership Project (3GPP). LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) modulation scheme. In LTE, the operating frequency bands are 800 MHz – 2.5 GHz. Theoretically, downlink data rate of 150 Mbps and uplink data rate of 50 Mbps are achievable in a 20-MHz downlink and uplink spectrums respectively. LTE/4G offers high mobility, reliability, low latency, scalability and high throughput features.

2.6.2 WiMAX

WiMAX or IEEE 802.16e is an improvement to the original WiMAX, which IEEE endorsed in the year 2004.

A wide range of transmission and high data rate to ensure high quality of service (QoS) are made possible by IEEE 802.16e, thereby providing a suitable environment for those applications that need these features, for example, VoIP, multimedia streaming etc. WiMAX uses Multiple-Input and Multiple-Output (MIMO) to achieve a high data rate [27].

2.6.3 DSRC/WAVE

DSRC originated from IEEE 802.11a. DSRC is improved for operations with low overhead in the DSRC spectrum and it is based on IEEE 802.11p [26, 28]. DSRC/WAVE provides a data rate of more than 27 Mbps, with 300 - 1000m communication range, and moving at a speed of 200 Km/h [8, 11].

2.6.4 UAV System

Due to the fast technological developments on communication, sensor, and electronic technologies, it is feasible to provide Unmanned Aerial Vehicle that can fly independently or are often remotely controlled without conveying any person. Due to their ease of installation, flexibility, versatility, and comparatively little operational costs, the use of UAVs guarantees new methods for civilian and military applications, for instance surveillance of border, search and destroy operations [29], managing wildfire [30], wind estimation [31], relay for ad hoc networks [32], disaster observation [33], traffic observation [34] and remote sensing [35]. Generally, UAV System has composed from Unmanned Aerial Vehicle (Drone), Ground Control Station (GCS) and MAVLink protocol. The GCS of UAV [36] has a laptop computer as a main component and it runs the intelligent controller ground program that can monitor the UAV's ICs (uplink communication) through IEEE 802.11b ad-hoc network. Whereas, MAVLink [37] is IEEE 802.11b-based protocol for communicating with unmanned vehicles and it is designed for packing structures necessary for communication between an unmanned vehicle, a GCS, and any internal components to the unmanned vehicle.

As I have shown in Figure 2.6, each MAVLink packet contains a header, a message, and a CRC trailer. The header contains a start of frame identifier, the message length, the packet sequence number, the system ID of the sending system, the component ID of the sending system, and the ID of the incoming message. The message or payload varies depending on the message id. And also CRC is used to confirm the integrity of a message.

Byte #	0	1	2	3	4	5	6	n + 5	n + 6	n + 7
Value	**0XFE**	**Msg Len**	**Seq #**	**Sys ID**	**Comp ID**	**Msg ID**	**Payload**		**CRC**	

Figure 2.6: MAVLink Packet Format [37]

2.6.5 WLAN/WiFi

Wireless access to ensure V2I or V2V communication can be provided by WLAN/WiFi. In order to provide wireless connectivity, IEEE 802.11 standards can be applied; in IEEE 802.11a, it provides a data rate of 54 Mbps and runs at a frequency of 5 GHz. IEEE 802.11g is another standard for IEEE 802.11, which covers the same range and provides the same data rate as IEEE 802.11a but runs at a frequency of 2.4 GHz [16]. Another standard is IEEE 802.11b, it provides a data rate of 11 Mbps and runs at a frequency of 2.4 GHz [26].

2.6.6 Coexistence of Heterogeneous Wireless Access Technologies

A set of wireless access technologies like GSM/GPRS/LTE and WiMAX are Continuous Air interface for Long and Medium range (CALM) and are adapted to IEEE 802.11p [7]. The main advantage of the coexistence of different wireless access technologies is to fill the limitations of them via incorporating to each other. Figure 2.7 shows that the coexisting of WiMAX, WiFi, and LTE technologies creates a new atmosphere for vehicular ad hoc networking scenarios.

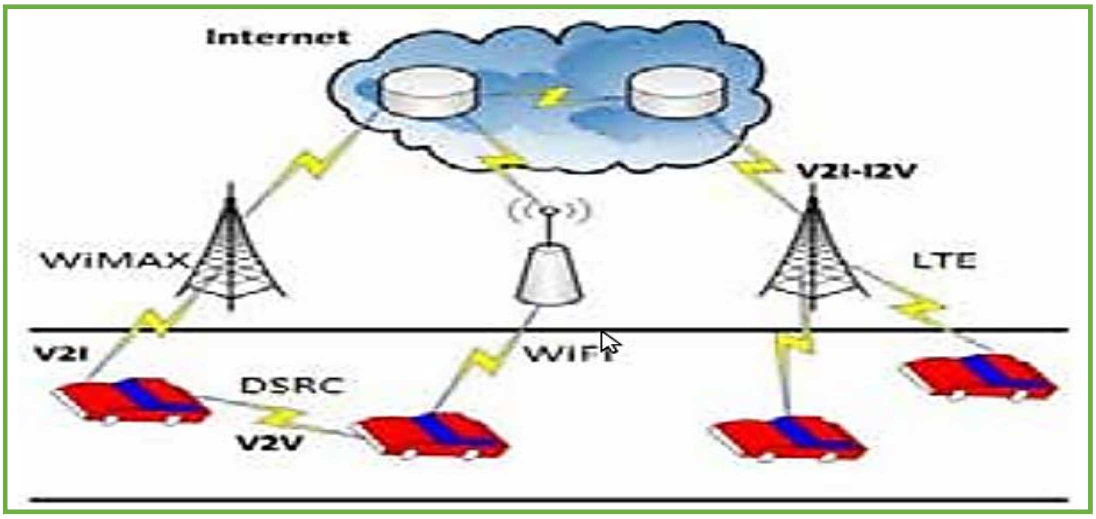


Figure 2.7: Wi-Fi, WiMAX, Cellular, and Combined DSRC (Vehicle) in a single form [5]

2.7 Comparison on the Features of Various VANETs Communication Technologies

Table 2.1: Features of VANETs Major Communication Technologies

Features	VANETs Major Communication Technology				
	LTE/4G	WiMAX	DSRC/WAVE	UAV System	WLAN/WiFi
Standard	LTE	IEEE 802.16d/e	IEEE 802.11p	IEEE 802.11b/g	IEEE 802.11a/b/g/n
Operating Frequency	800 MHz - 2.5 GHz	2 - 11 GHz	5.9 GHz	2.4 GHz	2.4 - 5 GHz
Channel Bandwidth	1.4 - 20 MHz	1.25 - 20 MHz	10 MHz	20 - 25 MHz	20 - 25 MHz
Transmission Power (AVG)	40 dBm	40 dBm	30 dBm	-	-
Transmission Range (MAX)	50 Km	50 Km	1 Km	500 m	300 m
Transmission Mode	Omnidirectional	Omni directional	Omnidirectional	Omni directional	Omni directional
Data Rate (MAX)	1Gbps	300 Mbps	27 Mbps	54 Mbps	300 Mbps
Multiplexing Techniques	SC-OFDM/ OFDM	TDM/OFDM	OFDM	DSSS/ OFDM	DSSS/MIMO-OFDM
Signal Interference	Low	High	Low	High	High
Security	High	High	High	Low	Low (a/b/g) high (n)
Accessibility	Contention based	Schedule based	Contention based	Contention based	Contention based
Maintenance	Difficult	Difficult	Easy	Easy	Easy
Upfront Cost	High	High	Moderate	Moderate	Moderate

As can be seen from the Table 2.1, we have compared the VANETs major communication technologies, LTE, WiMAX, DSRC/WAVE, UAV System and WLAN/WiFi, based on their basic features such as operating frequency band, channel bandwidth, data rate, transmission power, range, and mode. Hence, as per the comparison, LTE and WiMAX are highly capable to achieves the requirements of safety application that high data rate and coverage area. Moreover, regarding operational frequency band and channel bandwidth, almost all communication technologies can be integrated to each other in an easy manner.

2.8 VANET Applications

A large number of applications can be developed due to V2V and V2I communications and can support a wide range of information which is beneficial to travelers and drivers. The network interface and on-board devices can be incorporated, such as different types of GPS receivers and sensors that enable nodes to receive, process, and distribute information about its environment and itself to other nearby nodes.

As shown in Figure 2.9, the classification of VANET applications is presented in regards to their purpose.

2.8.1 Comfort Applications

It is known as non-safety applications and the objective of this application is to enhance passenger's comfort and to improve traffic efficiency [8], [26], [11]. These applications make available to drivers with the location of a petrol station, nearest restaurant, traffic information, weather information etc.

2.8.2 Safety Applications

In order to avoid accidents and enhance road safety, these applications use the communication between V2I and/or V2V. The foremost intention is to provide a safe environment and save lives.

The classification of safety applications is demonstrated as follows:

A. Public Safety

The aim of public safety applications is to assist drivers in case of an accident and to assist search and rescue teams to provide services efficiently and minimize their travel time. The range of communication used by this application is 300 to 1000m and the frequency is 1Hz which depends on V2I, V2V or both [5]. For example, SOS services, Emergency vehicle signal pre-emption, etc.

B. Collision Avoidance at Intersection

Many road accidents can be avoided by improving collision avoidance at the intersection based on V2I communication. Information is received from vehicles approaching the intersection, processed and analyzed by sensors at the infrastructure. After analysis of the data is completed, if the probability of an accident occurring, then warning signal is sent to vehicles when arriving at the intersection to take necessary and appropriate actions. For example, warning about violating traffic signal, etc.

C. Sign Extension

This is to warn drivers that are not paying attention to road signs which are stationed by the road side so as to avert road accidents. For example, curve speed warning, work zone warning, etc.

D. Information From Other Vehicles

It depends on V2V, V2I or both in order to perform safety applications function and the range of communication used by this application is 50 to 400m and the frequency is 2 to 50Hz [5]. For example, cooperative forward collision warning, etc.

E. Diagnostics and Maintenance of Vehicle

This is used to send warning notification to vehicles with the objective of reminding the driver of the need for the vehicle to receive timely maintenance and about safety defects. For example, Just-in-time repair notification, etc.

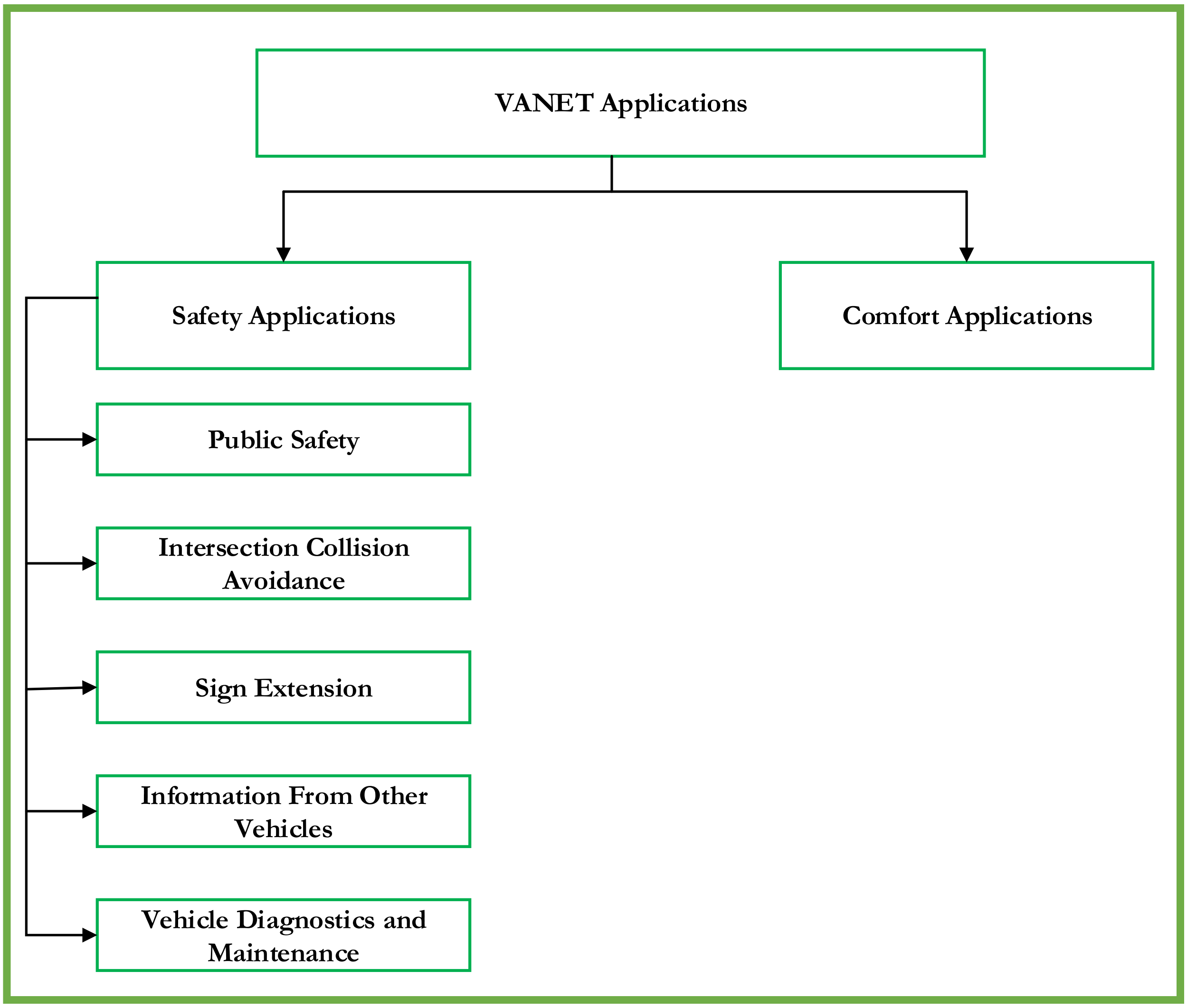


Figure 2.9: VANET Applications

Chapter Three: Related Work

Nowadays, smart ground vehicles have equipped with a number of wireless access technologies to communicate with other vehicles and roadside infrastructures; Due to this fact, it could possible to improve its communications and applications by achieving their requirements [42]. Coexistence of mixed wireless access technologies in VANETs have become a hot thematic topic in the wireless communication system world, and several research directions are going to enhance the services which is provided by VANET applications. And as well as a wise choice of access technologies is another important issue since it determines the transmission range, data rate, bandwidth consumption, deployment and operational costs, security and reliability, and etc. In this Chapter, I have categorized the works done so far based on technologies and approaches which used to optimize the performance of VANET communications and applications: VANET communications using LTE/4G and UAV System.

3.1 VANET Communications with Heterogeneous Wireless Access Technologies

In the following section, I will summarize the works which are carried out on the most well-known heterogeneous wireless access technologies for providing VANET communications.

3.1.1 VANET Communications Using LTE/4G

Recently, several researchers proposed LTE for VANET Communications. Here I summarize those that are relevant and quite related to the study.

In [15] a performance evaluation of LTE and IEEE 802.11p for VANETs has been conducted. The work demonstrated a detail performance evaluation study between LTE and IEEE 802.11p for VANETs based on a variety of parameter settings such as vehicle average speed, beacon transmission frequency, and vehicle density. This comparison between LTE and IEEE 802.11p was performed in terms of delay, reliability, scalability, and mobility support in the context of various applications requirements like safety, traffic management, and infotainment.

The authors have proposed two architectures to compare vehicular networking that utilizes whether IEEE 802.11p-based infrastructure-less network or infrastructure-based LTE cellular network. In these architectures, LTE eNodeB and RSU have deployed on the road side. Besides, the vehicles which IEEE 802.11p-enabled can use WAVE interface between V2V and V2I whereas to use LTE eNodeB, the vehicles should have whether LTE-OBU or drivers must have a smart phone with LTE connectivity.

The performance of LTE and IEEE 802.11p is evaluated by using ns-3, version 3.17, as a network simulator and the mobility of the vehicle generated by SUMO tool.

In the LTE simulation, the Friis path loss model is employed as a radio propagation model configured with an isotropic (omnidirectional) antenna, and also SISO transmission mode and proportional Fair MAC scheduler are used. In addition, there are two types of smart ground vehicles, one that adjusts to transmit beacons as per required by different applications, while a few other vehicles transmit background traffic that emulates real-time video stream. Actually, the work carried out two performance evaluation studies, the impact of varying beacon transmission frequency and vehicle's average speed on the performance of both technologies respectively.

In conclusion, the simulation results revealed that the LTE standard offered superior network capacity and mobility support as compared with IEEE 802.11p standard. In order to this, the LTE technology is suitable for most of the applications. On the other side, IEEE 802.11p standard provided acceptable performance when lower vehicle density, traffic load, and vehicle speed. Although the work has not been considered QoS-based scheduling algorithms for LTE technology. Furthermore, the study considered only the downlink-unicast communication, thus further exploration on downlink-broadcast is needed.

The authors in [43] proposed an architecture that the integration of IEEE 802.11-based VANET and LTE cellular network for an urban environment using mobile vehicular gateways. Each technology has a different objective and their integrated deployment will improve the vehicular system performance with long-range communication. The authors selected IEEE 802.11g (WiFi) standard due to its popularity, low cost and it is very suitable for short-range communication (V2V). Whereas the LTE standard has been selected for the reason of suitability in long-range communication (V2I).

The proposed architecture has two types of smart ground vehicles as shown in Figure 3.1. Vehicles that are equipped with both LTE and WiFi interfaces are called as Gateway Vehicles (GVs). While those only WiFi supported vehicles are Ordinary Vehicles (OVs). As simply, GV has present in the coverage area of LTE network and its WiFi interface is activated. On the other side, OV has not present in the range of LTE network though its WiFi interface is enabled. Basically, the architecture focused on the model which consists of seven cells with arranged in hexagonal honey-cell layout where each cell is covered by one eNodeB. And the vehicles have moved between these seven cells with the speed of 60 km/h. The LTE backhaul link can provide Internet access to OVs through the GVs. In addition, there are two types of links in the proposed architecture, downlink (LTE eNodeB unicast data to GVs) and uplink (GVs forward a data to LTE eNodeB) respectively. To manage the amount of traffic that exchanged between smart ground vehicles and eNodeB, a clustering mechanism is employed. However, the work has constraints due to the limitation of the members of the cluster (fixed in number), pre-defined mobility and no handoff techniques.

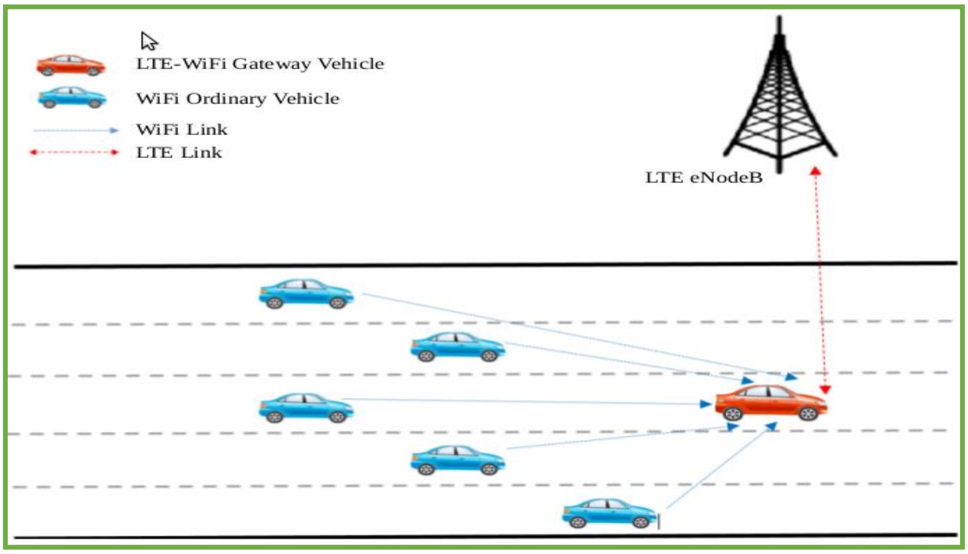


Figure 3.1: VANET-LTE Network Architecture [43]

The proposed architecture modeled/simulated by using OPNET modeler in terms of data rate, data loss ratio, delay and jitter metrics. During simulation, there are two types of models/mechanisms have employed, No Burst Model and Burst Recovery mechanism respectively. Actually, the burst technique proposed to prevent data packet losses in uplink communication. The simulation results showed that the delay, jitter, and data drops have an acceptable limit using the burst technique with only two packets per burst for uplink, downlink and video traffics.

3.1.2 VANET Communications Using UAV System

The work in [44] proposed a network model that uses a single UAV between VANET segments to improve the VANETs connectivity and network efficiency. The proposed network model presented a UAV in the form of a queuing system. The model consists of Gn groups of smart ground vehicles, UAV (queuing) system, which is static and at some point, on h height, as shown in Figure 3.2. The group of vehicles interacts with UAV via a radio channel. And also *R-value* describes the radius of the possible interaction between UAV and smart ground vehicles, which depends on the height h of UAV flight. However, the model doesn't take into account the terrain and weather conditions.

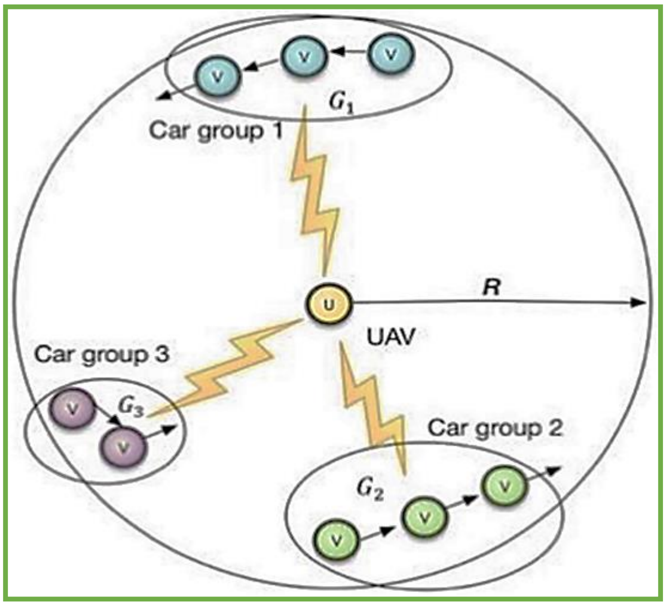


Figure 3.2: The Proposed Network Model [44]

Furthermore, the model has explained in calculation and simulation approaches. During calculation approach, the authors calculated the average data delivery time from vehicle to UAV, and the average service request time to UAV regarding on the arrival intensity of the service requests and service rate of requests. Whereas to evaluate the possibility and operating efficiency of the system, a group of software packages, OMNET++, MIXIM and Veins with environment model of radio wave propagation were being used. Besides, the authors have been carried out a real network simulation though it has not been a clearly enough explanation, and also a realistic vehicle movement pattern has not been considered.

Generally, the study results revealed that the UAV node acted as the same vehicle node that being between two vehicle nodes in VANETs. The vehicles can get an efficient service (connectivity) through UAV but it depends on the radius of the service UAV, data rate of the channel, length data and messages. While increasing the number of vehicles in a group affects transmission quality of data. Finally, the results of the real simulation showed that the UAV node has been high packet losses.

In [45] the work proposed a novel routing scheme for urban vehicular ad hoc networks called Connectivity-based Traffic Density Aware Routing using UAVs (CRUV), through cooperative and collaborative techniques. The routing protocol proceed based on information exchange between smart ground vehicles and UAVs to help vehicles in the ground search the best multi-hop path by selecting the most appropriate next intersection to deliver the data packets successfully to their destinations. Simply the protocol relies on choosing, at each moment and ahead of time, the most connected path among others available and avoid using paths that can be quickly broken.

The vehicles can select UAV as a forwarding node instead of a road segment. In this scheme, there are many assumptions being considered. For instance, a vehicle can communicate with UAVs (V2U/U2V) and other vehicles (V2V) within LOS (within a range) as demonstrated in Figure 3.3.

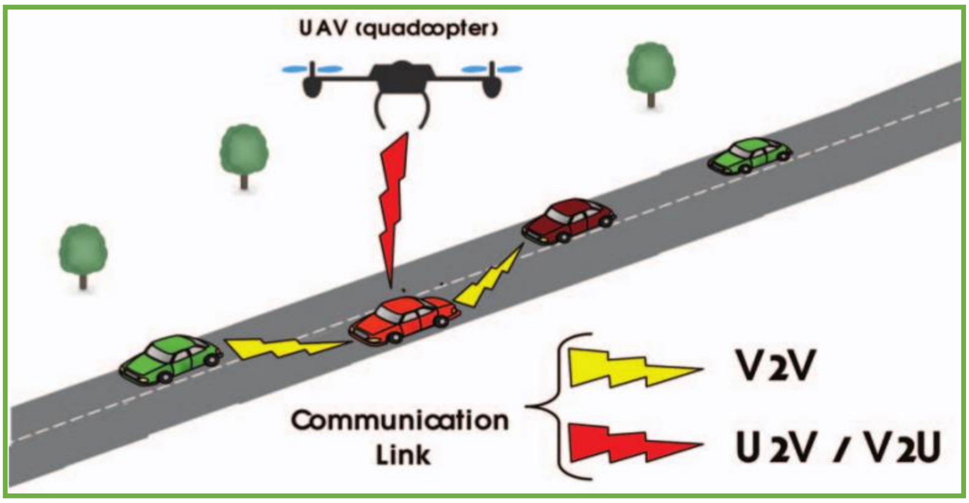


Figure 3.3: CRUV Architecture [45]

As depicted in Figure 3.4, a path connectedness is measured in three ways. These are by periodic Hello messages exchanged between smart ground vehicles, by forwarding the data packets directly to UAVs within range when there are no available routing paths and then forward the data packet directly to the destination if it is within the transmission range of the UAV, and the last by forwarding to the vehicle located at the most appropriate intersections where there are available connected road segments leading to destinations.

Generally, CRUV protocol uses Greedy Forwarding and Carry and Forward as a data delivering mechanism according to the situation of the network. The path selection is the most complicated mechanism in the approach though it will be done by a scoring system that is calculated based on the traffic density and the knowledge of the connectivity on the road segment, it will be done by either smart ground vehicles or UAVs.

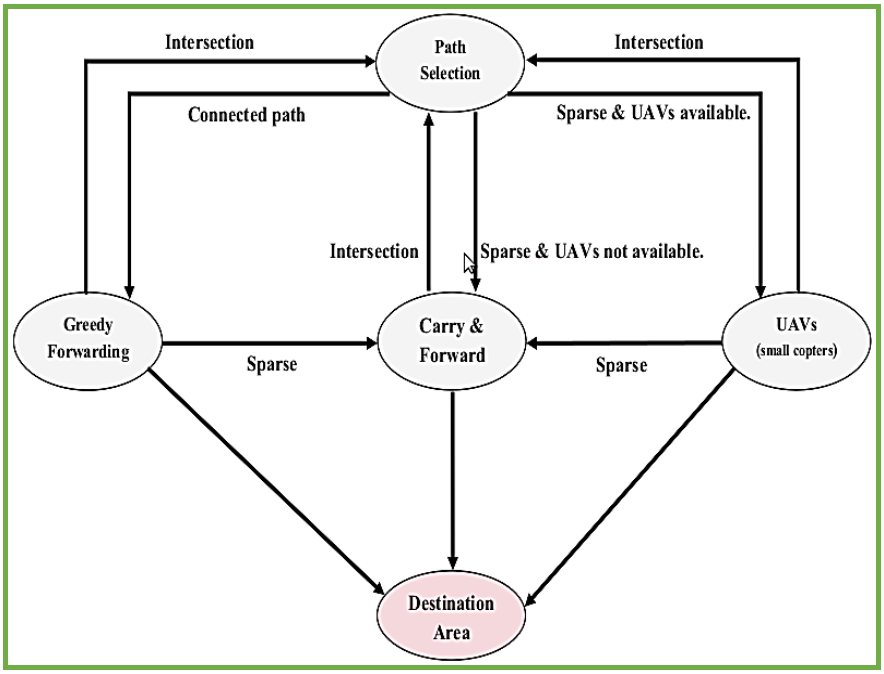


Figure 3.4: CRUV States [45]

To evaluate the performance of the novel routing scheme, three basic simulators are employed. The smart ground vehicles and UAVs mobility model generated by VanetMobiSim and MobiSim respectively. Then the generated mobility model trace files fed to NS2 network simulator to examined the CRUV and IRTIV protocols. In addition, the performance of the protocol evaluated in terms of packet delivery ratio, end-to-end delay, and an average number of hops.

The results of simulation exhibited that CRUV has a lower delay and high average packet delivery ratio for a different number of smart ground vehicles compared with IRTIV protocol. Hence, UAVs have been used to make the routing strategy more efficient and reliable in order to omit obstacles that have a negative impact in delivering packets. However, the study has not considered any road side units and wireless access network technologies. And, the carry and forward mechanism may have a negative impact on safety applications.

The work in [46] proposed a novel distributed location-based routing protocol known as Vehicle-Drone hybrid Vehicular ad-hoc Network (VDNet) to improve the V2V data message delivery with relatively low end-to-end delay.

The proposed work needs a drone, Quadrotor/Quadcopter, that has the ability to hover for a long while, and some smart ground vehicles equipped with the on-board drone to support the radio link of drones as shown in Figure 3.5. The protocol can take a geographic information through GPS. In this routing protocol, there is an important designed algorithm, a distributed vehicle location prediction algorithm, working based on peer-observed history location information and recent location data.

And also for this location information, a distributed database scheme with GPS has been designed on each vehicle and drone. Moreover, all vehicles are capable of carrying and forward data messages.

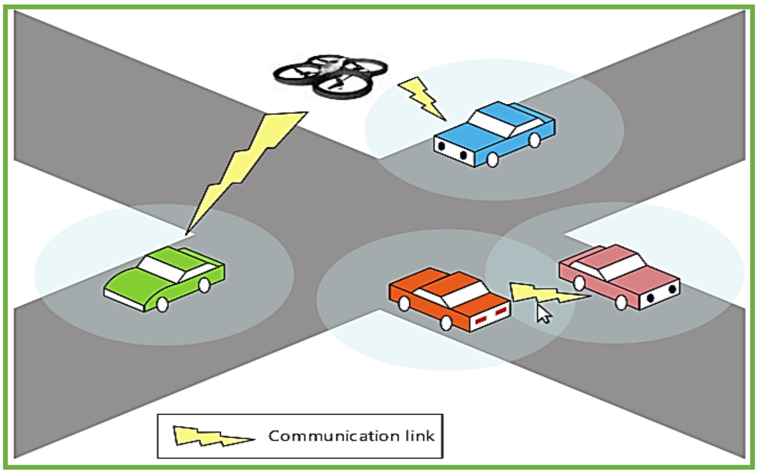


Figure 3.5: VDNet Architecture [46]

The location information in the database is continuously updated. To prevent bandwidth overhead due to broadcast a location information periodically, the system proposed two types/modes of smart ground vehicles, active and passive vehicles respectively. Passive vehicles have carried out a compare-and-exchange its location information database that each time it changes its relative position along the street with another vehicle. Whereas the passive vehicle wants to forward a data message, it will switch to an active mode that broadcasts its location message to neighbor vehicles every time. The proposed vehicle location prediction algorithm has been carried out whether raw prediction (based only the current location information) and/or advanced location prediction (by dividing a region into an area, route, and isolated location).

The proposed novel routing scheme (VDNet) has been evaluated respecting to all-knowing time and amount of information, data message delivery efficiency, and vehicle location prediction algorithm. The simulation results revealed that during the all-knowing time, a hybrid of active and passive modes have an intermediate performance than others modes and also the VDNet produced less amount of information. In case of data message delivery efficiency, using a drone and drone-mounted vehicles could have enhanced the average delivery ratio and minimized the average end-to-end delay. Finally, during the prediction algorithm, it has been the best performance, especially on the open-world model. However, the study performance evaluation way has not been clearly defined even the simulator type that they have used is not mentioned. Furthermore, they have not been generated a realistic vehicles movement pattern.

3.2 Comparison on Heterogeneous Wireless Access Technologies Regarding VANETs

As shown in Table 3.1, based on the papers [16], [47], [48] we have summarized the comparison on VANET communications with different wireless access technologies.

Table 3.1: Comparison on Heterogeneous Wireless Access Technologies Regarding VANETs

VANET Applications & Features	Major Heterogeneous Wireless Access Technologies of VANETs				
	LTE/4G	**WiMAX** (IEEE 802.16e)	**DSRC/WAVE**	**UAV System**	**WLAN/ WiFi**
V2V Support (Direct)	No	No	Native (ad hoc)	No	Native (ad hoc)
V2I Support	Yes	Yes	Yes	Yes	Yes
Safety Application	High (long range)	High (long range)	High (short range)	High (short range)	High (short range)
Traffic Management Application	High	High	Moderate	High	Moderate
Infotainment Application	High	High	Low	Moderate	Low
Mobility Support	High 100 - 250 Km/h	High 60 - 250 Km/h	Medium 40 - 150 Km/h	Medium 40 - 150 Km/h	Medium 40 - 150 Km/h
Highway/ Urban Scenario	More suitable for Highway	More suitable for Highway	More suitable for Urban	More suitable for Urban	More suitable for Urban
Broadcast/ Multicast Support	Through eMBMS	Broadcast & Multicast	Native Broadcast	Broadcast & Multicast	Native Broadcast
Connectivity	Ubiquitous	Ubiquitous	Intermittent	Ubiquitous	Intermittent
Scalability	High	High	Low	Moderate	Low

As can be seen from the Table 3.1, all heterogeneous wireless access technologies have specific advantages and disadvantages that make them suitable for certain types of scenarios. For instance, for infotainment applications such as voice/video conferencing, IP telephony, and other time-sensitive applications, LTE and WiMAX are pretty preferred than others, however, they have a lower capacity for direct V2V communications relative to others. Therefore, as per the comparison Table 3.1, the performance of VANET communications will be improved via integrating of heterogeneous wireless access technologies, and due to this fact, the different VANET applications requirements will be attained, that is why I are interested to work on the integration of different wireless access technologies for VANETs.

3.3 Summary

Even though all the works reviewed deal with different aspects of wireless access technologies for improvement of VANET communications and satisfy the demands of its applications, there is no work that describes and presents adequately and appropriately about the integrated architecture of the UAV System with LTE/4G and WAVE networks with its forwarding schemes to optimize the performance of VANET communications and satisfy the requirements of its basic applications regarding to connectivity, scalability and bandwidth. Thus, to provide an efficient communications and applications in vehicular ad hoc networks, there is a need to design a new architecture with its forwarding schemes will consider the above mentioned constraints.

According to the literature, the solution is intended to use UAV System with LTE/4G and WAVE technologies and I will address the following vital issues which were not covered by the works reviewed.

- Design a novel architecture by integrated the UAV System with LTE/4G and WAVE networks in highway scenario, in order to improve the performance of VANET communications. The proposed architecture is expected to minimize the high bandwidth usage of periodically broadcast environment info by vehicles and intermittent connectivity of V2V.
- Develop algorithms for a single small UAV's periodically sensing, tagging and broadcasting of the current states of smart ground vehicles info within UAV coverage area and forwarding schemes of the tagged info to respective wireless access technologies (LTE/RSUs) and smart ground vehicles to satisfy the requirements of VANET basic applications (safety and traffic), to minimize a high bandwidth consumption of vehicles and an intermittent connectivity of V2V.

Chapter Four: Design of the Proposed Solution

4.1 Overview

As we have described in Chapter 3 summary, most of the current VANET works deals with different aspects of wireless access technologies as whether separately or integrally for improvement of VANET communications, though there has not been work that describes and presents sufficiently about the integrating of UAV System, LTE/4G and RSU (DSRC/WAVE) networks architecture to optimize the performance of VANET communications and satisfy the basic VANET applications requirement regarding to connectivity and bandwidth to have a better QoS communications and applications. Thus, to provide an efficient communications and applications in vehicular ad hoc network, I have designed a new architecture that considered the above mentioned different wireless access networks. In this thesis, I propose to design an integrated of UAV System, LTE/4G and RSU (DSRC/WAVE) networks architecture for optimize the performance of VANET communications and satisfy different VANET applications requirement.

Following this overview, in the following sections, I describe the details about the architectures and the models developed for the proposed solution. In Section 4.2, I describe and present the proposed solution. Summary about the chapter is described in Section 4.3.

4.2 Architectures of the Proposed Solution

In this section, I described and presented the overall architecture of the proposed system in a highway environment as shown in Figure 4.1, 4.3 and 4.4. In Section 4.2.1, I discussed and presented the proposed UAV's periodically sensing, tagging and broadcasting operations of vehicles information in highway environment with MAVLink packets. In Section 4.2.2, approaches and objectives of forwarding models of the sensed information (tagged packets) to the respective wireless access network infrastructures via UAV's GCS are discussed. Propagating scheme of the sensed information to the target smart ground vehicles is demonstrated in Section 4.2.3. And finally, I discuss and present the general proposed architecture states as shown in Section 4.2.4.

Figure 4.1 shows the general low-level architecture of the proposed system in a highway scenario. In this low-level architecture, I have designed three fundamental wireless network infrastructures (UAV System, LTE/4G and RSUs) with their respective positions and I have assumed that the transmission range of each infrastructure and smart ground vehicle has considered as an ideal cell.

I have assumed that the UAV System has a single, small and full autonomous Quadrotor Drone (4 Rotor wing) type that does not require any direct human intervention for flying (uplink communication) and it capable to hover on a specific area for a long while.

The system is deployed along the highway segment with around 10m altitude (height) from the ground and its transmission range covered nearby 150-200 meter and completely confined by the transmission range of LTE/4G network. The drone has a hovering motion over the area of sensing operation and proceed different types of communications such as with drone-mounted vehicles and CCT BS/GCS via IEEE 802.11b interface. The CCT BS/GCS of UAV [36] has a laptop computer as the main component and it runs the intelligent controller ground program that can monitor the UAV's ICs (uplink communication) through IEEE 802.11b ad-hoc network. However, in the proposed architecture, I have only used a downlink communication that a UAV broadcasts the sensed information (tagged packet) within transmission range. In order for this to work, the IEEE 802.11b-enabled vehicles and GCS will receive the broadcasted packet via LOS or direct radio link of IEEE 802.11b communication. Besides, the GCS that is present in the proposed model uses a gateway of UAV to make a communication between UAV and LTE/RSUs.

The LTE/4G network is designed along the highway segment as one of the wireless access network infrastructures. I have assumed that the eNB cell covered about 1km which means it can completely cover the transmission range of the other deployed infrastructures as shown in Fig 4.1. The network can communicate with the UAV System through its core network (EPC server). Likewise, the LTE/4G network can make a direct communication with 4G-enabled vehicles (driver's LTE equipped cell phone) when those vehicles are within the eNodeB cell.

Two RSUs (DSRC/WAVE) are also designed on the left and right sides of UAV System respectively. I have thought that each RSU has about 250 to 300m coverage area and absolutely confined by LTE/4G transmission range as like as UAV System. They are also connected and proceed a communication with UAV System via Internet or their own gateways. Moreover, the infrastructures can make direct communications with WAVE-enabled vehicles via IEEE 802.11p wireless interface when those vehicles are in the RSUs coverage area.

Furthermore, I have also considered a few basic assumptions when I design the proposed architecture. Such as a deployment distance between infrastructures, the flow, and transmission range of vehicles, and street type as I have discussed below.

I have assumed that the deployment distance between RSU 1 (the left one) and UAV, and again between UAV System and RSU 2 (the right one) have about 180 and 300 meters respectively. However, the deployment distance of eNB is not compulsory because it has a high coverage area than others, thus I have thought that wherever the eNB is deployed, it has no significant effect in the proposed architecture. Though, for better clarification of the proposed system, I have simply deployed the eNB about 80 meters far away from RSU 1 (the left one).

While I have assumed that the transmission range of vehicles is less than the range of remaining deployed wireless access infrastructures and it varies from vehicle to vehicle as shown in Fig 4.1 and 4.2. Also the vehicles are highly exposed to intermittent connectivity due to a highway scenario and their own dynamic movements. Additionally, I have considered the street type as a two-lane highway with a different flow of directions which means on the upper lane the flow of vehicles proceeds from right to left whereas on the lower lane it proceeds from left to right as demonstrated in Fig 4.1.

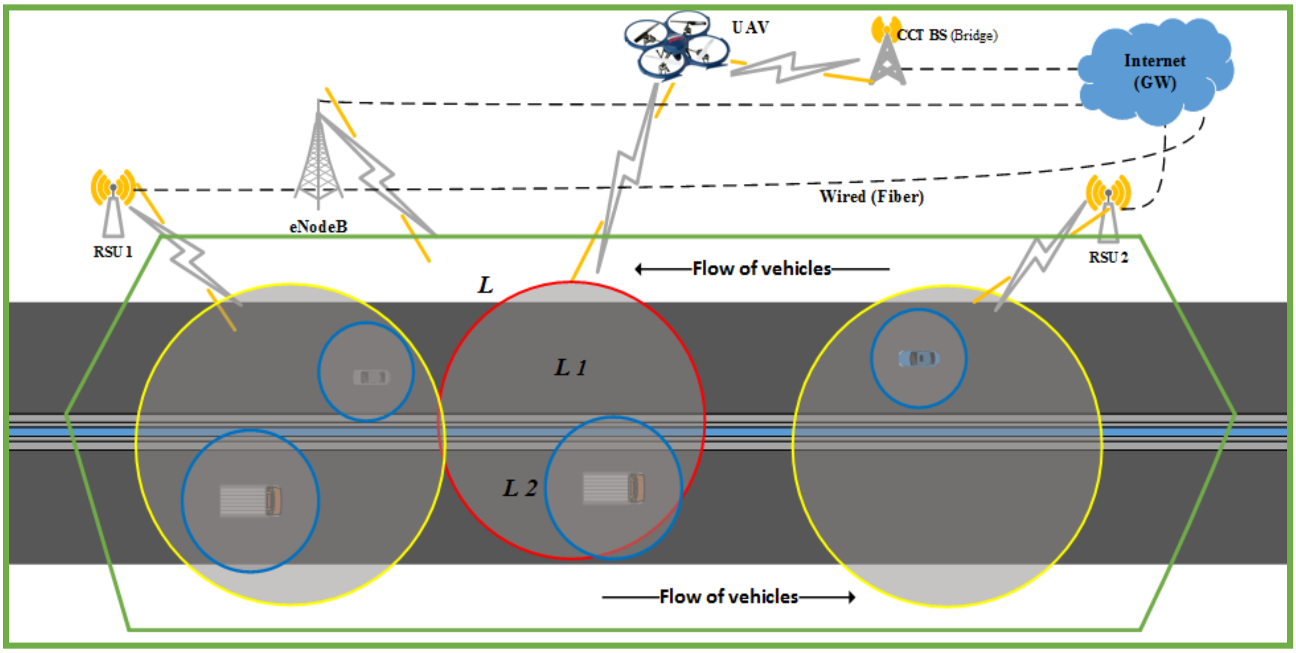


Figure 4.1: General Low-Level Architecture of the Proposed Solution

Figure 4.2: Transmission Range of Different Model of Smart Ground Vehicles [49]

Fig 4.3 depicts the overall high-level architecture that will be implemented in the proposed system in a highway scenario. Generally, the architecture has four core modules those are Unmanned Aerial Vehicle (UAV), Long Term Evolution (LTE/4G), Road Side Unit (RSU 1/RSU 2) and Smart Ground Vehicle modules. And also there are four proposed forwarding schemas: from UAV (GCS) to LTE/4G, UAV (GCS) to RSU 1/RSU 2, LTE/4G to Smart Ground Vehicles and RSU 1/RSU 2 to Smart Ground Vehicles respectively.

In the UAV module, there are four fundamental layers such as application, network and transport, processing unit, and communication layers correspondingly as revealed in Fig 4.3 as shown below. The communication layer is capable to transmit and/or receive various data from/to on-board drone vehicles and/or GCS via IEEE 802.11b based RF transceiver. In the processing unit layer, there are three major internal modules such UAV Controller (FCS), Task/Mission Manager and Sensor Unit. The primary operation of UAV controller is to read and analyzes data from a wide variety of sensors and produces a mission flight plan, and it has direct communications with sensor unit and task manager modules. Task/Mission Manager module is responsible for registering new and monitoring ongoing missions, and it has three direct communications: with sensor unit module, UAV controller module, and communication interface layer. The third module of processing unit layer is a sensor unit which is responsible for detecting and measuring a different stimulus and signal of UAV's internal part and sensing operation area. In this module, there are many well-known sensors, such as GPS for navigating a position of UAV and operation area, Accelerometer for detecting the velocity of UAV and the moving objects within the operation area and HD Video/Photo for capturing high-quality pictures and videos from operation area. The network and transport layer of UAV is a fundamental layer that primarily responsible for routing a MAVLink packet [37] and end-to-end communication via UDP or TCP/IP respectively. Whereas, the last layer of UAV module is application layer that accountable for supporting and providing different services such as mapping, surveying, traffic controlling, military operation and border monitoring. However, those applications are depending on the type and capacity of UAV.

As presented in Fig 4.4, the LTE/4G module has two major components which named as eNodeB (eNB) and EPC server respectively. The eNB is a fixed base station that has E-UTRAN interface and it can transmit and receive a data from/to LTE-enabled devices via its own transceiver antenna within a cell. Whereas, EPC server has encapsulated the core network of LTE/4G which includes S-GW and PDN-GW. Besides, when downlink communication proceeds, the packet will be EPS bearer by EPC server.

The Smart Ground Vehicles module that is demonstrated in Fig 4.4 has six basic layers. They are applications, facilities, network & transport, communication media, management and security. The communication layer is responsible to make a connection with smart vehicles and different wireless access technologies via their own different wireless/wired external interfaces. Mostly the OBU of communication media consists of Ethernet, GPS, WiFi, 2G/3G and IEEE 802.11p external interfaces. In the proposed work, the smart ground vehicles have LTE/4G, IEEE 802.11p and IEEE 802.11b/g external communication interfaces. Moreover, this layer can communicate with the management and security layers of OBU via management and security internal interfaces respectively, and also it has communication with network and transport layer through the internal network interface. The second layer, network and transport layer, has comprised different protocols such as GeoNetworking protocol, TCP/UDP and IPv6 mobility extensions. The primary function of the layer is to make a routing, IP mobility and an end-to-end connectivity. Generally, it has a communication with management, security and facilities layers through management network, security network and network facilities internal interfaces respectively. While the facilities layer is accountable for supporting application, information and session/communication. Moreover, it has a direct communication with management, security and application layers. The upper layer in OBU of smart ground vehicles is application layer that is responsible for providing different applications for drivers and/or passengers in a suitable manner such as a road safety, traffic efficiency and infotainment. As other stated layers, application layer has direct communications with management, security and facilities layers. The last two layers of smart ground vehicles module are management and security layers. Management layer is considered as a cross-layer and it has a direct communication with all the remaining layers except security layer. Basically, it provides a management information base (MIB) services such as regulatory, cross-layer, station and application managements. Whereas, the security layer is also considered as a cross-layer and it offers a hardware security module, firewall & intrusion management, authentication, authorization and profile management, and also security management information base (identity, crypto-key and certificate management) services. Besides, it has direct communications with all the remaining layers except management layer.

RSU 1/RSU 2 module is the last module that resides in the proposed overall high-level architecture and it has almost identical components with smart ground vehicles except for the communication media which supports only IEEE 802.11p (DSRC/WAVE). Furthermore, the module is implemented on the static infrastructures (RSUs) rather than dynamic objects (vehicles).

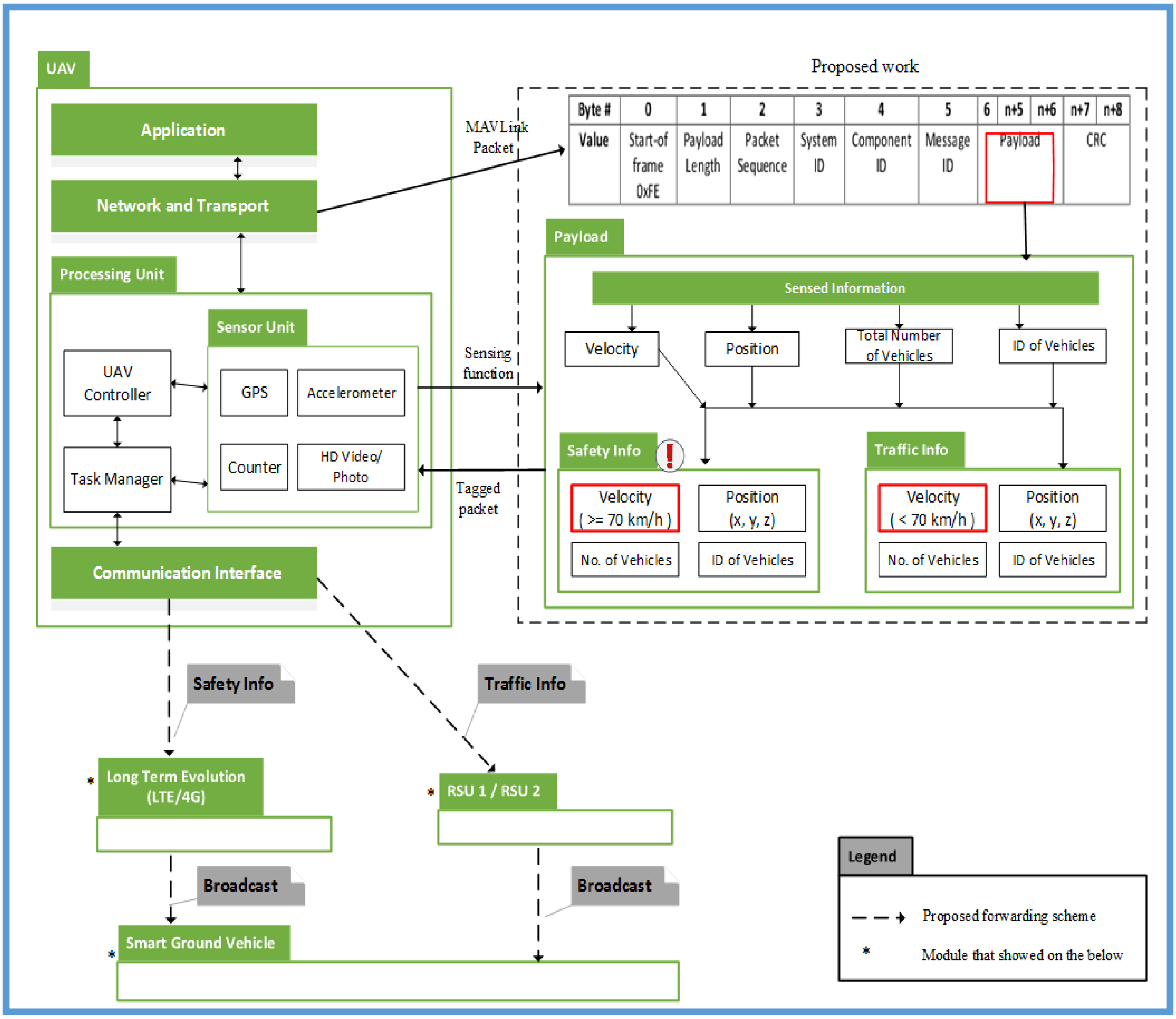


Figure 4.3: General High-Level Architecture of the Proposed Solution

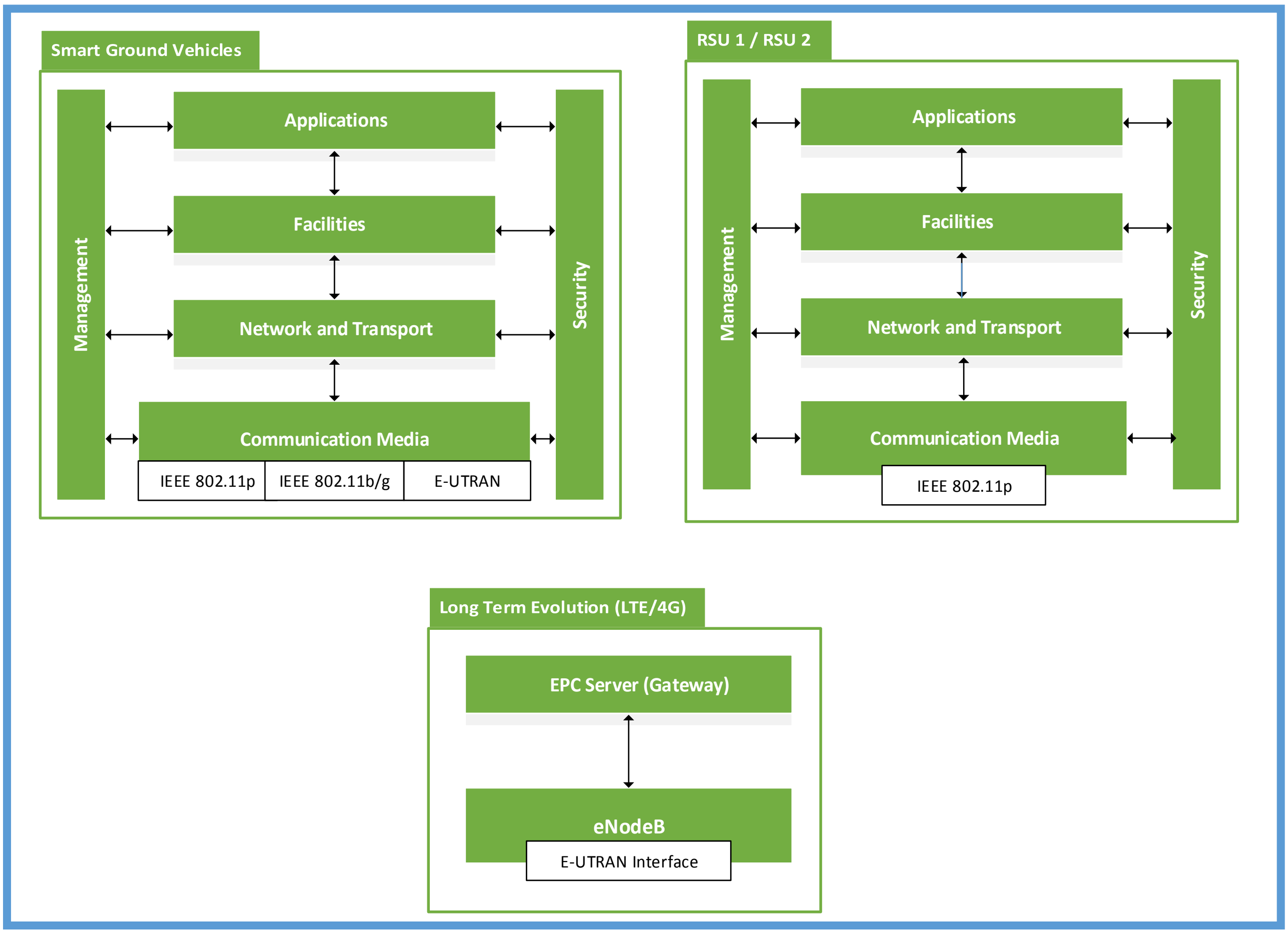


Figure 4.4: The Remaining Modules in General High-Level Architecture of the Proposed Solution

4.2.1 The Proposed UAV's Periodically Sensing, Tagging and Broadcasting of Vehicles Information

In this section, we have designed a single small UAV's periodically sensing, tagging and broadcasting operations of the current states of drone-mounted vehicles info within UAV coverage area to minimize a bandwidth consumption of vehicles that periodically broadcast their current states to other nearest vehicles and RSUs. Next, we discussed each UAV's proposed operation as follows.

A. Periodically Sensing Vehicles Info in Highway Environment

In this first task of the proposed high-level architecture model, I assumed that any vehicle within the highway scenario doesn't broadcast any sensed highway environment information to their surrounding vehicles and wireless access infrastructures. However, the vehicles can use the information for its own purpose if they want. In other word, there is no direct V2V and V2I uplink communications in the proposed system. Actually, the assumption is partially deduced from the theory of a high swiftness and sparseness of smart ground vehicles in highway environment [6], [18], [9], [10].

In this theory, to minimize the intermittent connectivity (to enhance V2V communication), it has used a direct V2I uplink communication. However, in the proposed work, I have excluded the direct V2I uplink communication and substituted it by UAV System and V2I downlink communication.

As I have demonstrated in Figure 4.3, the proposed architecture model is designed to overcome the above mentioned problems by using UAV's different sensors function from the sensor unit for detecting the different states of vehicles within UAV's transmission range. In this work, I have interested to periodically sense the speed, position, total number and ID of smart ground vehicles in UAV's transmission range. To achieve this, the UAV will periodically broadcast a beacon or Hello message to on-board drone vehicles within its transmission range, and if the message is received by the vehicles then I will use a UAV's GPS, Accelerometer and counter functions to detect current position, speed, total number and ID of smart ground vehicles respectively. As shown in Fig 4.1, the UAV's transmission range has covered both lanes, thus the vehicles those being in those tracks within UAV's transmission range would be detected by UAV's sensors. And the detected information will be organized as safety or traffic information and stored in a payload of MAVLink packet as I have discussed as follows.

B. Tagging a Sensed Information in a MAVLink Packet

After completing the UAV's sensing operation, the sensed information will be tagged in a MAVLink packet via UAV. In this tagging operation phase, I will organize the sensed information as for safety or traffic information/application. To proceed the organization process, I have proposed a model that helps us to arrange the sensed information in an easy manner. Additionally, this proposed model is not only significant for arranging the sensed information even it is very compulsory for forwarding the information to the respective wireless access network infrastructures as shown as in Fig 4.5.

- **The Proposed Model of Safety and Traffic Information**

Generally, in the proposed model, any periodically sensed information in the coverage area of UAV have always the speed, position, total number and ID of smart ground vehicles. Then based on this circumstance, I have proposed a model of safety and traffic info that used to organize the information as safety or traffic info and optimize the forwarding of the information to the target wireless access network infrastructures (LTE/RSUs). I have discussed this proposed model in details below.

I have assumed that the total sensed information within transmission range and sensing interval time of UAV from both lanes denoted by *L* and the total number of sensed smart ground vehicles which detected from upper and lower lanes within the same coverage area and sensing interval time symbolized by *L1* and *L2* respectively as shown in Figure 4.1 and 4.5. Moreover, the total number of sensed smart ground vehicles those being in the coverage area of UAV denoted by *V*. And as I have demonstrated in Fig 4.1, the transmission range of UAV is considered as ideal or circle thus the area of transmission range is equivalent to πr^2. Therefore, I have inferred that the total sensed information is equivalent to the total number of sensed smart ground vehicles per UAV's coverage area as shown in EQ. 4.1.

$$L = V/\pi r^2 \text{ .... } \textit{(EQ. 4.1)}$$

Furthermore, I have assumed that *L* is equivalent to the summation of the total number of sensed smart ground vehicles on upper and lower lanes as shown in EQ. 4.2.

$$L = L1 + L2 \text{ .... } \textit{(EQ. 4.2)}$$

As I have stated above, any sensed information within sensing interval time and transmission range of UAV always contains the speed, position, total number and ID of smart ground vehicles. Consequently, *L* contains all of this information. Then, on the basis of this circumstance, I have proceeded the organization process of the sensed information as safety or traffic information.

In Chapter 2, safety warning speed has considered as one of safety applications. So, I have assumed that the speed of vehicles that beyond from the reasonable one, it may be a cause of collision/collision warning. So, in the information arrangement process, I have assumed that the reasonable vehicle speed in the proposed work is less than 70 km/h. Therefore, if there is any vehicle's speed from *L1* and/or *L2* which greater than or equal to 70 km/h, *L* will be classified as a safety information and tagged in the Safety Info module of the proposed work in the payload of MAVLink packet. Whereas if the speed of all vehicles from *L1* and/or *L2* is less than 70 km/h, *L1* and/or *L2* will be classified as a traffic information and then tagged in a different Traffic Info module if there is *L1* and *L2.* Else tagged in single Traffic Info module if there is only *L1* or *L2*. This last tagging process is very significant when during forwarding traffic information to RSUs as shown in Fig 4.5.

After accomplishing the tagging process, the UAV will broadcast the tagged packets within its own transmission range.

Algorithm 4.1 shows the pseudo code of UAV's sensing, tagging and broadcasting operations of vehicles info in the highway environment.

Input: *Vehicles n*

Process:

1. *UAV (Drone) broadcast a beacon message in every 0.5 second within its own range*
2. ***While** (Vehicle (on-board drone) received a beaconed message) **Do***
3. *Drone sense a current position of vehicles // by GPS*
4. *Drone sense a current speed of vehicles // by Accelerometer*
5. *Drone sense a current total number and ID of vehicles // by counter*
6. *IF (the current speed of one of vehicles >= 70 km/h) // from L_1 and/or L_2*
7.   *The Drone tag all of the above sensed information in Safety Info module // L*
8.   *Drone broadcast the tagged packet within its own coverage area*
9. *ENDIF*
10. *ELSE*
11.   *IF (the current speed of all vehicles < 70 km/h) // from L_1 and/or L_2*
12.   *IF (L_1 && L_2 exist)*
13.   *The Drone tag L_1 and L_2 in different Traffic Info Modules*
14.   *Drone broadcast the tagged packets within its own coverage area*
15.   *ENDIF*
16.   *ELSE*
17.   *IF (L_1 || L_2 exist)*
18.   *The Drone tag L_1 or L_2 in a single Traffic Info Module*
19.   *Drone broadcast the tagged packet within its own coverage area*
20.   *ENDIF*
21.   *ENDIF*
22. *END**While***

Output: *Vehicles Info in highway environment is sensed, tagged and broadcasted in a MAVLink packet*

Algorithm 4.1: Algorithm for UAV's Sensing, Tagging and Broadcasting Operations of Drone-mounted Vehicles Info

4.2.2 The Proposed Forwarding Model of the Tagged Information to Infrastructures

After accomplished the operations of sensing, tagging and broadcasting information by UAV, the actual forwarding of the sensed information to the respective infrastructures will proceed via UAV's GCS. In this phase, I have used one of the above models of tagged information which capable to optimize the forwarding schemas as shown in Figure 4.5, Algorithm 4.2 and Algorithm 4.3. I have discussed the forwarding process as follows.

After UAV broadcasted the tagged information within its own transmission range, the drone-mounted ground vehicles and GCS within UAV's transmission range will receive the broadcasted packet via LOS or direct radio link of IEEE 802.11b communications. Then the GCS will proceed again the inspection process that the received packet as for whether it is safety or traffic information depending on the packet's tagged vehicles speed.

If there is a safety information that a high vehicles speed from the accepted one (70 km/h), the GCS will forward it to the LTE-enabled vehicles through the LTE/4G core network to satisfy the nature of the information/application that required a high data rate and coverage area as shown in Fig 4.5 and Algorithm 4.2. During this forwarding process, the tagged packet will be an EPS bearer deliberately by EPC server or LTE/4G core network because the eNB has only process and propagate an EPS bearer packets within its own cell.

Whereas, if there is a traffic information that the speed of all vehicles is less than the accepted one (70 km/h) in *L1* and/or *L2*, the GCS will forward the information to the respective RSUs. In other word, if the GCS will receive *L1* in a single MAVLink packet, then GCS will only forward it to RSU 2 as shown in Fig 4.5 and Algorithm 4.3 because *L1* is most mandatory for smart ground vehicles moving from right to left and found within a coverage area of RSU 2. While if the GCS will receive *L2* in a single MAVLink packet, then GCS will only forward it to RSU 1 as shown in Fig 4.5 and Algorithm 4.3, because *L2* is most significant for smart ground vehicles those moving from left to right and being within transmission range of RSU 1. Otherwise, if the GCS will receive *L1* and *L2* in different single MAVLink packets, then GCS will forward *L1* to RSU 2 and *L2* to RSU 1 concurrently. Generally, I have assumed that proposed forwarding schemes of traffic information to RSUs will minimize the bandwidth usage when the RSUs broadcast the information to WAVE-enabled vehicles within their own coverage areas.

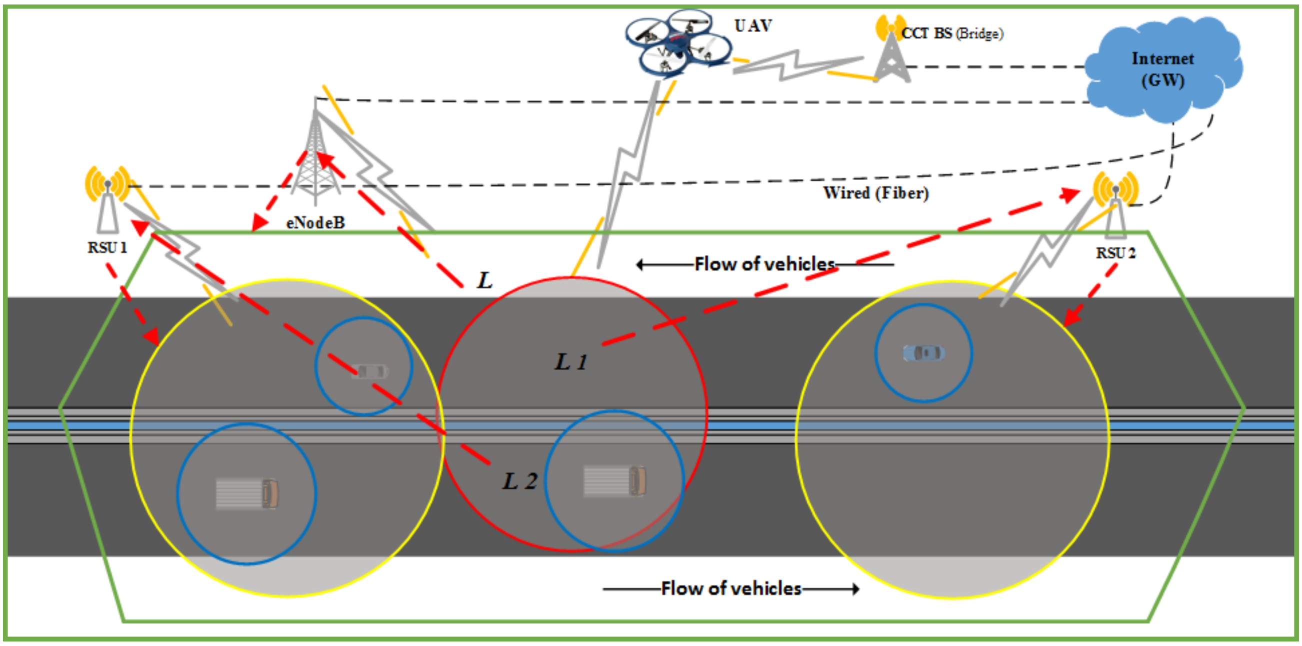


Figure 4.5: The Proposed Forwarding Schemes of the Sensed Information (Tagged Packets)

4.2.3 Propagating the Sensed Information to the Target Smart Ground Vehicles

As demonstrated in Figure 4.5, propagating the forwarded Information to the target smart ground vehicles is designed.

When a GCS forward a safety information to 4G-enabled vehicles via EPC server or LTE/4G core network, the eNodeB will be used to broadcast the information with EPS to the 4G-enabled vehicles within the eNB cell as shown in Fig 4.5 and Algorithm 4.2. In order for this, all 4G-enabled vehicles present in eNB cell will receive the safety information. As I have discussed in Chapter 2, the safety applications require a high data rate and coverage area because they are delay-sensitive applications. Besides, in Chapter 3 I have discussed that LTE/4G network has a high data rate and coverage area. Due to this, the proposed safety info forwarding model will realize the above mentioned circumstances.

Whereas, when a GCS forwards a traffic information to RSUs, the RSUs will broadcast the information to the WAVE-enabled vehicles found in the coverage area of RSUs. In other word, when GCS forwarded *L1* to RSU 2, then the RSU 2 will immediately broadcast it to WAVE-enabled vehicles within its own transmission range. While, when GCS forwarded *L2* to RSU 1, the RSU 1 will instantly broadcast it to vehicles within its own coverage area. Otherwise, when GCS simultaneously forwarded *L1* and *L2* to RSU 2 and RSU 1 respectively, then the RSU 2 will broadcast *L1* and RSU 1 will broadcast *L2* to vehicles within their own transmission ranges as shown in Fig 4.5 and Algorithm 4.3.

Algorithm 4.2 shows the pseudo code of the proposed forwarding and propagating schemas of safety information to the target 4G-enabled vehicles.

Input: *Vehicles n*

Process:

1. ***While*** *(GCS received the broadcasted tagged packet from UAV)* ***Do***
2. *IF (the speed of one of vehicles >= 70 km/h)* *// check L by GCS*
3. *GCS forward the tagged packet (L) to all LTE/4G-enabled vehicles via EPC server and eNB cell*
4. *ENDIF*
5. *END**While***

Output: *The safety information is broadcasted to all LTE/4G-enabled vehicles*

Algorithm 4.2: Algorithm for Forwarding and Broadcasting of Safety Info to 4G-enabled Vehicles

Algorithm 4.3 shows the pseudo code of the proposed forwarding and propagating schemas of traffic information to respective RSUs and WAVE-enabled vehicles respectively.

Input: *Vehicles n*

Process:

```
1.  While (GCS received the broadcasted tagged packet from UAV) Do
2.        IF (the speed of all vehicles < 70 km/h)        // L1 and/or L2
3.            IF (the broadcasted packet is L1 only)
4.                GCS forward L1 to RSU 2
5.                RSU 2 broadcast L1 to WAVE-enabled vehicles within its own
                  transmission range
6.            ENDIF
7.        ELSE
8.            IF (the broadcasted packet is L2 only)
9.                GCS forward L2 to RSU 1
10.               RSU 1 broadcast L2 to WAVE-enabled vehicles within its own
                  transmission range
11.           ENDIF
12.     ELSE
13.           IF (the broadcasted packets are L1 and L2)
14.               GCS forward L1 to RSU 2 and L2 to RSU 1 simultaneously
15.               RSU 2 broadcast L1 and RSU 1 broadcast L2 to WAVE-enabled
                  vehicles within their own transmission ranges
16.           ENDIF
17.     ENDIF
18. ENDWhile
```

Output: *The traffic information is forwarded and broadcasted to respective RSUs and WAVE-enabled vehicles*

Algorithm 4.3: Algorithm for Forwarding and Broadcasting of Traffic Information to Respective RSUs and WAVE-enabled Vehicles

4.2.4 The Proposed General Architecture States

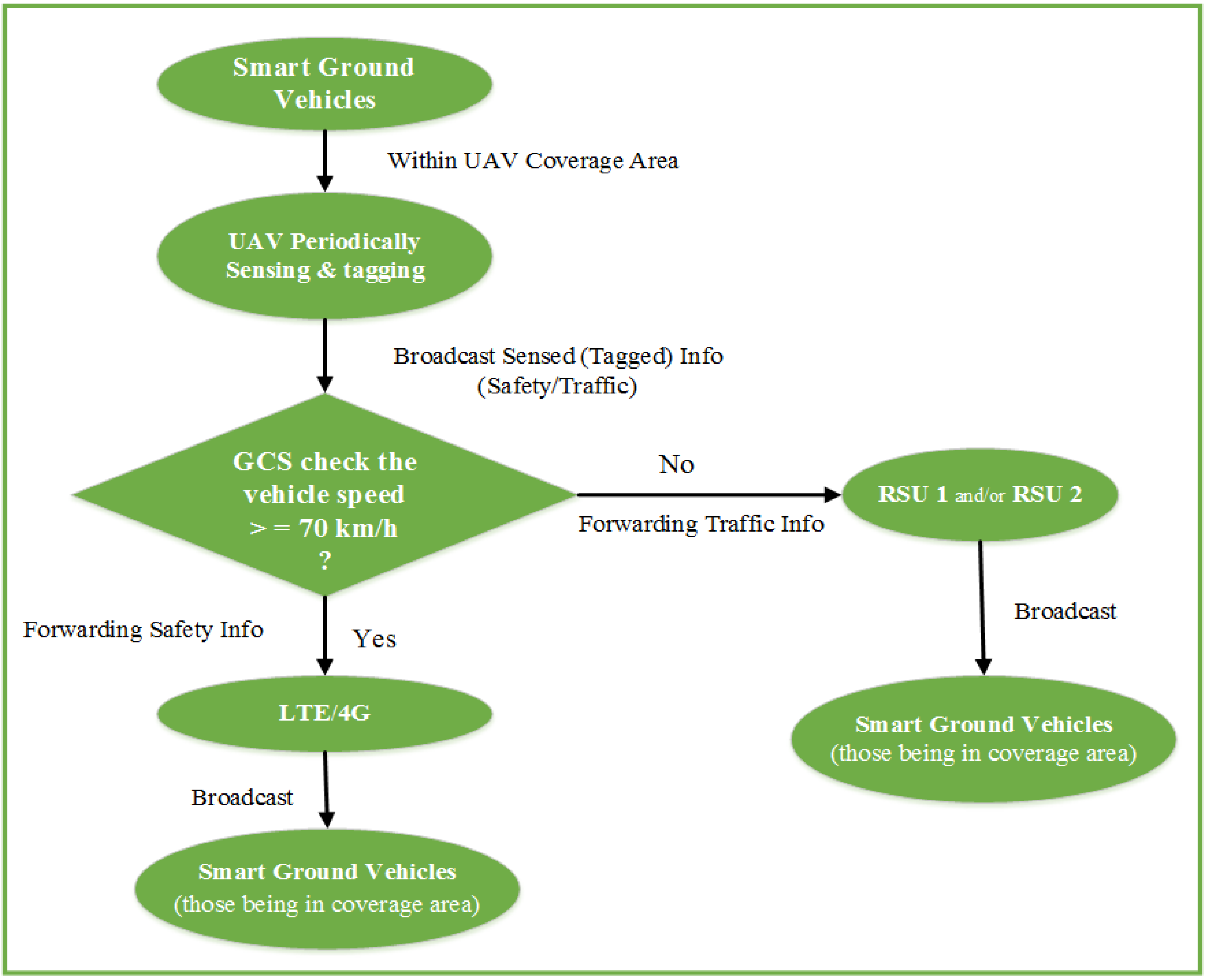


Figure 4.6: The Proposed General Architecture States

Fig 4.6 demonstrates the states of the proposed general architecture that will be implemented as the general proposed system. In these states, the smart ground vehicles are considered as the main input to proceed the UAV's sensing and tagging operations. As I have shown in the figure when the smart ground vehicles present in the coverage area of UAV then the operations of UAV's periodically sensing and tagging will be continued. The UAV senses the current states of smart ground vehicles (on-board drone vehicles) by using its different sensors, specifically GPS, Accelerometer and Counter. After sensing operation accomplished, immediately the tagging operation will be proceeded based on the proposed model of safety and traffic information as I have discussed in Section B. When the UAV finished the tagging process, it will broadcast the tagged packet within its own coverage area.

4.3 Summary

In this chapter, I have discussed the general designed proposed solution in highway scenario that the integration of UAV System with LTE/4G and WAVE wireless access network technologies in order to improve the VANET communications and satisfy its basic applications (safety/traffic) requirement.

I have presented and discussed the designed novel architecture as low-level and high-level architectures in highway scenario. In low-level architecture, I have designed three basic wireless network infrastructures (UAV System, LTE/4G and RSUs) with their respective positions. Whereas in the high-level architecture, I have designed four core modules those are UAV System, LTE/4G, RSUs and Smart Ground Vehicle modules.

The deigned novel architecture has two principal operations. These are UAV's periodically sensing of vehicles information in highway environment and tagging them in MAVLink packets, and forwarding of the sensed information (tagged packets) to the respective wireless access network infrastructures (LTE/RSUs). In the first operation that UAV's periodically sensing of vehicles information in highway environment and tagging them in MAVLink packets, I have used the UAV's GPS, Accelerometer and Counter sensors (their functions) to detect the current states of smart ground vehicles those being UAV's coverage area. After accomplished the sensing operation, I have proceeded the tagging operation based on the proposed model of safety and traffic info. Finally, the GCS has forwarded the broadcasted tagged packet from UAV to the respective infrastructures based on the types of info/application. Then, after the respective infrastructures received the forwarded packet from GCS, they have broadcasted the tagged packet to smart ground vehicles within their own transmission ranges.

Chapter Five: Implementation and Evaluation

5.1 Overview

To date, the majority of VANET research efforts have relied greatly on simulations, due to excessive costs of engaging real-world experiments. Current VANET simulators have gone a long way from the early VANETs simulation environments, which often assumed unrealistic models such as random way-point mobility, circular transmission range, or an interference-free environment. However, substantial efforts still remain in order to improve the practicality of VANET simulators, at the same time providing a computationally low-priced and competent platform for performance evaluation of VANET. Simulation of VANET routing protocols and its applications [52] is fundamentally different from MANETs simulation because in VANETs, vehicular environment impose new issues and requirements, such as multi-path fading, roadside obstacles, trip models, traffic flow models, traffic lights, traffic congestion, vehicular speed and mobility, driver's behavior and etc. Generally, there are three key building blocks of VANET simulators. These are traffic mobility, networking (data exchange) and signal propagation (radio) models [53].

Models of traffic mobility deal with a realistic demonstration of vehicular movement, including mobility configurations such constraining vehicular mobility to the actual roadway, interactions between the vehicles like speed adjustment based on the traffic conditions, and traffic rule enforcement such as intersection control through traffic lights and/or road signs. The traffic mobility models are modeled through traffic simulation software. Traffic simulators focus on vehicular mobility and it generates a trace file which provides realistic vehicles movement. These trace files have fed into network simulators which define the realistic position of each vehicle during the network simulation. Generally, there are many types of traffic simulators as I have discussed in Section 5.2.1.

Networking models are designed to provide realistic data exchange, including simulating the medium access control (MAC) mechanisms, routing, and upper layer protocols. The network simulator has taken the trace files of traffic simulator and implements the VANET protocols and produces a trace file which provides a complete information about the events taking place in the scenario. The common VANET's network simulators are discussed in Section 5.2.2.

Models of signal propagation intention at realistically modeling the complex environment surrounding the communicating vehicles, including both static objects such as buildings, overpasses and hills, and as well as mobile objects other than the vehicles on the road.

Due to prohibitive costs and intensive labor of employing VANET (smart ground vehicles and RSUs) and the wireless access network technologies (UAV System and LTE/4G) in real-world testbeds, we have implemented and evaluated the proposed integrated novel architecture with its forwarding schemes using a simulated and integrated VANET environment with wireless access infrastructures.

The implementation detail description of this work is presented in various Sections of this Chapter. Section 5.2 describes the development environment employed to implement the architecture. Section 5.3 presents the implementation description of the various components. In Section 5.4, the simulation experiment and evaluation result are described. Finally, I summarize the Chapter in Section 5.5.

5.2 Development and Simulation Tools

The selection of development environment and simulation tools that were used for implementation and evaluation of the proposed solution is described in this Section. First, I have discussed different types of vehicle traffic mobility simulators in Section 5.2.1 and then I have presented basic types of VANETs network and integrated simulators as shown in Section 5.2.2. Furthermore, all traffic mobility and network simulators have varied factors to be considered in simulating a VANETs environment. Thus, selecting an appropriate traffic mobility and network simulators and assessing which they will provide a realistic vehicle mobility model, optimum performance, and appropriateness of traffic and network simulators for implementing and evaluating the proposed work is essential.

5.2.1 VANETs Traffic Mobility Generators

Here I have summarized surveys and comparative studies on some VANETs traffic mobility simulators as follows:

In [52], authors have described and analyzed VANETs traffic mobility simulators like SUMO, VanetMobiSim, MOVE, FreeSim, and Citymob. The analyses done for these simulators are on the basis of their features like portability, freeware, XML based trace support, GUI support, ease of use, user-defined map and available examples. After comparison of these simulators on the basis of their features given above, the authors recommended that SUMO and VanetMobiSim should be the best choice when support all traffic models and good software features are considered for research work.

In [54], various traffic mobility generators like VanetMobiSim, TranSim, SUMO, and MOVE are evaluated. The authors have examined these simulators in languages support, weaknesses and strengths. Based on this assessment, SUMO is highly portable, functional across various scenarios, designed for use in traffic strategies and enhancement of route layout.

5.2.2 VANETs Network and Integrated Simulators

In this section, we have summarized surveys and comparative studies on some VANETs network and integrated simulators as follows:

In [52], authors have described and examined VANETs network simulators like NS-2, OPNET, GloMoSim, and QualNet. While they have also presented and analyzed VANETs integrated simulators (traffic and network) such as GrooveNet, TraNS, and NCTUns. The analyses done for network simulators are on the basis of their features like GUI support, distributed simulation support, scalability, antenna support, and multiple wireless technologies support. Based on this assessment, OPNET and QualNet have supported all the above mentioned features though they are not free and does not support real mobility pattern of vehicles. Besides, NS-2 does not support multiple wireless technologies. Whereas, the integrated simulators have evaluated based on some metrics such as mobility generator, VANET built-in application Support, intersection model, trip model and road topology. Based on the evaluation results, almost all the mentioned integrated simulators have not supported a realistic mobility model.

In [54], various network simulators like NS-2, OPNET, and OMNET are assessed. Whereas, they have also discussed VANETs integrated simulators like SWANS++, GrooveNet, TraNS, and NCTUns. The examines done for network simulators are on the basis of their features like languages support, weaknesses and strengths. The results of these both examines are almost similar with the general assessment outcomes that mentioned in [52].

In [55], NS-3 allows handle large-scale scenarios, with even 10,000 nodes and support multiple wireless interfaces in a single node. Furthermore, it is an open source with GNU licensed.

As I have observed from the surveys and comparative studies [52], [54], [55], SUMO is the best choice as a traffic mobility generator which provides realistic mobility model, functionality in different scenarios and high portability of trace file for VANETs. While from VANETs network simulators, NS-3 is the preferred one regards to supporting multiple wireless interfaces in a single node and freely available or non-commercial. Thus, I have selected SUMO as a traffic mobility generator and NS-3.25 as a network simulator for implementing and evaluating the proposed novel architecture.

SUMO [56] is stands for Simulation of Urban Mobility (SUMO), it is an open source, highly portable microscopic road traffic simulation package that deals very large number of nodes in VANET. It can be used on most of the operating system. Because of high portability and its GNU General public license, SUMO has become more popular and most widely used in vehicular ad hoc networks.

It has progressed into a full-featured suite of traffic modeling utilities uses own formats for traffic demand generation and road networks and routing utilities. The main merits of SUMO are that it is OpenGL GUI based, generate a real traffic mobility, highly portable, open source, easy simulation set-up, portable libraries, collision-free movement, imports different formats and a large number of the map defined for better understanding.

NS-3 [55] is a discrete-event network simulator, directed primarily for educational and research use. It is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use. The NS-3 project has started since 2006, it is not a backward-compatible extension of NS-2; it is a new simulator. The two simulators are both written in C++ but NS-3 is a different simulator that does not support the NS-2 APIs and it allows coding in C++ and Python to simulate a simple and complex networking scenarios. NS-2 some models have already been exported to NS-3, and the NS-3 project will continue to maintain NS-2 while NS-3 is being built, and will study transition and integration approaches. Furthermore, NS-3 has support two kinds of visualizers, PyViz and NetAnim. PyViz is standing for Python Visualization, a default live simulation tool of NS-3 that programmed in Python script but it is not attractive. While NetAnim is shorts for Network Animator, an offline animator based on the Qt toolkit and use an XML trace files that generated by NS-3. Hence, besides PyViz, I have used the NetAnim visualizer to emphasis the user interface of the simulation.

5.3 Prototype Implementation

In the previous section, the necessary tools are identified for designing and implementing of the integrated novel architecture. This section describes the configuration and implementation detail of the different components of the architecture, and discusses their challenges.

5.3.1 Smart Ground Vehicles Configuration and Implementation

Before implementing the network configuration of smart ground vehicles, I have produced a real mobility model of the vehicles via SUMO simulator. I have assumed that in real highway scenario there are a few number of vehicles present at the same time. And also I have interested to implement and evaluate the integrated architecture in the sparsest network (very less number of vehicles). Thus, as I have shown in Fig 5.1, I have generated a real mobility model in highway scenario with 8 and 12 vehicles respectively.

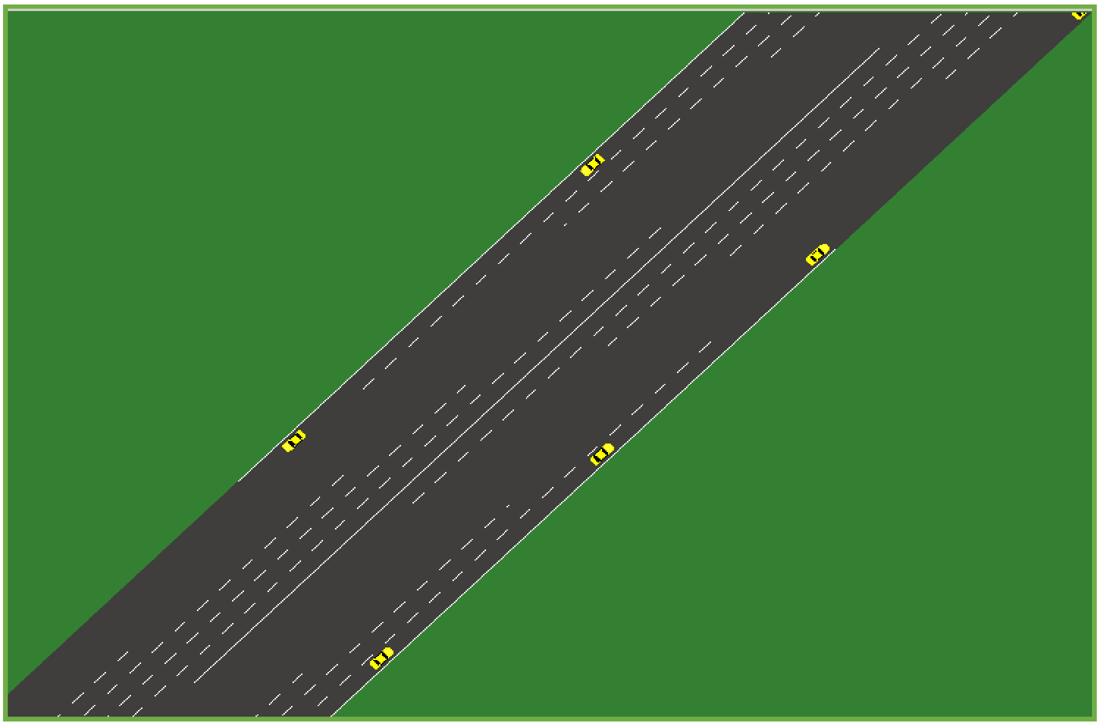


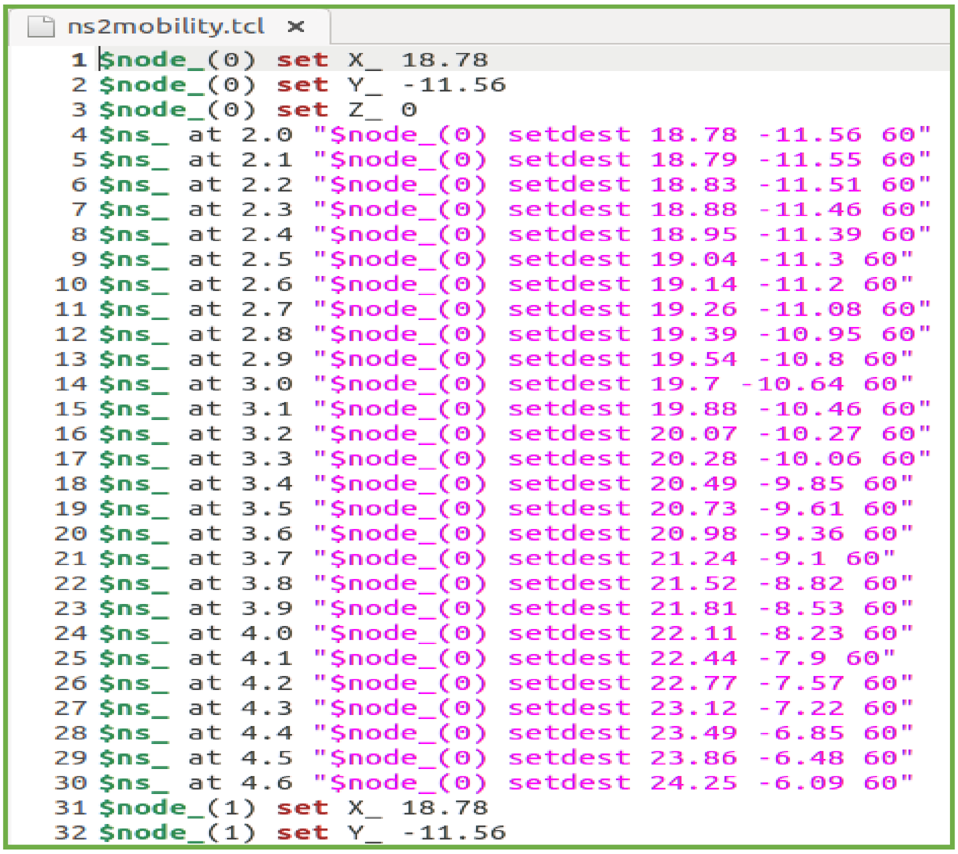
Figure 5.1: Sample Mobility Model of vehicles in Highway Scenario

In this generation of mobility model, I have used an ordinary (conventional) vehicles/cars those will transform to smart ground vehicles during network configuration. Generally, I have summarized the mobility generation parameters in Table 5.1.

Table 5.1: Summary of Generation of Mobility Model Parameters

Parameter	**Value**
Number of ordinary vehicles	8 and 12
Type of street	Highway
Number of lanes	2 with different direction
Delay between vehicles	40 milliseconds
Simulation area (m x m)	100 x 100
Simulation time	50 seconds

As I have mentioned in Section 5.2.2, SUMO is highly portable microscopic road traffic simulation package or its trace files (XML files) can export to different network simulators such as NS-3. However, NS-3 is programmed with C++ and Python, so it primarily used a Tcl and py extension files. Thus, before I start the actual network configuration of vehicles, I have converted the generated trace file of vehicles mobility model to Tcl file which is readable via NS-3 network simulator as shown in Fig 5.2.



ns2mobility.tcl

```
$node_(0) set X_ 18.78
$node_(0) set Y_ -11.56
$node_(0) set Z_ 0
$ns_ at 2.0 "$node_(0) setdest 18.78 -11.56 60"
$ns_ at 2.1 "$node_(0) setdest 18.79 -11.55 60"
$ns_ at 2.2 "$node_(0) setdest 18.83 -11.51 60"
$ns_ at 2.3 "$node_(0) setdest 18.88 -11.46 60"
$ns_ at 2.4 "$node_(0) setdest 18.95 -11.39 60"
$ns_ at 2.5 "$node_(0) setdest 19.04 -11.3 60"
$ns_ at 2.6 "$node_(0) setdest 19.14 -11.2 60"
$ns_ at 2.7 "$node_(0) setdest 19.26 -11.08 60"
$ns_ at 2.8 "$node_(0) setdest 19.39 -10.95 60"
$ns_ at 2.9 "$node_(0) setdest 19.54 -10.8 60"
$ns_ at 3.0 "$node_(0) setdest 19.7 -10.64 60"
$ns_ at 3.1 "$node_(0) setdest 19.88 -10.46 60"
$ns_ at 3.2 "$node_(0) setdest 20.07 -10.27 60"
$ns_ at 3.3 "$node_(0) setdest 20.28 -10.06 60"
$ns_ at 3.4 "$node_(0) setdest 20.49 -9.85 60"
$ns_ at 3.5 "$node_(0) setdest 20.73 -9.61 60"
$ns_ at 3.6 "$node_(0) setdest 20.98 -9.36 60"
$ns_ at 3.7 "$node_(0) setdest 21.24 -9.1 60"
$ns_ at 3.8 "$node_(0) setdest 21.52 -8.82 60"
$ns_ at 3.9 "$node_(0) setdest 21.81 -8.53 60"
$ns_ at 4.0 "$node_(0) setdest 22.11 -8.23 60"
$ns_ at 4.1 "$node_(0) setdest 22.44 -7.9 60"
$ns_ at 4.2 "$node_(0) setdest 22.77 -7.57 60"
$ns_ at 4.3 "$node_(0) setdest 23.12 -7.22 60"
$ns_ at 4.4 "$node_(0) setdest 23.49 -6.85 60"
$ns_ at 4.5 "$node_(0) setdest 23.86 -6.48 60"
$ns_ at 4.6 "$node_(0) setdest 24.25 -6.09 60"
$node_(1) set X_ 18.78
$node_(1) set Y_ -11.56
```

Figure 5.2: Sample Generated Mobility Model of vehicles in Tcl File

After accomplishing the generation and conversion of vehicles realistic mobility model, I have proceeded the network configuration of the vehicles or operation of transformation from ordinary vehicles to smart ground vehicles. As I have demonstrated in Fig 4.4, the on-board of the smart ground vehicles in communication interface layer have mounted IEEE 802.11p (WAVE), LTE/4G (E-UTRAN) and IEEE 802.11b (on-board drone) interfaces. As an initial step of the configuration, I have directly imported the mobility Tcl file or I have called the full path of the file to use the generated vehicles mobility in NS-3.

5.3.1.1 WAVE Interface Configuration on Vehicles

I have configured the IEEE 802.11p communication interface on-board the vehicles to acquire a traffic information when the RSUs broadcast it within their own coverage area. To configure the interface, I have primarily used *YansWifiPhyHelper* and *WaveMacHelper* [55] of NS-3 helpers which are implemented on PHY and MAC layers of vehicles respectively.

By using these NS-3 helpers, I have configured a few basic attributes for vehicles on PHY and MAC layers correspondingly as I have shown in Table 5.2. And the attributes are combined and installed in a single communication interface of vehicles via *Wifi80211pHelper*. Then, we have provided IPv4 network address for the interfaces to enable IP communication between vehicles and RSUs (V2I downlink communication).

Table 5.2: Attributes of WAVE Interface on Vehicles

Attribute	Value
Network address	10.1.2.0/24
Transmission radio range	250 to 300m
Channel width	10MHz
Number of transceiver antenna	1
Propagation delay	Constant Speed Propagation Delay Model [55]
Energy Detection Threshold	default
Rx Noise Figure	default (1dB)

However, as I have discussed in Chapter 4, I have designed and considered a downlink communication only, and it has highly depended on the coverage area of the infrastructure instead of the vehicle range. Thus, the WAVE transmission range of vehicles is not significant during actual simulation.

5.3.1.2 E-UTRAN Interface Configuration on Vehicles

I have configured the LTE/4G communication interface on-board the vehicles to get a safety information when the eNB broadcast it within its own cell. To configure the E-UTRAN interface, I have used NS-3 *LteSpectrumPhy* that implement on PHY layer and *LteHelper* [55] which takes care of the configuration of the LTE radio access network, as well as of coordinating the setup and release of EPS bearers. Based on the helpers, I have configured some common attributes for vehicles and eNB as demonstrated in Table 5.3. Furthermore, I have provided IPv4 network address for the interface of vehicles to enable a communication with a remote host via LTE/4G core network (EPC server) such as a communication with UAV's GCS (V2I downlink communication).

Table 5.3: Attributes of E-UTRAN Interface on Vehicles

Attribute	Value
Network address	7.0.0.0/8
Control Error Model	true (ON)
Data Error Model	true (ON)
RRC	true (ON)
PDSCH CQI generation	true (ON)
AMC Model	default (PiroEW2010)

5.3.1.3 IEEE 802.11b Interface Configuration on Vehicles

Here, I have discussed the configuration of the IEEE 802.11b communication interface on on-board of vehicles to acquire UAV's beaconed message, and tagged information when the UAV broadcast it within its own coverage area.

To configure the interface, I have used *YansWifiPhyHelper* and *WifiMacHelper* [55] of NS-3 helpers which employed on PHY and MAC layers of vehicles respectively. By using the helpers, I have configured some basic attributes for vehicles on PHY and MAC layers correspondingly as I have shown in Table 5.4. And the attributes have combined and installed in a single communication interface of vehicles via *WifiHelper*.

Then similarly with Section 5.3.1.1, I have provided IPv4 network address for the interface of vehicles to enable IP communication between vehicles and UAV (V2I downlink communication).

Table 5.4: Attributes of IEEE 802.11b Interface on Vehicles

Attribute	**Value**
Network address	10.1.4.0/24
Transmission radio range	150 to 200m
Number of transceiver antenna	1
Propagation delay	Constant Speed Propagation Delay Model [55]
Energy Detection Threshold	default
Rx Noise Figure	default (1dB)

Similarly, as Section 5.3.1.1, the IEEE 802.11b transmission range of vehicles are not worth during actual simulation.

5.3.2 Long Term Evolution (LTE/4G) Configuration and Implementation

In this Section, I have described the LTE/4G wireless access infrastructure configuration and implementation regards to the integrated architecture. Actually, in this configuration, I have used two kinds of models, LTE and EPC model respectively.

In the LTE model, I have configured the eNodeB with its RRC at PHY layer by using NS-3 *LteHelper*. While in the EPC model, I have used NS-3 *EpcHelper* [55] which takes care of the configuration of the EPC server, to use as a gateway when the GCS broadcast a safety information to LTE-enabled vehicles. Furthermore, I have used NS-3 *PointToPointHelper* which is used to make a point-to-point wired link between EPC server and UAV's GCS. And finally, I have provided a network address for the point-to-point interfaces between EPC server (GW) and GCS to enable a wired IP communication. In Table 5.5, I have summarized the major attributes of the LTE/4G configuration.

Table 5.5: Attributes of LTE/4G Configuration

Attribute	Value
Network address (P2P)	10.1.1.0/24
Data rate (P2P)	500kbps
Delay (P2P)	2 milliseconds
Control Error Model	true (ON)
Data Error Model	true (ON)
RRC	true (ON)
PDSCH CQI generation	true (ON)
AMC Model	default (PiroEW2010)
DlEarfcn (for eNB)	default (100)
UlEarfcn (for eNB)	default (18100)

Figure 5.3 shows the broadcasting of safety information to all LTE-enabled vehicles using LTE/4G network when UAV's GCS forwarded the information via EPC server (GW). Actually, I have used NetAnim for visualization, and the dots where on the lines indicates the movement of the vehicles on their respective lanes, as well as each circle, represents the capacity of the eNB cell.

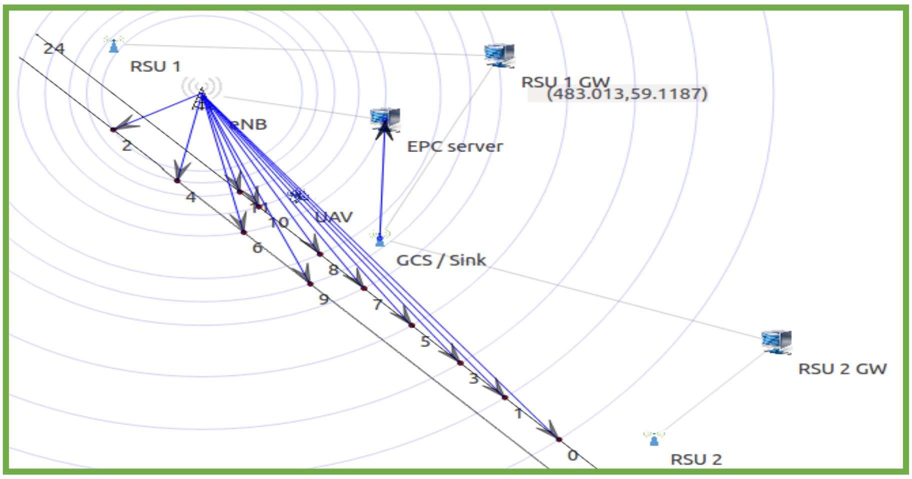


Figure 5.3: Sample Broadcasting of Safety Information via LTE/4G Network

5.3.3 Road Side Units (RSU 1 & RSU 2) Configuration and Implementation

Here, I have presented the configuration of RSU 1 & RSU 2 wireless access infrastructures. The RSUs configurations are similar with WAVE interface on vehicles configuration. However, the RSUs have their own gateways which are used to make communications with UAV's GCS. Moreover, I have provided three network addresses which one for the WAVE interfaces of RSUs (*10.1.3.0/24*), the second for the point-to-point interfaces between RSU 1 and its GW (*10.1.8.0/24*) and the third for the point-to-point interfaces between RSU 2 and its GW (*10.1.9.0/24*).

Figure 5.4 shows the RSU 1 broadcasting a traffic information to WAVE-enabled vehicles those being in RSU 1 coverage area when UAV's GCS forwarded the information via RSU 1 GW. Each circle indicates the capacity of the UAV and RSU 1 coverage area.

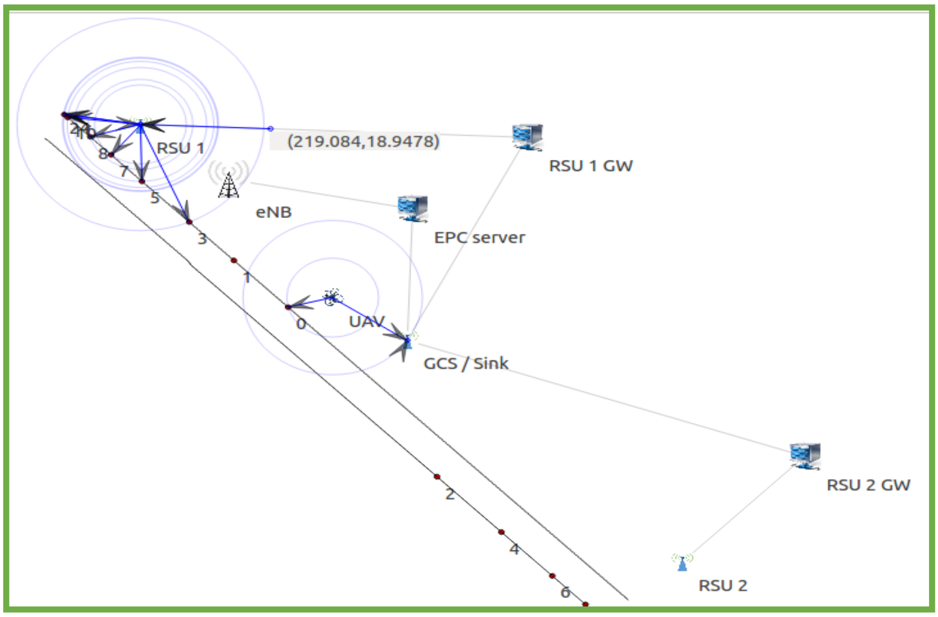


Figure 5.4: Sample Broadcasting of Traffic Information via RSU 1

5.3.4 UAV's Ground Control Station (GCS) Configuration and Implementation

The configuration and implementation UAV's GCS has discussed in this Section. In this configuration, there are some similarities with the configuration of IEEE 802.11b interface on on-board of vehicles such as regards to a number of transceiver antenna, energy detection threshold, and transmission range. However, I have used NS-3 *PointToPointHelper* which used to create point-to-point wired links between UAV'S GCS and EPC server, UAV's GCS and RSU 1 GW, and UAV's GCS and RSU 2 GW correspondingly. Furthermore, as I have stated in Sections 5.3.2 and 5.3.3, the GCS has also three IP address for its respective point-to-point interfaces. And again, it has another IP address for its own IEEE 802.11b interface that used to make IP-enabled downlink communication with UAV via LOS.

As I have discussed in Chapter 4, Figure 5.5 shows the UAV'S GCS forwarding a traffic information to RSU 1 via RSU 1 GW. The circles indicate the capacity of the UAV coverage area, as well as the arrows, represents UAV broadcasted the tagged info within its own transmission range and then GCS forwarded it to RSU 1.

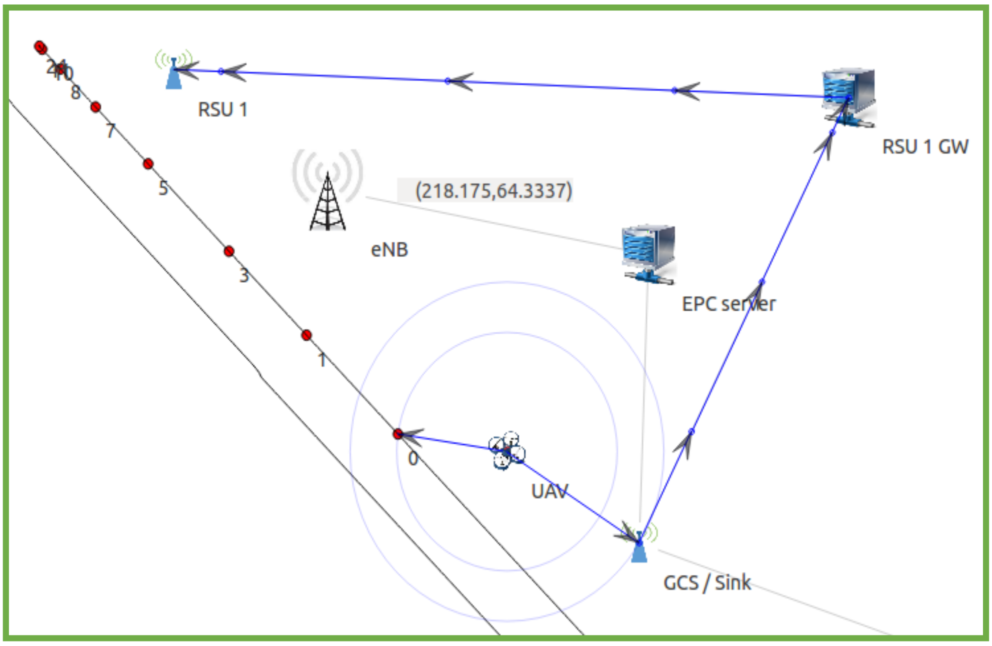


Figure 5.5: Sample Forwarding of Traffic Information from GCS to RSU 1

5.3.5 Unmanned Aerial Vehicle (UAV) Configuration and Implementation

In this Section, I have presented the network configuration and implementation of Unmanned Aerial Vehicle (Drone) as much as possible. As I have mentioned in Chapter 4, the UAV has about 10m height from the ground and a hovering motion. Based on these circumstances, I have configured some network parameters of UAV as almost similar as its GCS as shown in Table 5.6.

Table 5.6: Attributes of UAV (Drone) Configuration

Attribute	Value
Network address	10.1.4.0/24
Transmission range	150 to 200m
Height	~10m
Mobility	Hovering Motion
Number of transceiver antenna	1
Propagation delay	Constant Speed Propagation Delay Model [55]
Energy Detection Threshold	default
Rx Noise Figure	default (1dB)

Figure 5.6 shows the UAV sensing (tagging) and broadcasting operations within its own coverage area to on-board drone vehicles and its GCS via LOS. Actually, for sensing operation I have used *GetPosition()*, *GetVelocity()*, *GetReferenceCount()* and *GetId()* functions of sensors to detect the current position, speed, total number and ID of smart ground vehicles respectively. For tagging operation, I have adopted a tag header file of NS-3 [55], it is called "*steve.h*" as presented in Appendix B. Additionally, for broadcasting the tagged information, I have used *socket* $\longrightarrow$ *Send()* function.

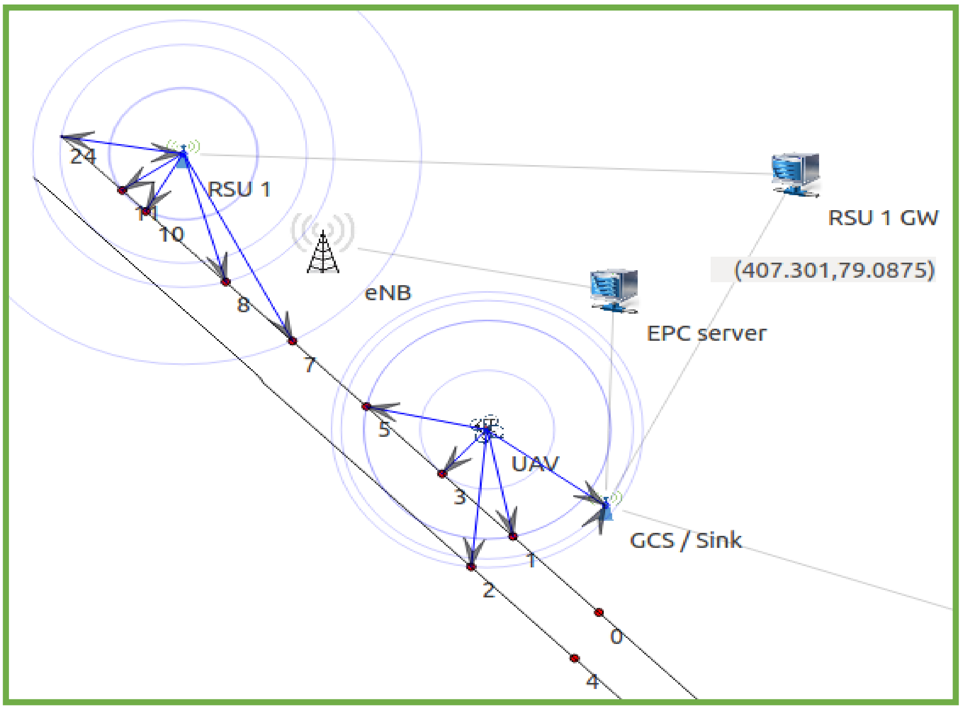


Figure 5.6: Sample Operations of UAV's Sensing (Tagging) and Broadcasting Vehicles Information

5.3.6 The Integrated Architecture Implementation and Challenges

Figure 5.7 shows the novel integrated architecture in NetAnim visualizer. In this architecture, I have used the entire configuration attributes which are demonstrated in Sections 5.3.1, 5.3.2, 5.3.3, 5.3.4 and 5.3.5 respectively. Generally, the integrated architecture has some major components and communications that presented in Table 5.7.

Table 5.7: Major Components/Communications of Integrated Architecture

No.	Name of Component/Communication	Total Number
1.	Wireless Access Network Infrastructures (UAV, RSU 1, RSU 2, eNB and GCS)	5
2.	Gateways (*RSU 1 & RSU 2 GWs, EPC server and GCS*)	4
3.	Smart Ground Vehicles	8 and 12
4.	Highway	1 with two-lanes
5.	Point-to-Point Wired Communications	6

As a remark, I have considered UAV's GCS as one of a component of wireless access network infrastructures and also a gateway, due to the GCS has a single IEEE 802.11b wireless interface and three point-to-point wired interfaces.

Furthermore, I have tackled by some challenges of the different components of architecture during their configuration and implementation phase. The primary challenge is the integrating of the three various protocols (standards), IEEE 802.11b, LTE/4G and IEEE 802.11p (DSRC/WAVE).

Though I have settled it by makings a different point-to-point wired communications via their different gateways (Internet). While the other challenge that when LTE/4G network broadcast the safety info to 4G-enabled ground vehicles within its cell, it has spent a mighty processing (simulating) time of NS-3. Hence, due to this fact, the simulation process of safety info broadcasting task via LTE/4G network is very sluggish. However, it has no relation with the performance of LTE/4G network. Besides, I have tried to overcome this sluggish problem by incrementing the simulation speed of NS-3 during actual simulation period.

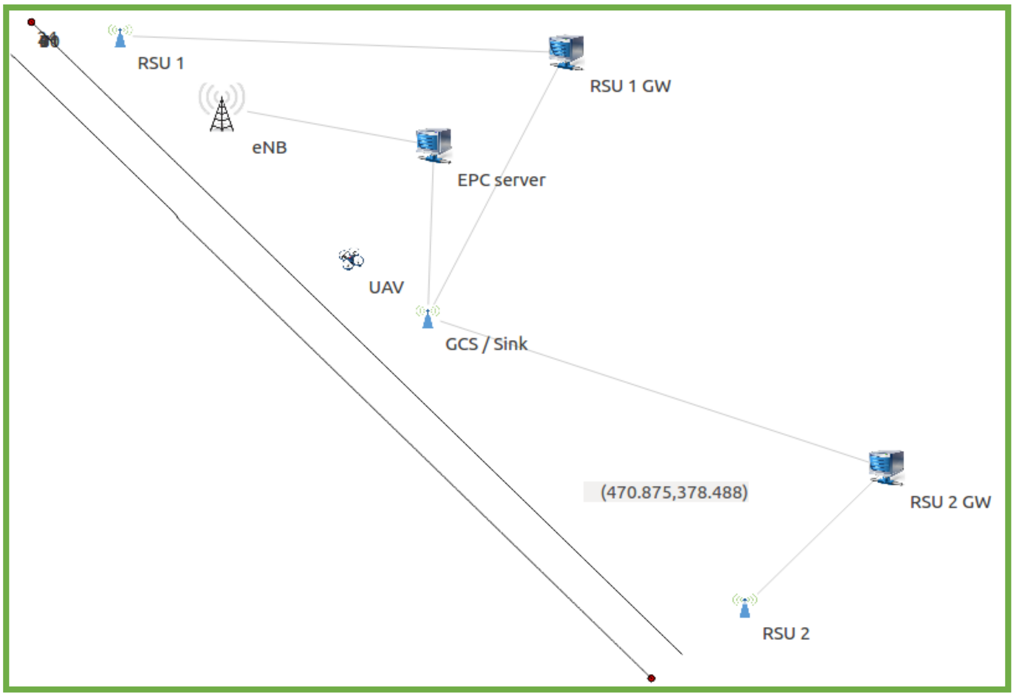


Figure 5.7: The Integrated Novel Architecture in NetAnim Visualizer

5.4 Simulation Experiment and Results

To test the performance of the proposed novel integrated architecture with its forwarding schemes, I have performed a simulation experiment and evaluation via different metrics. To achieve this, I followed the following procedure: first, I defined the simulation setup where it encompasses defining the configurations of integrated architecture as described in Section 5.4.1. Second, I determined the evaluation metrics that help us to observe the performance of the algorithms as mentioned in Chapter 4, and finally conduct and record simulation results in Section 5.4.2.

5.4.1 Simulation Setup

As I have discussed in Section 5.3.1, I have generated the Tcl file of vehicles real mobility model via SUMO simulator. Then, I have exported the Tcl file to NS-3 simulator to implement the network configurations of the integrated architecture with respects to the mobility model. The simulation period takes 50 seconds due to high speed of vehicles in highway scenario, as well as the simulation area is 740 m x 560 m. The different parameters are shown in Table 5.8.

Table 5.8: Summary of Simulation Parameters

Parameter	Value
Number of Smart Ground Vehicles	8 and 12
Type of street	Highway
Number of lanes	2 with different direction
Transmission range of UAV	150 to 200m
Transmission range of RSU 1 & RSU 2	250 to 300m
Data rate	500kbps
Scenario size (m x m)	740 x 560
Simulation time	50 seconds

5.4.2 Performance Evaluation Metrics and Results

In this section, in order to optimize the performance of VANET communications and satisfy the requirements of its basic applications (safety and traffic) via the integrated novel architecture with its forwarding schemes, I have evaluated the performance of the designed solution with existing work (basic principle of VANET communications in highway scenario that I have implemented as it has direct V2V and V2I communications/hybrid architecture [6], [18], [9], [10]). The designed solution is evaluated in terms of packet delivery ratio, mean (average) delay and total throughput. According to [55], the metrics are discussed as follows:

a) **Packet Delivery Ratio (PDR):** It is the ratio of a total number of delivered data packets to the total number of data packets transmitted by all sources. This evaluation metric will give us a concept of how well the designed solution is performing in terms of packet delivery at different network (vehicle) density.

b) **Mean Delay (MD):** It is the average time delay for data packets received. This metric is calculated by dividing the sum of all end-to-end delays for all received packets by total received packets. This might include the processing delay at intermediate nodes (GWs).

c) **Throughput (T):** It is the total number of delivered data packets divided by the total duration of simulation time. In this case, the throughput of each of the forwarding and broadcasting schemes in terms of a number of information delivered per one second is evaluated. Additionally, the throughput is measured in Mbps.

Based on the evaluation metrics, the performance of the integrated novel architecture with its forwarding schemes is evaluated using NS-3 with its flows monitor. Additionally, detail simulation parameters of UAV module are demonstrated in Appendix A.

Table 5.9: Performance Evaluation Results

	Network Size (#vehicle)	Total Packet Sent (#packet)	Total Packet Delivered (#packet)	Performance		
				PDR (%)	MD (second)	T (Mpbs)
Existing Work	8	1096	434	39	0.0683754	2.14379
	12	1939	777	40	0.0435663	2.49405
Integrated Novel Architecture	8	2297	1266	55	0.0197291	8.96427
	12	2086	1388	66	0.0193086	10.3705

After realizing extensive simulations with varied vehicle sizes regarding highway scenario for the defined parameters, vector, and scalar data are recorded and stored in a PCAP and spreadsheet files. The data can later be analyzed and transformed into a table as shown in Table 5.9, as well as demonstrated in a graph as follows:

To evaluate the ability of the integrated architecture to reliable delivery of packets, I have computed and compared the PDR achieved by a testing packet. In Table 5.9, I have shown the total number of packets sent and delivered to the destinations on the forwarding and broadcasting schemes.

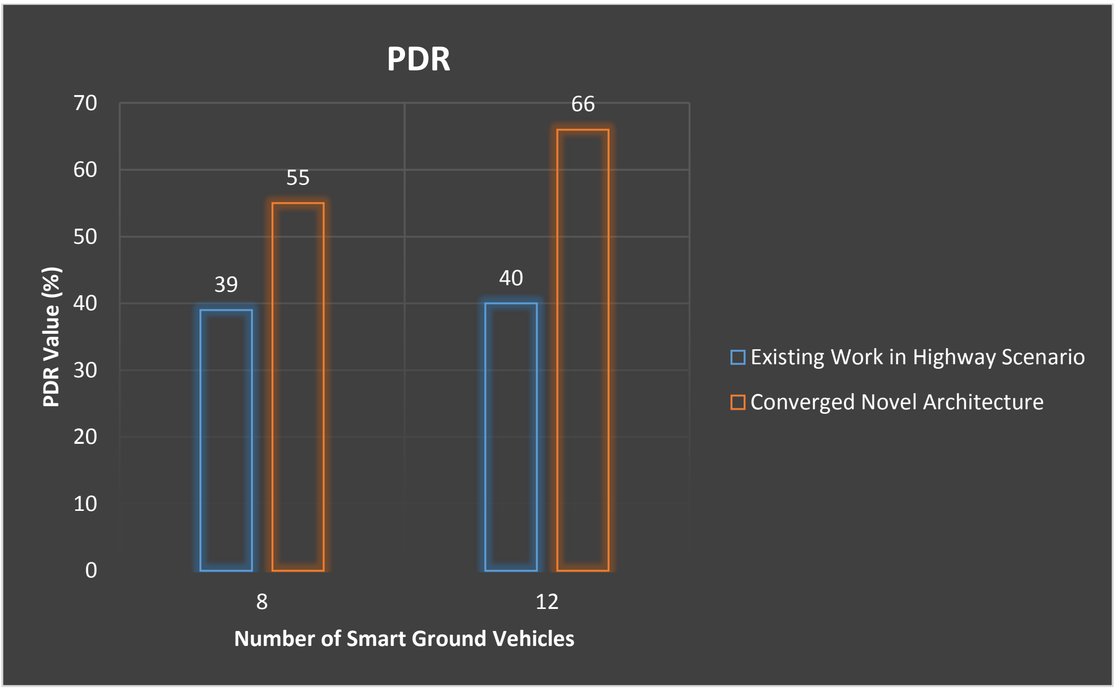


Figure 5.8: PDR Results for Integrated Architecture and Existing Work in Highway Scenario

Packet delivery ratio for the integrated architecture (broadcasting and forwarding safety and/or traffic information schemes) and existing work in highway scenario increases as the size of the smart ground vehicles (network) increases. This is because, at higher vehicles size, when the wireless access network infrastructures broadcast a packets/information, there is a high possibility that the presence of the vehicle in the infrastructures transmission range.

In order to this, the packets/information will be received by many vehicles. As shown Figure 5.8, compared with existing work in highway scenario, the proposed integrated novel architecture has the highest packet delivered ratio because I have used high capable wireless access infrastructures like LTE/4G and UAV System with a good forwarding and broadcasting schemes as I have demonstrated in Chapter 4, as well as I have not implemented a V2V communication directly, however, I tried to improve it through integrated infrastructures (V2I downlink communications). Moreover, the results revealed that the integrated architecture with its forwarding schemes has capable to minimize the intermittent connectivity (high packet loss) of a direct V2V communication.

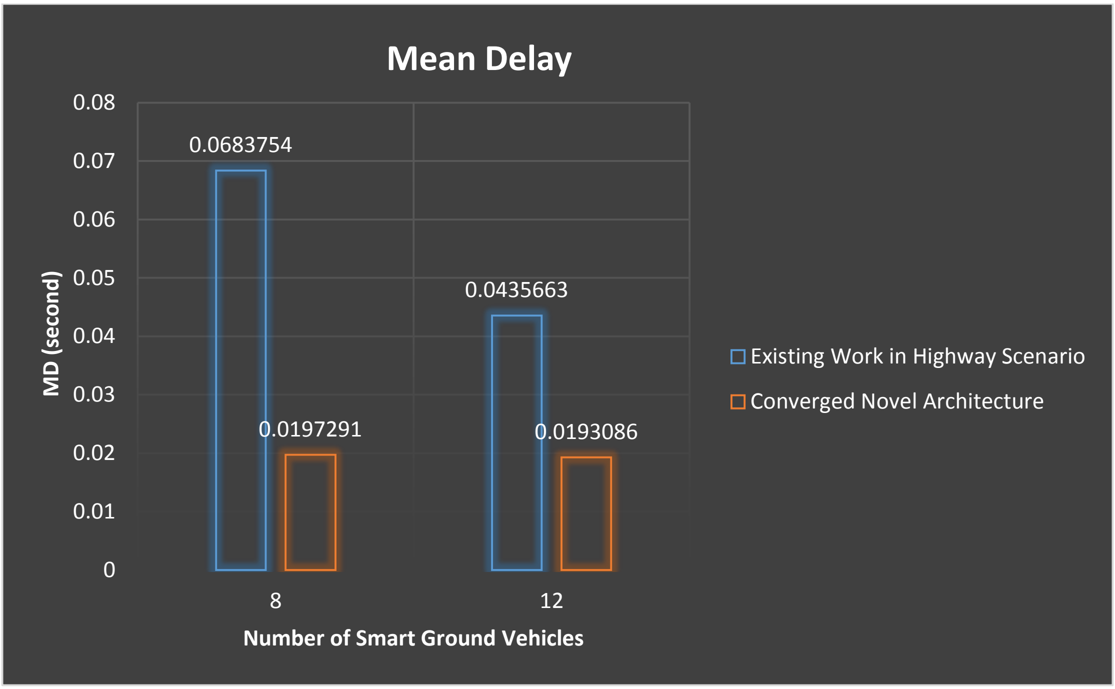


Figure 5.9: MD Results for Integrated Architecture and Existing Work in Highway Scenario

As I observe from the simulation results shown in Figure 5.9, the mean delay for both works decreases as the size of the smart ground vehicles (network) increases. This is due to the fact that if the number of vehicles increases within the transmission ranges of wireless access network infrastructures then the total number of received packets or PDR increases as I have mentioned in Figure 5.8. In other words, if the total number of packets/information delivered increases within the coverage areas of the infrastructures, the mean delay will dramatically fall because I have calculated mean delay as the sum of all end-to-end delays for all received packets divided by the total delivered packets. Furthermore, as can be seen from the graph, the proposed integrated architecture has revealed lower mean delay in all vehicles size than the existing work in highway scenario. This is because the architecture has used integrated infrastructures with optimized forwarding schemes those are capable to enhance the PDR and consequently the mean delay minimized. Furthermore, the results have revealed that the integrated architecture with its forwarding schemes has capable to achieve the requirement of delay-sensitive or high data rate required VANET applications (safety).

As can be seen from the Figure 5.10, the total number of packets/information which is effectively delivered by all destination smart ground vehicles within a simulation time increases in the network which is more efficient. This efficiency comes through well-optimized forwarding and broadcasting schemes via integrated infrastructures. As well as, the total throughput increases when the number of smart ground vehicles increases, this is because, if the number of smart ground vehicles increases within transmission range of infrastructures, the total number of delivered bytes/packets/information will increase as I have discussed in Figure 5.8.

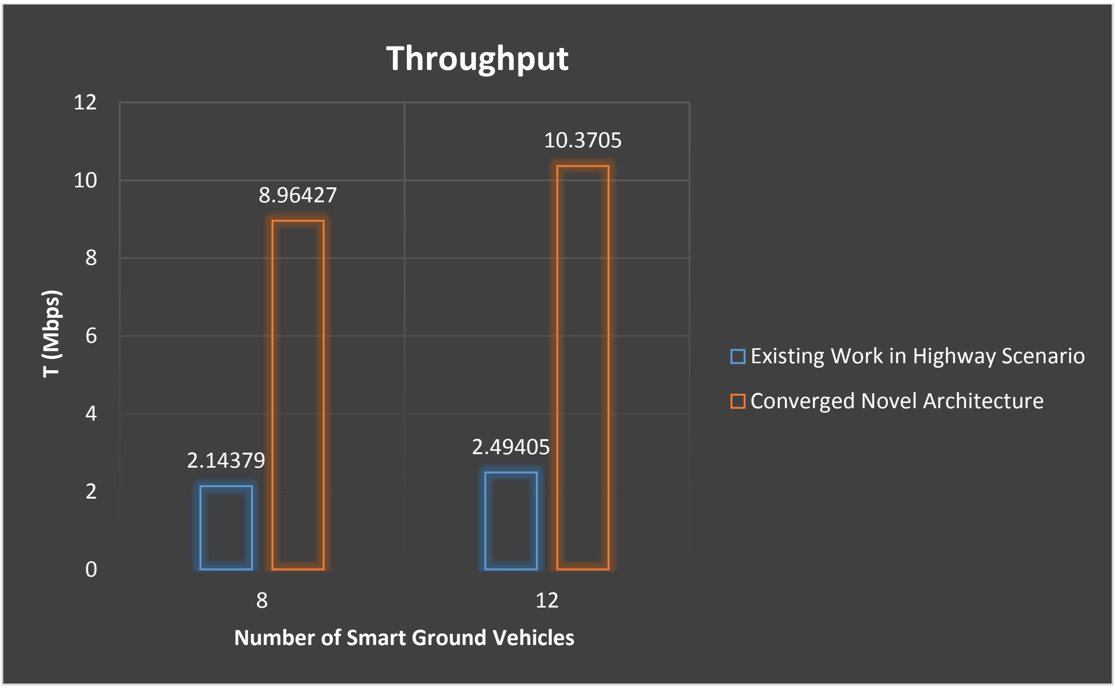


Figure 5.10: T Results for Integrated Architecture and Existing Work in Highway Scenario

Furthermore, from Figure 5.10, it can be observed that the performance of the proposed integrated novel architecture provided better packet/information delivery over the simulation time. This is due to the fact that applying the optimized forwarding schemes on the integrated architecture helps forwarding the information (safety/traffic) to appropriate destinations via right infrastructure. As a results, the forwarding schemes through the integrated architecture is very effective in delivering the safety/traffic information to appropriate smart ground vehicles within the specified simulation time. In other words, the results revealed that the integrated architecture with its forwarding schemes has proficient to achieve specifically the demand of delay-sensitive or high data rate required VANET applications (safety), and also it could have minimized that the bandwidth usage of periodically broadcast a beacon or Hello message by vehicles in existing work, because I have replaced it by UAV's operations and V2I downlink communications. Additionally, a higher value of total throughput requires higher packet delivery ratio and lower mean delay.

5.5 Summary

As the objective of performance optimizing of VANET communications in highway scenario, an integrated novel architecture was designed to satisfy the requirements of VANET basic applications (safety and traffic), minimize the intermittent connectivity of a direct V2V communication and bandwidth usage of periodically broadcasting a beacon or Hello message via smart ground vehicles. To compare it with the existing work (basic principle of VANET communications in highway scenario [11], [21], [57], [58], [59]), I conducted a simulation in an integrated environment of VANETs with wireless access network infrastructures (LTE/4G and UAV System) using SUMO and NS-3 simulators, and performed evaluation with different parameters. In all simulation parameters, the performance of the integrated architecture (network) increases with the increase of the number of smart ground vehicles. This is due to the increase in the number of smart ground vehicles within the coverage area of wireless infrastructures resulting in high probability of packet/information receiving and decreases the mean delay of the received packets/information.

The simulation experiment results show that the proposed integrated novel architecture provides a better performance for VANET communications and some basic applications in highway scenario with high throughput and packet delivery ratio, and minimizing delay. This is due to the fact that in the proposed integrated novel architecture, I was designed and implemented an optimized forwarding scheme regards to the right infrastructures. As I see the results, all the architecture evaluation metrics have worth performance which makes the proposed integrated novel architecture a nominee and foremost choice architecture for implementing (deploying) VANETs in highway scenario.

Chapter Six: Conclusion and Future Work

6.1 Conclusion

Presently, with the rapid development of Internet and mobile computing devices as well as evolution in different wireless access network technologies, Ad hoc networking is gaining prominence with its various types of networking and applications. One of the major types of Ad-hoc networking is a VANET that originated from the desire to ensure drivers and passengers safety and comfort in road transportation so as to reduce the risk of accidents on the roads. Typically, VANET has two types of communications regards to urban and highway scenarios, V2V and V2I communications respectively. However, achieving a high performance of VANET communications in highway scenario is very tough due to the high sparseness and swiftness of smart ground vehicles. To achieve a better performance, the wireless access network technologies/infrastructures and packet/information forwarding schemes in the network should be optimized, integrated in an efficient manner and high capacitated to do their operations.

In this work, an integrated novel architecture of UAV System, LTE/4G, and WAVE with its forwarding schemes to optimize the performance of VANET communications and satisfy the basic requirements of applications (safety and traffic) in highway scenario were discussed. For instance, to satisfy the requirements of safety application that a high data rate and coverage area, I have integrated and implemented LTE/4G network and UAV System (includes GCS) with their forwarding schemes. As well as, to minimize the bandwidth consumption of periodically broadcasting a beacon or Hello message via smart ground vehicles and/or intermittent connectivity of a direct V2V communication, I have proposed and implemented UAV's algorithm of sensing, tagging and broadcasting of vehicles' current states information within UAV range, algorithm of forwarding the information to respective infrastructures (if it is safety to LTE/4G else to RSUs) via GCS and the infrastructures broadcasts it to vehicles within their own transmission range.

Finally, I have evaluated, analyzed, and proved the proposed integrated novel architecture and its forwarding schemes with the existing ones (basic principle of VANET communications in highway scenario). The proposed work outperforms in all mentioned evaluation criteria on varied traffic density. It provides a better performance for VANET communications and satisfy the requirements of basic applications (safety and traffic) with high throughput and packet delivery ratio, and reducing delay. Thus, deploying the integrated architecture of UAV System, LTE/4G and WAVE with its forwarding schemes in highway scenario can enhance the VANET communications and satisfy the requirements of safety and traffic applications.

6.2 Contribution

The main contribution of this thesis is proposed and implemented an integrated novel architecture with its forwarding schemes in highway scenario via UAV System, LTE/4G and WAVE wireless access technologies. In order for this, to enhance the performance of VANET communications (minimize the high intermittent connectivity and bandwidth consumption of periodically broadcast a beacon or Hello message by smart ground vehicles) and satisfy the requirements of the VANET basic applications, particularly safety (high data rate and coverage area) and traffic applications (effective management).

6.3 Future Work

Though I did my best to realize the proposed integrated novel architecture with its forwarding schemes for VANET communications in highway scenario with the objective of overcoming the limitations of existing work (the basic principle of VANET communications in highway scenario), I do not trust that the architecture is standard enough to incorporate potential matters in VANETs highway scenario. For example, despite the importance of the issue, I have not considered the security and privacy aspect of the VANETs in my architecture since it was beyond the scope of this work. Thus, I hope that the proposed integrated architecture can be enriched in such a way that the security of VANETs is taken into account.

Regarding forwarding schemes, I have not considered/implemented a geo-cast forwarding scheme for RSUs to overcome the bandwidth consumption when the RSUs (RSU 1 and RSU 2) broadcasts the traffic information to WAVE-enabled vehicles within their own coverage areas (both lanes). For better clarification, by using geo-cast forwarding scheme, RSU 1 forwards a traffic information (L2) to lower lane only within its own transmission range, and as well as RSU 2 forwards a traffic information (L1) to upper lane only within its own transmission range. Therefore, I believe that the proposed integrated novel architecture with its forwarding schemes can be enriched in such a way that the geo-cast forwarding scheme on RSUs is taken into account.

Regarding infrastructure deployment consideration, I have not considered an optimal deployment of many UAVs (Drones) to proceed UAV's operations (sensing, tagging, and broadcasting of the current states of on-board drone vehicles information within UAV coverage area) on different areas of highway. Hence, I hope that the proposed integrated novel architecture can be enriched in such a way that the optimal deployment of many drones on different areas of highway is taken into account.

Furthermore, concerning with scenarios, I have not considered the implementation of my integrated architecture in urban scenario. Thus, I trust that the proposed integrated novel architecture can be enriched in such a way that the implementing/deploying the proposed architecture in urban scenario is taken into account.

References

[1] B. P. Kumar, P. C. Sekhar and N. B. Bhushan, "A SURVEY ON MANET SECURITY CHALLENGES AND ROUTING PROTOCOLS", *Int.J. Computer Technology & Applications*, Vol 4 (2), March-April, 2013, pp. 248-256.

[2] Flurscheim H (1925). Patent No. (US 1612427 A) 28522/23. UK, 1925.

[3] J. Santa, P. J. Fernandez, F. Pereniguez, F. Bernal and A. F. Skarmeta, "A Vehicular Network Mobility Framework: Architecture, Deployment and Evaluation", *IEEE INFOCOM International Workshop,* 978-1-4673-7131-5/15, 2015.

[4] M. Nekovee, "Sensor networks on the road: the promises and challenges of vehicular ad hoc networks and grids", *Workshop on ubiquitous computing and e-Research*, 2005.

[5] S. Olariu and M. C. Weigle, "Vehicular networks: From Theory to Practice", in *Chapman & Hall/CRC, First Edition ed,* 2009.

[6] J. Issac and M. Shafie, "VANETs AND ITS RELATED ISSUES: AN EXTENSIVE SURVEY", *Journal of Theoretical and Applied Information Technology*, 1992-8645, 20th August, 2014.

[7] J. Blum, A. Eskandarian and L. Hoffman, "Challenges of Intervehicle Ad hoc Networks", in *IEEE Transactions on Intelligent Transportation Systems*, 2004, pp. 347– 351.

[8] J. Jakubiak and Y. Koucheryavy, "State of the Art and Research Challenges for VANETs", *IEEE 5th Consumer communications and networking conference, CCNC*, 2008.

[9] F. Li and Y. Wang, "Routing in Vehicular Ad hoc Networks: A Survey", in *Vehicular Technology Magazine*, *IEEE*, 2007, pp. 12-22.

[10] S. Yousefi, M. S. Mousavi, and M. Fathy, "Vehicular ad hoc networks (vanets): challenges and perspectives: *the 6th international conference on ITS telecommunications,* 2006.

[11] Y. Toor, P. Muhlethaler and A. Laouiti, "Vehicle Ad hoc Networks: Applications and Related Technical Issues", in *IEEE Communications Surveys Tutorials*, 2008, pp. 77-88.

[12] D. Reichardt, M. Miglietta, L. Moretti, P. Morsink and W. Schulz, "CarTALK 2000 – Safe and Comfortable Driving Based Upon Inter-Vehicle-Communication", *IEEE IV*, 2002.

[13] S. Yamada, "The strategy and deployment for VICS", in *IEEE Communications*, 1996, pp. 94–97.

[14] W. Franz, R. Eberhardt and T. Luckenbach, "FleetNet - Internet on the Road", *the 8th World Congress on Intelligent Transportation Systems, Sydney, Australia*, 2001.

[15] Z. Hameed and F. Filali, "LTE and IEEE 802.11p for vehicular networking: a performance evaluation", *EURASIP Journal on Wireless Communications and Networking,* 2014.

[16] V. Devarajan and R. Gunasundari, "Performance evaluation of IEEE 802.11p and Mobile WiMAX in Vehicular Communication", *ICIIECS*, 2015.

[17] K. Zheng, Q. Zheng, P. Chatzimisios, W. Xiang and Y. Zhou, "Heterogeneous Vehicular Networking: A Survey on Architecture, Challenges and Solutions", *IEEE Communications Surveys*

& Tutorials, 10.1109/COMST.2015.2440103, 2015.

[18] "Dedicated Short Range Communications (DSRC) Home". leearmstrong.com. Retrieved 2008-02-29.

[19] M. Kumar, Pooja and I. Khughar, "Flying Ad-hoc Networks", August, 2014.

[20] R. Morris, J. Jannotti, F. Kaashock, J. Li and D. Decouto, "CarNet: A Scalable Ad hoc Wireless Network System", *the 9th ACM SIGOPS European Workshop*, *Kolding, Denmark*, 2000.

[21] C. C. Communication Consortium, Car 2 Car Communication Consortium Manifesto.

[22] R. Karimi, N. Ithnin, S. A. Razak and S. Najafzadeh, "DTN Routing Protocols for VANETs: Issues and Approaches", *IJCSI,* Vol. 8, Issue 6, No 1, November, 2011.

[23] M. Rahnema, "Overview of the GSM System and Protocol Architecture", in *IEEE Communications Magazine*, 1993, pp. 92–100.

[24] Europian Commission, "Road safety in the European Unio: Trends, statistics and main challenges", [online] available: http://ec.europa.eu/transport/road _ safety/pdf/vademecum _ 2015.pdf . [Accessed: August, 2016].

[25] K. D. Singh, P. Rawat and J. M. Bonnin, "Cognitive radio for vehicular ad hoc networks (CR-VANETs): approaches and challenges", *EURASIP Journal on Wireless Communication and Networking,* 2014.

[26] H. Moustafa and Y. Zhang, "Vehicular Networks: Techniques, Standards, and Applications", *CRC Press,* 2009.

[27] R. Bhakthavathsalam, and S. Nayak, "Operational Inferences on VANETs in 802.16e and 802.11p with Improved Performance by Congestion Alert", in *IEEE Consumer communications and networking conference (CCNC)*, 2011, pp. 467– 471.

[28] D. Jiang, V. Taliwal, A. Meier, W. Holfelder, and R. Herrtich, "Design of 5.9 Ghz DSRC-Based Vehicular Safety Communication", in *IEEE Wireless Communications,* 2006, pp. 36-43.

[29] J. George, P. B. Sujit, and J. Sousa, "Search Strategies for Multiple UAV Search and Destroy Missions", in *Journal of Intelligent and Robotics Systems*, 2011, pp. 355-367.

[30] C. Barrado, R. Messeguer, J. Lopez, E. Pastor, E. Santamaria and P. Ro "Wildfire Monitoring Using a Mixed Air-Ground Mobile Network", in *IEEE Pervasive Computing*, 2010, pp. 24–32.

[31] A. Cho, "Wind Estimation and Airspeed Calibration Using a UAV With a Single-antenna GPS Receiver and Pitot Tube", in *IEEE Transactions on Aerospace and Electronic Systems*, 2011, pp. 109–117.

[32] F. Jiang and A. L. Swindlehurst, "Dynamic UAV Relay Positioning for the ground-to-air uplink", *IEEE Globecom Workshops*, 2010.

[33] I. Maza, F. Calballero, J. Capitan, J. R. Martinez-De-Dios and A. Ollero, " Experimental Results in Multi-UAV Coordination for Disaster Management and Civil Security Applications", in *Journal*

of Intelligent and Robotics Systems, 2011, pp. 563–585.

[34] E. Semsch, M. Jakob, D. Pavlicek and M. Pechoucek, "Autonomous UAV Surveillance in Complex Urban Environments", *Web Intelligence,* 2009.

[35] H. Xiang and L. Tian, "Development of a Low-cost Agricultural Remote Sensing System Based on an Autonomous Unmanned Aerial Vehicle", in *Biosystems Engineering*, 2011, pp. 174–190.

[36] O. K. Sahingoz, "Networking Models in Flying Ad-Hoc Networks (FANETs): Concepts and Challenges", *Springer Science+Business Media Dordrecht*, DOI 10.1007/s10846-013-9959-7, 2014.

[37] N. Reker, D. Troxell and D. Troy, "Universal UAV Payload Interface*", California Polytechnic State University, San Luis Obispo, USA,* June 12, 2015.

[38] C., Harsch, A. Festag, and P. Papadimitratos, "Secure Position-Based Routing for VANETs", in *IEEE 66th vehicular technology conference*, *VTC-2007, Baltimore*, 2007, pp. 26–30.

[39] S. Sun, J. Kim, Y. Jung, and K. Kim, "Zone-Based Greedy Perimeter Stateless Routing for VANET", in *International conference on information networking*, *ICOIN*, 2009, pp. 1-3.

[40] D. Yu, and Y.-B. Ko, "FFRDV: Fastest- Ferry Routing in DTN-Enabled Vehicular Ad hoc Networks", *11th international conference on advanced communication technology,* 2009.

[41] B. Mohandas, and R. Liscano, "IP Address Configuration in VANET Using Centralized DHCP", *33rd IEEE conference on local computer networks, Montreal, Canada*, 2008.

[42] M. S. Anwer, "A Survey of VANET Technologies", *Journal of Emerging Trends in Computing and Information Sciences,* Vol.5, No.9, September, 2014.

[43] N. M. Sadek, H. H. Halawa, R. M. Daoud and H. H. Amer, "A Robust Multi-RAT VANET/LTE for Mixed Control & Entertainment Traffic", in *Journal of Transportation Technologies,* Vol. 5, 2015, pp. 113-121.

[44] P. Shilin, R. Kirichek, and A. Paramonov, "Connectivity of VANET Segments Using UAVs", in *Springer International Publishing,* 10.1007/978-3-319-46301-8_41, 2016, pp. 492–500.

[45] O. S. Oubbati, A. Lakas, N. Lagraa, and M. B. Yagoubi, "CRUV: Connectivity-based Traffic Density Aware Routing using UAVs for VANets", *International Conference on Connected Vehicles and Expo (ICCVE),* 2015.

[46] "VDNET: An Infrastructure-less UAV- Assisted Sparse VANET System with Vehicle Location Prediction", 2014.

[47] V. Devarajan, Dr. R. Gunasundari, T. Karthik, and V. Rajasekaran, "Integration of VANET-WiMAX Networks", *Puducherry, India*.

[48] I. C. Msadaa, P. Cataldi, and Filali, "A Comparative Study between 802.11p and Mobile WiMAX-based V2I Communication Networks", *Sophia-Antipolis, France.*

[49] J. Kenny, "Dedicated Short Range Communications: Connecting Vehicles", *Toyota Info Technology Center, USA,* June 11*,* 2014.

[50] T. Kekec, B. C. Ustundag, M. A. Guney, A. Yildirim and M. Une, "A Modular Software Architecture for UAVs", *Sabanci University, Istanbul, Turkey.*

[51] "LTE Simulator Documentation", *Centre Tecnològic de Telecomunicacions de Catalunya (CTTC),* September 10, 2012.

[52] N. M. Mittal and S. Choudhary, "Comparative Study of Simulators for Vehicular Ad-hoc Networks (VANETs)", *International Journal of Emerging Technology and Advanced Engineering,* Volume 4, Issue 4, April, 2014.

[53] M. Boban and T. V. T. Vinhoza, "Modeling and Simulation of Vehicular Networks: Towards Realistic and Efficient Models", *intechopen, USA and Portugal.*

[54] Y. R. B. Al-Mayouf, M. Ismail, N. F. Abdullah, S. M. Al-Qaraawi and O. A. Mahdi, "SURVEY ON VANET TECHNOLOGIES AND SIMULATION MODELS", *ARPN Journal of Engineering and Applied Sciences,* Volume 11, No. 15, August, 2016.

[55] The Network Simulator – ns-3. http://www.nsnam.org/.

[56] Simulation of Urban MObility (SUMO). <http://sumo.sourceforge.net>.

[57] S. K. Samantha and N. N Afrose, "Simulation Study of On-Demand Scheduling Algorithms in Road Side Units (RSUs)-Based Vehicular Ad Hoc Networks (VANETs)", *International Journal of Modeling and Optimization*, Vol. 2, No. 5, October, 2012.

[58] S. S. Guclu and D. T. Altilar, "Downlink Utilization with R2V2V Communications in Clustered Vehicular Networks". *International Symposium on Communication Systems, Networks & Digital Sign (CSNDSP), IEEE,* 978-1-4799-2581-0/14, 2014.

[59] S. Sou and O. K. Tonguz, "Enhancing VANET Connectivity Through Roadside Units on Highways", *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY,* VOL. 60, NO. 8, October, 2011.

Appendix A: Simulation Parameters of the Unmanned Aerial Vehicle (UAV) Module

// Create Devices/Attributes for UAV

```
YansWifiPhyHelper wifiPhy1 = YansWifiPhyHelper::Default();      // for PHY layer
YansWifiChannelHelper wifiChannel1 = YansWifiChannelHelper::Default ();
wifiChannel1.SetPropagationDelay ("ns3::ConstantSpeedPropagationDelayModel");
wifiPhy1.SetChannel (wifiChannel1.Create ());
wifiPhy1.SetPcapDataLinkType (YansWifiPhyHelper::DLT_IEEE802_11);
WifiMacHelper wifiMac1;      // for MAC layer
WifiHelper wiHelper1 = WifiHelper::Default();
wiHelper1.SetStandard((WIFI_PHY_STANDARD_80211b));
wiHelper1.SetRemoteStationManager("ns3::ConstantRateWifiManager", "DataMode",StringValue
("OfdmRate6MbpsBW10MHz"), "ControlMode", StringValue ("OfdmRate6MbpsBW10MHz"));
```

// Assign some attributes for UAV on PHY layer (wifiPhy1)

```
wifiPhy1.Set ("EnergyDetectionThreshold", DoubleValue (-96.0));   // the PHY layer to detect the signal (the energy of
                                                                     a received signal should higher than this
                                                                     threshold)
wifiPhy1.Set("TxGain", DoubleValue(0.0));
wifiPhy1.Set("RxGain", DoubleValue(0.0));
wifiPhy1.Set("TxPowerStart", DoubleValue(10.));        // minimum transmission range  {150-200 meter
                                                          transmission range (value = 10)}
wifiPhy1.Set("TxPowerEnd", DoubleValue(15.));          // maximum transmission range {150-200 meter
                                                          transmission range (value = 15)}
wifiPhy1.Set("TxPowerLevels", UintegerValue(15.));     // Number of transmission power levels available
                                                          between TxPowerStart and TxPowerEnd included
wifiPhy1.Set ("RxNoiseFigure", DoubleValue (1));       //  the difference noise (db) b/n actual and ideal
                                                          receivers of noise output  (SNR)
wifiPhy1.Set("ChannelWidth", UintegerValue(10));
wifiPhy1.Set("TxAntennas", UintegerValue(1));          //  the number of supported Tx antenna
wifiPhy1.Set("RxAntennas", UintegerValue(1));          //  the number of supported Rx antenna
```

// Install the above attributes and assign IP address for UAV

```
NetDeviceConatainer uavDevs =wiHelper1.Install(wifiPhy1, wifiMac1, uav);
Ipv4InterfaceContainer Uavinterface = address5.Assign (uavDevs);      // address5 = 10.1.4.0/24
```

Appendix B: Adopted Header File for Drone Tagging Operation (steve.h)

```
* steve.h
#ifndef STEVE_H_
#define STEVE_H_

#include <fstream>
#include <sstream>
#include <stdint.h>
#include <ns3/vector.h>
#include "ns3/tag.h"
#include "ns3/packet.h"
#include "ns3/uinteger.h"
#include "ns3/integer.h"
#include <iostream>
#include "ns3/object-base.h"
#include "ns3/tag-buffer.h"

namespace ns3 {

class SteveThesisWorkTag : public Tag
{
public:
  static TypeId GetTypeId (void);
  virtual TypeId GetInstanceTypeId (void) const;
  virtual uint32_t GetSerializedSize (void) const;
  virtual void Serialize (TagBuffer i) const;
  virtual void Deserialize (TagBuffer i);
  virtual void Print (std::ostream &os) const;

// these are my accessors to my tag structure
   void SetSimpleValue (uint8_t value);
   uint8_t GetSimpleValue (void) const;

   void SetSimplePosition (Vector a);
   void GetSimplePosition (void) const;

   void SetSimpleVelocity (Vector b);
   void GetSimpleVelocity (void) const;

//private:
  uint8_t m_simpleValue;
  Vector m_simplePosition;   // variable to hold position info
  Vector m_simpleVelocity;   // variable to hold velocity info
};

TypeId SteveThesisWorkTag::GetTypeId (void)
{
  static TypeId tid = TypeId ("ns3::SteveThesisWorkTag")
    .SetParent<Tag> ()
    .AddConstructor<SteveThesisWorkTag> ()
    .AddAttribute ("SimpleValue", "A simple value", EmptyAttributeValue (), MakeUintegerAccessor
     (&SteveThesisWorkTag::GetSimpleValue), MakeUintegerChecker<uint8_t> ());
  return tid;
}

TypeId SteveThesisWorkTag::GetInstanceTypeId (void) const
{
  return GetTypeId ();
}
```

```
uint32_t SteveThesisWorkTag::GetSerializedSize (void) const
{
 return 5; // 5 bytes
}
void SteveThesisWorkTag::Serialize (TagBuffer i) const
{
 i.WriteU8 (m_simpleValue);

 i.WriteU8 (m_simplePosition.x);    // this writes the X-coordinate of position
 i.WriteU8 (m_simplePosition.y);    // this writes the Y-coordinate of position

 i.WriteU8 (m_simpleVelocity.x);    // this writes the X-coordinate of velocity
 i.WriteU8 (m_simpleVelocity.y);    // this writes the Y-coordinate of velocity

}

void SteveThesisWorkTag::Deserialize (TagBuffer i)
{
   double tmp_x_pos, tmp_y_pos;

   double tmp_x_vel, tmp_y_vel;


   tmp_x_pos = i.ReadDouble();     // this reads the X-coordinate in a tmp variable for position

   tmp_y_pos = i.ReadDouble();     // this reads the Y-coordinate in a tmp variable for position

   tmp_x_vel = i.ReadDouble();     // this reads the X-coordinate in a tmp variable for velocity

   tmp_y_vel = i.ReadDouble();     // this reads the Y-coordinate in a tmp variable for velocity

   m_simpleValue = i.ReadU8 ();

// now I need to use these tmp variables to update the m_simplePosition and m_simpleVelocity

   m_simplePosition = Vector (tmp_x_pos, tmp_y_pos, 0);    //  x, y so z=0 for position

   m_simpleVelocity = Vector (tmp_x_vel, tmp_y_vel, 0);    //  x, y so z=0 for velocity

}

void SteveThesisWorkTag::Print (std::ostream &os) const
{
 os << "v=" << (uint32_t)m_simpleValue;

 //os << "p="<<(Vector)m_simplePosition;
 //os << "v="<<(Vector)m_simpleVelocity;
}

void SteveThesisWorkTag::SetSimpleValue (uint8_t value)
{
 m_simpleValue = value;
}

uint8_t SteveThesisWorkTag::GetSimpleValue (void) const
{
 return m_simpleValue;
}
```

```
void SteveThesisWorkTag::SetSimplePosition(Vector a)
{

        m_simplePosition = a;
}

void SteveThesisWorkTag::GetSimplePosition (void) const
{
 return;
}

void SteveThesisWorkTag::SetSimpleVelocity(Vector b)
{

        m_simpleVelocity = b;
}

void SteveThesisWorkTag::GetSimpleVelocity (void) const
{
 return;
}

}

#endif   /* STEVE_H_ */
```