Detecting Non-Line of Sight to Prevent Accidents in Vehicular Ad hoc Networks

PhD Thesis

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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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Dedication

To my Parents

For all their prayers, love, sacrifices without their endless support

I could not have accomplished my Thesis

To my Brothers and Sisters

For their support and encouragement, from the beginning of my study till the end

To my Wife

For her endless love, support, and patience

Without her patience most of this work would not have been done

To my son **Mohammed** who came to this world while I am in the final stages of this

thesis

Thank you very much indeed for everything you have done for me

Abstract

There are still many challenges in the field of VANETs that encouraged researchers to conduct further investigation in this field to meet these challenges. The issue pertaining to routing protocols such as delivering the warning messages to the vehicles facing Non-Line of Sight (NLOS) situations without causing the storm problem and channel contention, is regarded as a serious dilemma which is required to be tackled in VANET, especially in congested environments. This requires the designing of an efficient mechanism of routing protocol that can broadcast the warning messages from the emergency vehicles to the vehicles under NLOS, reducing the overhead and increasing the packet delivery ratio with a reduced time delay and channel utilisation.

The main aim of this work is to develop the novel routing protocol for a high-density environment in VANET through utilisation of its high mobility features, aid of the sensors such as Global Positioning System (GPS) and Navigation System (NS). In this work, the cooperative approach has been used to develop the routing protocol called the Co-operative Volunteer Protocol (CVP), which uses volunteer vehicles to disseminate the warning message from the source to the target vehicle under NLOS issue; this also increases the packet delivery ratio, detection of NLOS and resolution of NLOS by delivering the warning message successfully to the vehicle under NLOS, thereby causing a direct impact on the reduction of collisions between vehicles in normal mode and emergency mode on the road near intersections or on highways. The cooperative approach adopted for warning message dissemination reduced the rebroadcast rate of messages, thereby decreasing significantly the storm issue and the channel contention.

A novel architecture has been developed by utilising the concept of a Context-Aware System (CAS), which clarifies the OBU components and their interaction with each other in order to collect data and take the decisions based on the sensed circumstances. The proposed architecture has been divided into three main phases: sensing, processing and acting. The results obtained from the validation of the proposed CVP protocol using the simulator EstiNet under specific conditions and parameters showed that performance of the proposed protocol is better than that of the GRANT protocol with regard to several metrics such as packet delivery ratio, neighbourhood awareness, channel utilisation, overhead and latency. It is also successfully shown that the proposed CVP could detect the NLOS situation and solves it effectively and efficiently for both the intersection scenario in urban areas and the highway scenario.

Declaration

I declare that the work described in this thesis is original work undertaken by me for the degree of Doctor of Philosophy, at the software Technology Research Laboratory (STRL), at De Montfort University, United Kingdom.

No part of the material described in this thesis has been submitted for any award of any other degree or qualification in this or any other university or college of advanced education.

Khaled Alodadi

Publications

Khaled. Alodadi, and Ali. Al-Bayatti (2014, April). Intersection Collision Avoidance by Detecting None-Line of Sight (NLOS). Poster presented at Research Degree Students' Poster Competition. De Montfort University, Leicester

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List of Acronyms

AODV	Ah hoc ON-Demand Distance Vector
AU	Application Units
BE	Best Effort
BS	Base Stations
CAR	Connectivity-Aware Routing
CAS	Context-Aware System
CASS	Context Awareness Sub Structure
CCH	Control Channel
CEDAR	Core Extraction Distribution Ad hoc Routing
CoBRA	Context Broker Architecture
CVP	Co-operative Volunteer Protocol
DDU	Directional Dissemination Unit
DL	Download Link
DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communication
DTN	Delay Tolerant Network
EDU	Emergency Dissemination Unit
ER- Model	Entity Relationship model
ertPS	extended real time Polling Service
ETC	Electronic Toll Collection

FCC	Federal Communication Commission
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
GRANT	Greedy Routing with Abstract Neighbour Table
GSR	Geographic Source Routing
ICCU	Intersection & Road Coverage Control Unit
IDS	Information Data Sensor
IVC	Inter-Vehicle Communication
InVC	In-Vehicle Communication
ITS	Intelligent Transport System
LDU	Location and Direction Unit
LOS	Line of Sight
MANET	Mobile Ad hoc Networks
MIMO	Multi Input Multi Output
nrtPS	non-real time Polling Service
NLOS	Non-Line of Sight
NLOS-DU	Non-Line of Sight Detecting Unit
Non-DTN	Non-Delay Tolerant Network
NS	Navigation System
OBU	On Board Unit
OFDMA	Orthogonal Frequency Division Multiple Access
P2P	Peer-to-Peer
PDA	Personal Digital Assistant

PGB	Preferred Group Broadcasting
QoS	Quality of Service
RCP	Resource Command Processor
RIT	Routing Information Table
RLS	Reactive Location Services
RSU	Roadside Unit
RVC	Road-to-Vehicle Communication
rtPS	real time Polling Service
SCH	Service Channel
SPF	Short Path First
SSAR	Single Stability Based Adaptive Routing
TLO	The Last One
TORA	Temporarily Ordered Routing Algorithm
TRG	Two Ray Ground
UGS	Unsolicited Grant Service
UL	Up Link
UML	Unified Modelling Language
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VADD	Vehicle Assisted Data Delivery Routing Protocol
VANET	Vehicular Ad hoc Networks
VoIP	Voice over IP
WAVE	Wireless Access in Vehicular Environment

WBA	Wireless Broadband Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks
WMB	Warning Message Byte
ZRP	Zone Routine Protocol

Chapter 1

Introduction

Objectives:

- Introduction and motivation to this research

- Development of the research question and sub questions

- Presentation of methodology

- Providing the insight into contributions of the research

- The overall thesis structure

1.1 Introduction

Vehicular Ad hoc Networks (VANET) is a special case of Mobile Ad hoc Network (MANET) application, having an impact on the wireless communications and Intelligent Transport System (ITS). VANETs are employed to develop the safety applications for vehicles in order to create a safer and cleaner environment on the road. Currently, vehicles are equipped with several sensors including On Board Units (OBU); this allows the vehicles to sense hazardous situations which are communicated through the exploitation of other vehicles establishing the Vehicle-to-Vehicle (V2V) pathway or through the utility of the Roadside Unit (RSU) creating a Vehicle-to-Infrastructure (V2I) pathway. Due to the expense of V2I communication associated with the high cost incurred during the installation of infrastructure along the roads, the focus of this research is placed on the investigation of V2V communication rather than the V2I communication.

Under VANET, vehicles need to exchange information about real time locations and vehicle information, to support applications like, safety messages and information broadcasting. Direct communication techniques are used by vehicles within respective radio signal range. Physical obstacles end up blocking the radio signals that are required for proper communication and localisation. An obstacle can block effective communication between vehicles even if the vehicles are within the required physical range. Non-Line of Sight (NLOS) is developed between vehicles as they are not able to communicate, which restricts the effective flow of information and localisation of various services. It has been observed that moving obstacles is a requirement for the effective functioning of the VANETs. However, these obstacles, such as large trucks,

are a part of VANET. These trucks (obstacles) are characterised by high mobility and altering driver behaviour, which obstructs the radio signals.

1.2 Research Motivations

Traffic mobility patterns are not the same; they vary according to the congestion level of traffic on the road. Moreover, vehicle communication is vulnerable to these conditions. Physical objects and various constructions on the roadsides pose obstruction to radio signal based communication. Area topography, buildings, trees, poles, etc, pose a threat to effective communication among vehicles. Heavy trucks and other automobiles are among the few moving obstructions, which hinder successful communication. Moving obstructions block the sight and increase the possibility of NLOS, and reduce time for drivers while changing lanes, merging into highways and overtaking vehicles. An important characteristic of VANET is to maintain the level of information about the neighbouring vehicle. It can also lead to better and secured localisation services, which is supportive in reducing the overall obstacles.

The buildings and fixed objects are not the only source of the signal blockage in VANETs, but moving objects like trucks, lorries or buses moving on the road can also cause similar problems. Vehicles of different sizes and shapes can serve as obstacles between the vehicles moving in the same communication range. In contrast to the fixed structures and buildings for which the extent of interference in signal propagation and signal quality factors can easily be measured while the vehicles are moving in a given direction and area, the moving obstacles of different shapes, speeds, densities and compositions can result in the creation of a NLOS situation that is subject to changes in

an unpredictable tempo-spatial manner (relating to time and space). Consequently, this situation can cause a hindrance in the reception of information relating to location verification, consistent updates and sharing of information of high priority (warning messages) for the avoidance of hazardous situations on the road.

In Figure 1.1, the vehicle has multiple paths and directions to go such as at roundabouts/intersections where more than one exits, exist. The emergency vehicle (E) needs to send the warning message to other vehicles coming from other legs of the intersection. Vehicle (A) receives the packet because it is in the range of (E). Due to the obstacle (building or vehicle C) vehicles (B) and (D) did not receive the packet. Hence, (A) will rebroadcast the massage to its surrounding neighbours. Even though that (D) in the range of (A), and due to the presence of (C), which did not resend the message, (D) did not get the warning massage which will notify it about the presence of vehicle (E). Therefore, the importance of the cooperative approach will arise which will allows vehicle (B) to volunteer itself as a repeater to solve this problem.
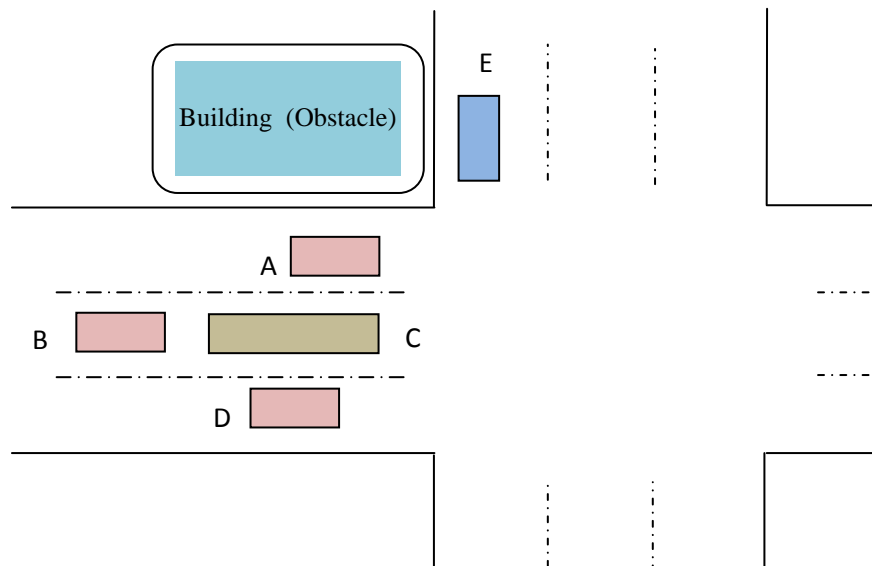
Figure 1.1 Obstacles in VANET

This is paramount for the vehicles moving on the road to have better knowledge of surroundings and their immediate vicinities in order to perform well in the NLOS situations, otherwise the lack of it can lead to the creation of fatal accidents on the road due to collisions between emergency vehicles and other vehicles which are in the normal mode. The two terms have been used frequently during course of discussion in this thesis: vehicle in emergency mode and vehicle in normal mode. The former category describes those vehicles that have the authorised emergency sirens to alert other vehicles on a road to leave an open space for their movement, such as police vehicle, ambulance and fire-engine.

1.3 Research Problem Statement

The response of drivers driving vehicles on the road is normally delayed in response to the emergency siren, which is mainly due to lack of their understanding and information about what to do and where to turn to (left or right). In making decision, they take longer than the usual reaction time. Subsequently, this situation leads them to make wrong moves and decisions, thereby resulting in fatal accidents on the road or some delay in the arrival of the emergency vehicle. As the emergency vehicle has limited time to reach its destination, the chances of collision with other vehicles are normally higher in the wake of an emergency. The term "emergency vehicle" in this thesis means any vehicle authorised to use the siren such as police, fire-engine or ambulance, which are required by law to follow the traffic rules and regulations [181]. However, the latter is used to distinguish other vehicles on the road without any authority to bugle the emergency siren while moving on the road.

According to a report issued by the German Federal Highway Research Institute, the risk of serious accidents is eight times higher for an emergency vehicle to get involved in, and four times higher getting involved in fatal accidents [1]. Similarly, the risk of being involved in property damage is 17 times higher. This data clearly shows that any mistake made by a driver of an emergency vehicle on the road can cause disastrous consequences [2]. It has been reported that erroneous driving of the emergency vehicle drivers can lead to 60% of accidents, out of which 30% are caused by faults of other drivers driving vehicles on the road. Around 40% of such accidents take place at the intersections of roads. A recent survey shows that in the UK, emergency vehicles get involved in over 12000 accidents in the past three years [182].

Furthermore, the wrong decisions made by drivers of other vehicles can precipitate the delays in arrival of emergency vehicles at their destination points, and that can result in serious implications for the patients being rushed to hospitals in the case of ambulances and the escape of criminals being chased by police vehicles. Intelligent Transportation Systems (ITSs) are being applied nowadays to increase the surface transportation systems. Several ITS projects have initiated in the USA, Japan and Europe, which employ Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications to relay the emergency messages to the target vehicles within short times which enable the drivers to make quick decisions and avoid the collisions with either emergency vehicle or with other vehicles. The underlying network utilised by these communications V2V is termed as vehicular ad-hoc networks (VANET), which deliver the information in timely and cost-efficient way.

However, there is still a lack of comprehensive protocol of communication, which can reduce latency in the dissemination of messages. The major challenge in this dissemination of messages is related to how to shorten the time period between the time of emergency event and the time of delivery of warning message to other vehicles to avoid collisions. The coverage of all vehicles with the target range in terms of dissemination of messages is another issue. Due to plenty of vehicles on the road at intersections, the dissemination of messages is normally challenging. The vehicles, buildings and foliage can pose a major obstacle in the way of dissemination of warning messages from the emergency vehicle to the target vehicles. This stresses on the need of continuous research to detect the amount of obstacles in the dissemination of messages, which will ultimately result in the reduction of collisions due to timely received messages and quick decision-making processes of the drivers.

The moving vehicles can constitute obstacles with different compositions, densities, speeds and shapes, and this can further generate the issue of NLOS, which can affect the communication of location information and updates among the neighbouring vehicles. Therefore, there will be no exchange of information between vehicles about the speed, location, direction, etc, and hence fatal accidents will happen on the road. A multi-hopping technique is used to disseminate the message beyond the transmission range, but unfortunately hidden nodes, interference and packet-collisions can terminate the dissemination process during the multi-hopping mediated broadcasting. Furthermore, the higher utility of wireless resources mediated by unnecessary re-transmissions is another problem associated with the employment of multi-hopping techniques for broadcasting the messages. Due to these challenges associated with the

multi-hop broadcast, the focus is being diverted to use a Co-operative Volunteer Protocol (CVP) for reliable, effective and efficient multi-hop message broadcasting. Most of the solutions proposed in this context rely on direct Line of Sight (LOS), which uses Roadside Unit (RSU) or cellular networks to overcome the NLOS issue/situation for disseminating the messages to vehicles close to each other. This shows that the existing solutions are infrastructure based and require infrastructure for the dissemination of information among neighbouring vehicles. However, the major challenge is how to create infrastructure-less communication of messages to the proximity vehicles.

Therefore, in this thesis, an effective CVP for emergency vehicles warning message dissemination in VANETs has been postulated. Firstly, this will enable reduction of the issue of NLOS situation by assuring the broadcast of emergency messages to each and every node in the coverage zone, and will utilise the volunteer nodes for the relay of messages to those nodes lying out of the coverage zone. Secondly, this will help to reduce the dissemination latency, thus delivering the warning messages to the target nodes efficiently and in a timely manner, which plays a fundamental role in designing safety applications for emergency vehicles. Thirdly, the storm problem in message dissemination will be reduced using CVP. Finally, the issues associated with the previous protocols, such as robustness, reliability and coverage, will be enhanced using the proposed CVP. The simulation tool such as EstiNet is used to evaluate the effectiveness of the proposed routing protocol in comparison with other protocols being used in the area of transmission of warning messages from emergency vehicles and other vehicles. The selection of EstiNet as a simulation tool has been made due to its

special features, relatively easy manipulation of features and its ability to simulate the various parameters and conditions at the intersection of roads.

1.4 Research Questions

Based on the foregoing research issue and scanning the literature relating to LOS and NLOS detection and associated issues, the following research questions have been formulated:

How can an effective and efficient routing protocol be designed for solving the Non-Line of Sight situations to prevent accidents on the road?

The main aim of this thesis is to deal with the above question; however, it can be divided into sub-questions which can be tackled individually. The sub-questions are given below:

1- *How can the Non-Line of Sight situation (NLOS) be detected?*

2- *What type of approach can be adopted to design an effective and efficient routing protocol to deliver the message to the hidden node compared to the existing approaches?*

3- *How can the proposed routing protocol solve the latency problem in VANET by delivering the packet in time?*

4- *How can the proposed protocol solve the broadcast storm problem by minimising the rebroadcast of the warning messages?*

1.5 Research Methodology

This research work utilises the constructive research paradigm, which is applied to the scientific research approach. It enables the researcher to contribute to the existing knowledge through development of techniques, models, new architecture, etc. It must be noted that scientific research cannot be taken within the defined boundaries of knowledge; it employs the study of the existing literature, formulating hypotheses or generating the research questions and generating reproducible knowledge and empirical solutions to solve certain social and natural issues. The acquisition of knowledge and execution of steps for the constructive research are the main components of this research work. The scientific approach to detect NLOS by using the proposed protocol has been divided into four phases. The first phase consider the review of literature and the second phase propose and present the On Board Unit (OBU) architecture for detection of NLOS as presented in Chapter 4. The third phase elaborate the proposed routing protocol presented in Chapter 5 for detection of NLOS situations. The fourth and last phase deals with the implementation and validation of the proposed routing protocol.

Phase 1: Research background

The different sources have been consulted to retrieve the relevant literature such as books, library sources (digital library), and journal articles. The literature review has been divided into two stages. The first stage covers an overview of VANET, context-aware systems; the second stage covered the overview of NLOS, models and proposed architectures relating to detection of NLOS.

Phase 2: Design of OBU architecture

In this phase, the context-aware OBU architecture is developed to collect the knowledge about the immediate vicinity in order to locate the hidden nodes that have not received the warning message. Ultimately an OBU framework contains a system which is aimed to trigger the proposed routing protocol on detection of NLOS in the network.

Phase 3: Design of the proposed routing protocol

The design of the routing protocol for detection of NLOS situations involved the contextual information collected by different sensors, which would be taken by the proposed protocol to process this information and send the warning messages to the vehicles facing NLOS situations.

Phase 4: Simulation and Evaluation

Finally, one has to validate the performance of the proposed routing protocol using EstiNet tool and demonstrate the protocol ability to solve the NLOS situations.

1.6 Measure of Success

In order to evaluate the research work, the following measures of success were used:

- Answering the research question and sub-questions described in Section 1.3

- An evidence obtained from the implementation and validation of the proposed CVP showing that the proposed architecture can be applied in VANET and will be able to detect NLOS

- An analysis of performance of the proposed CVP in comparison with other routing protocols. This will show that the proposed CVP can be better than other protocols

The proposed CVP can reduce the time of delivery of warning message to the target vehicles. This shows the importance of the proposed CVP in reducing the accidents occurring due to delayed delivery of warning messages to the recipient vehicles.

1.7 Thesis Contributions

The main contributions of the work concluded from this thesis can be shown as follows:

Co-operative Volunteer Protocol (CVP): A novel routing protocol is proposed, that is triggered after NLOS detection in order to solve the NLOS situation to prevent collisions. Furthermore, the proposed protocol is the first protocol of its kind which has been effectively applied to identify the NLOS situations and rebroadcast the warning messages to the hidden nodes to avoid collisions and accidents on the road.

On Board Unit Architecture for Non-Line of Sight: An architecture that is used to detect NLOS situation by comparing Routing Information Table (RIT) for each vehicle in the coverage zone.

1.8 Thesis Outlines

This section describes the outline of the remaining chapters of this thesis:

Chapter 2: Vehicular Ad hoc Networks and Context-Aware Systems

This chapter presents an overview of VANETs with regards to different aspects such as: communication types, applications and characteristics. After that, carry out the work based on safety application and how this application will be essential in VANET. This

chapter sum up by describing the context-aware system, definitions, what and how to capture context.

Chapter 3: Critical Analysis of Non-Line of Sight Routing Protocols

This chapter presents the challenges in warning message dissemination and factors affecting the message dissemination in VANETs, giving insight to develop the robust protocol which can overcome the challenges faced during the message dissemination in order to answer the research questions properly. The discussion on the main routing protocols in VANETs has been presented as well, in order to look into the weaknesses and strengths of the existing protocol. Finally the choice and justification of the proposed CVP are provided in this chapter.

Chapter 4: Context-Aware System On Board Unit Architecture

This chapter describes the detection of NLOS and how the protocol will be triggered accordingly. Also, it shows on board unit architecture for detection NLOS, which is designed utilising the context-aware system and has been divided into three phases. All three phases have been described and elaborated in detail to display the various components and associated functions within each phase. Furthermore, the interactions of the components between various phases have been demonstrated to show how the detection of NLOS situation is performed.

Chapter 5: Co-operative Volunteer Protocol

This chapter presents the actual protocol that has been used throughout the thesis. Moreover, it describes the two-stage methodology of the CVP; the first stage, detecting

the NLOS situation and the second stage delivering warning messages to the hidden node in order to prevent accidents on roads.

Chapter 6: Simulation and Evaluation

This chapter illustrates the validity of the proposed protocol by using the EstiNet Tool Simulator. EstiNet will show how the protocol will do in the real world under different metrics such as Latency, Packet Delivery Ratio and Storm Problem.

Chapter 7: Conclusions and Future Work

This chapter presents a summary of the work that has been presented in the thesis. Moreover, it draws the attention of the readers to the suggested future work.

Chapter 2

Vehicular Ad hoc Networks and Context-Aware System

Objectives:

- Give an overview of VANET

- VANET Architecture

- Vehicle Communication Categories

- Applications in VANET

- Provide literature on context, context-aware systems, context

  modelling

2.1 Introduction

MANET is an abbreviation of Mobile Ad hoc Networks, which contains a chain of self-organised nodes which are able to communicate with each other without requirement of the established infrastructure. The working principle of MANET is based on the utility of multi-hop communication requiring nodes, whereby each node in the chain serves as an end- user as well as a router [3]. This has gained tremendous popularity and penetration in the potential wireless technology market, as is evidenced from the greater use of Bluetooth and Wireless Local Area Networks (WLAN) technologies.

2.2 VANET Overview

VANETs come into view as the subset of the MANETs applications. It is believed to be a significant approach for the Intelligent Transportation Systems (ITS) [4]. In addition to this, VANET can be applied in the non-safety applications [5]; for instance, it can be applied in the applications related to information and entertainment. In order to create a safe, clean and more intelligent environment in non-safety environments, VANET uses the support drivers which can drive in an environment without any complexity [6]. These days, adequate number of sensors and devices come with the vehicles, for example, OBU. With the help of the sensors and drivers, vehicles can sense the position of all other vehicles that come in range of its communication. This sensing is possible by making use of the infrastructure, like road side units, which build the V2I or built V2V, if a vehicle needs to connect to the other vehicle directly.

Every vehicle is used to collect the information regarding the non-safety environment, such as warning messages related to traffic jams, accidents, and collision situations. Besides, vehicles can also collect information related to the weather forecast, tourism and Electronic Toll Collection (ETC) [6]. Vehicles can provide information regarding their direction and position with respect to other vehicles, while they collect information related to the environment. This information helps the vehicle in choosing a particular lane or direction and helps in making adjustments in the direction and speed. The purpose behind the sharing and distribution of such kinds of information is to disseminate the warning messages to warn drivers of other vehicles to take safety precautions in order to avoid hazard situations. The dissemination of such information is useful in making drivers make their decisions quickly in the wake of emergency situations [7, 8, 9, 4].

2.3 VANET Architecture

The communication process may occur between the drivers of vehicles and RSU or between vehicles, and that is facilitated by a wireless medium called WAVE (Wireless Access in Vehicular Environment). This mode of communication is of critical importance in terms of enabling the drivers and passengers to travel safely on roads by means of a safety application fitted into vehicles. The major components of this system include the Application Unit (AU), OBU and RSU. The RSU component provides various sources including safety and non-safety information and internet facility to the road users; therefore it is called the service provider. The vehicle contains an OBU component which receives the services from RSU, and is therefore called the user. It contains applications capable to use the service provided by RSU, which receive the

information and messages through an array of sensors in the vehicle. OBUs along with sensors are capable of receiving and processing the information and sending the messages and information to other vehicles through wireless communication. The internet connection is provided by the RSU to multiple vehicles through AUs from multiple vehicles [3, 7, 8, 9].

2.3.1 On Board Unit

The On Board Unit (OBU) is the device mounted on board a vehicle and is usually employed to exchange the information with the OBUs of other vehicles and with RSUs. The resource command processor (RCP) is the critical part of these devices along with the read/write memory part, which retrieves and stores the information gathered from external sources. It also contains some user interface and customised and specialised interfaces, enabling it to be connected to OBUs in other vehicles through short-range wireless communication (IEEE 802.11p radio technology). It may include some non-safety applications supporting devices working on radio technologies (IEEE 802.11a/b/g/n).

OBU becomes connected to RSUs and OBUs in other vehicles through the wireless technology based on IEEE 802.11p, and is responsible for forwarding data packets to AUs, receiving services from RSUs, and forwarding data packets to OBUs of other vehicles, network congestion control, geographical routing, data security and IP mobility [3, 7].

2.3.2 Application Unit

The Application Unit (AU) device is equipped within the vehicles and resides within the OBU as a unique unit. The distinction between OBU and AU can be made as

OBU is responsible for networking functions while AU is connected to the internet and other services through the OBU. AU may be the Personal Digital Assistant (PDA) and can be a specialised device dedicated for safety applications [3, 7].

2.3.3 Roadside Unit

Roadside Unit (RSU) is a WAVE device which is fixed along the roadside near the intersections, junctions and parking spaces. This device is capable to operate much safety software, gateway application and contains a processor with significant storage capacity to support the required applications and software. RSU is connected with vehicles' OBU through the short-range wireless communication IEEE 802.11p and an antenna; it also contains some other network devices for communications with other infrastructure network. It communicates with OBUs, the RSUs for forwarding information of OBUs of vehicles and runs safety applications, such as warning of low bridges and internet connectivity to the OBU [3, 7].

2.4 Vehicle Communication Categories

VANET Communication can be divided into three categories that are shown in Figure 2.1[3]:

- In-vehicle communications
- Inter-vehicle communications
- Roadside to vehicle communications
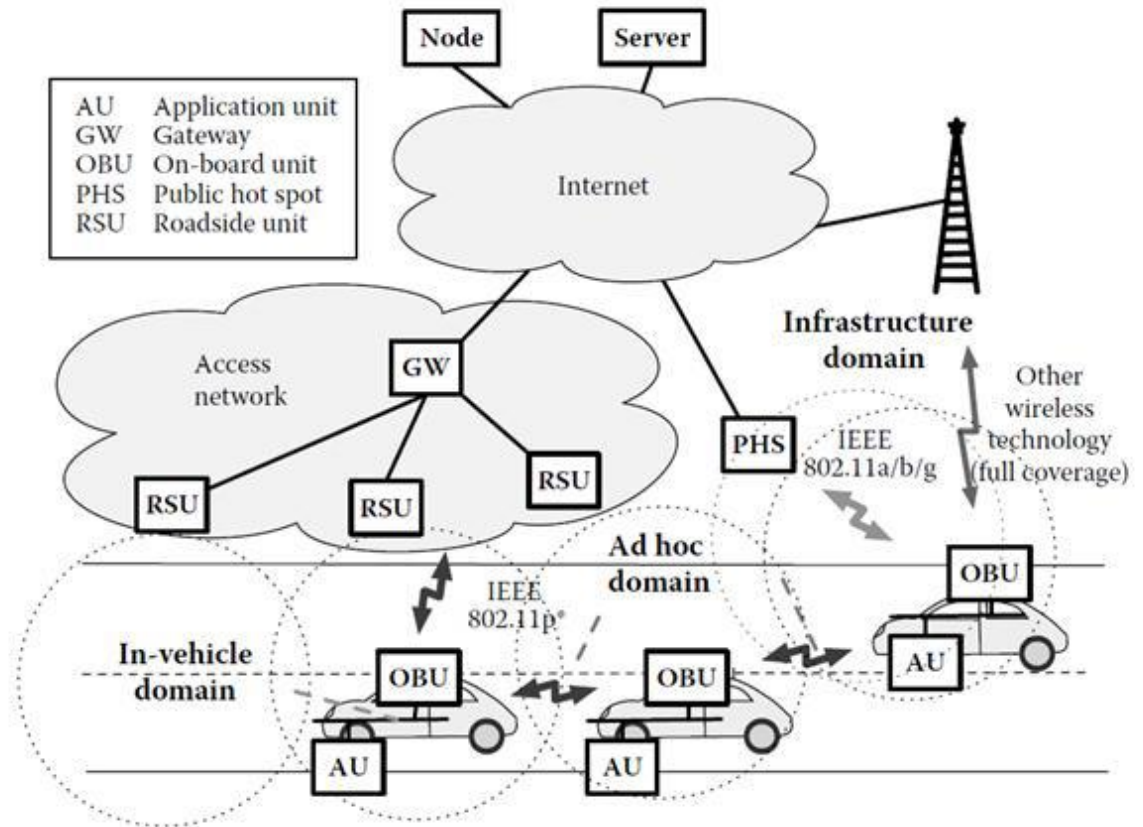
Figure 2.1 Communication Categories in VANET [3]

2.4.1 In-Vehicle Communications

In-Vehicle Communication (InVC) helps in switching the information between two units, i.e, OBU and AU, which are generally used in the modern cars. Most commonly, In-Vehicle Communications can be used in two areas. The first area includes actuators, controllers, in-vehicle network of sensors; the second area includes multimedia with high rates which is used for the comfort applications, such as passenger entertainment. Generally, during the lifetime of a vehicle, the number of communicating entities does not vary, also in-vehicle communication networks'

topology is stable in nature; therefore, it only explains the limited group made up with the communication partners. More commonly, violation of the rules related to integrity and delay is considered to be more serious in the controller networks, while the delay and corruption of data is regarded as less serious in the comfort applications. However, comfort applications need the higher data rates. The concept of standardisation of the communication system comes from the high rate of increment in the number of integrated electronic components. Increased number of integrated electronic constituents has triggered the necessity of standardisation of communication infrastructure [10].

2.4.2 Inter-Vehicle Communication

These days researchers focus more on the Inter-Vehicle Communication (IVC), especially in the USA, EU and Japan, as this ensures more safety by expanding the driver's decision-making possibilities. IVC enhances and supports road traffic management and increases the efficiency of the system safety [11]. A decentralised manner is used to manage vehicles in such a communication system, and allows vehicles to manage direct communication without the use of V2I or any other infrastructure. It can be used as a potential building block to develop an effective Intelligent Transport System (ITS). As the infrastructure cost is high and deploying a completely new infrastructure is a complex process, this inter-vehicle communication is more preferential [12, 38].

The most significant stream used in IVC is microwaves, especially the Dedicated Short Range Communication (DSRC) established by the FCC (Federal

Communication Commission) in the US which uses the spectrum over 75 MHz in the 5.9 GHz bands, while, in the EU and Japan 5.8 GHz band is used [8].

Figure 2.2 shows the communication modes between different vehicles. At time vehicle A transmits its information related to its direction, location and speed to other vehicles which falls in its range of communication. On the other hand, vehicle B receives vehicle A's information and retransmits this information along with the information about itself. After a t + d time, the other vehicle catches the information transmitted by vehicle B, so that vehicle C keeps all the predicted traffic conditions [13].
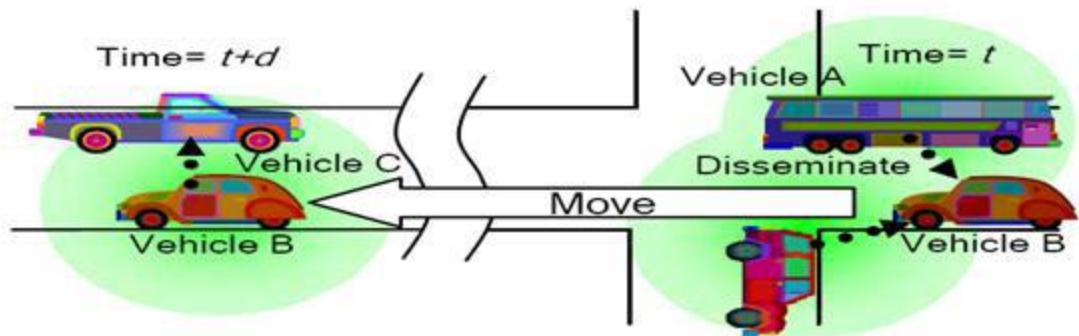
Figure 2.2 IVC Ad hoc V2V Communications [13]

2.4.3 Vehicle-to-Infrastructure Communication

Vehicle-to-Infrastructure Communication (V2I) is also known as the Road-to-Vehicle Communication (RVC). It is very expensive as it requires a high number of terminals, for instance, RSU and Base Stations (BS). These terminals work as a coordinator between the cellular networks and subscribers, in order to make sure the complementary cover all roads [14]. For monitoring the negotiation process and

arranging the connection between the infrastructure and mobile vehicle, Base Stations plays a major role.
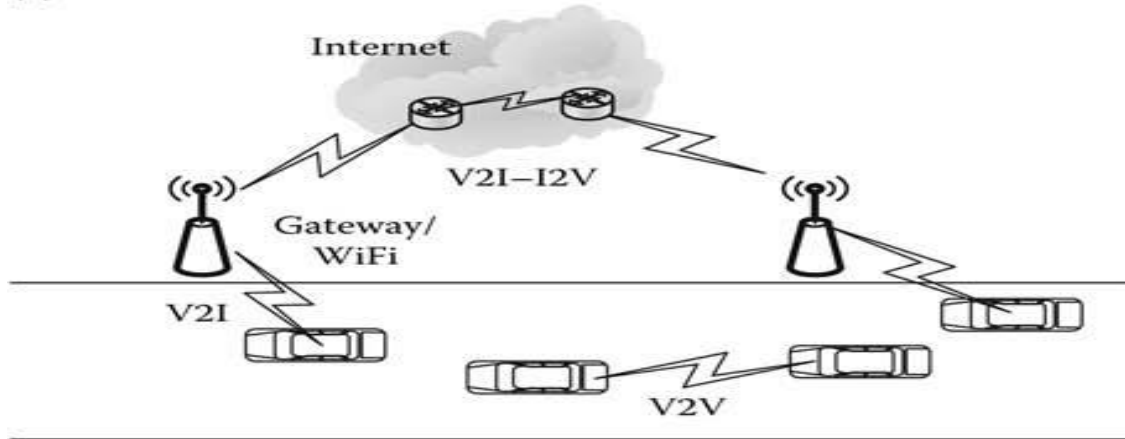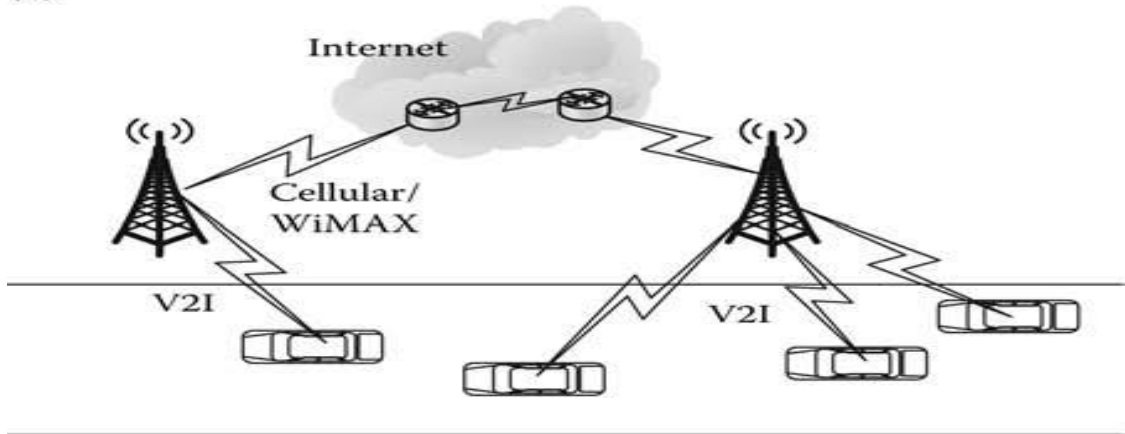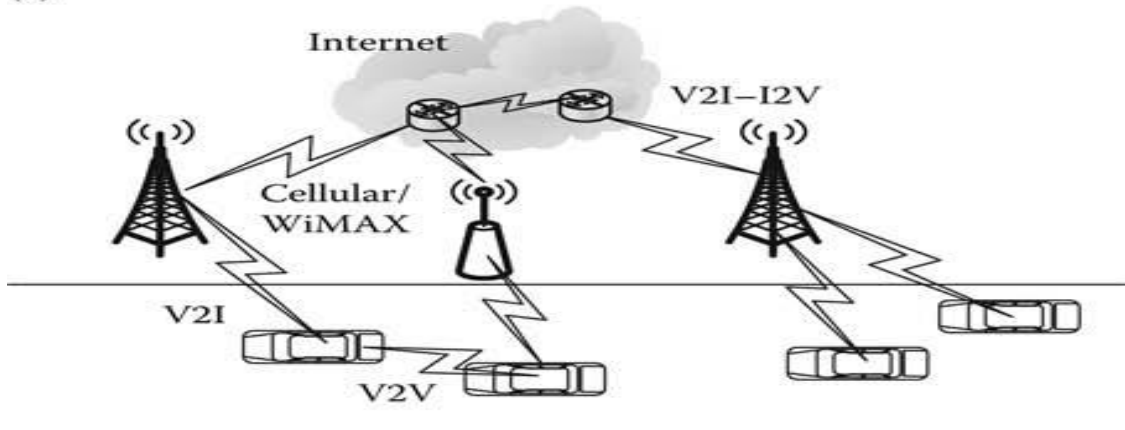
Figure 2.3 I2V & V2V Communication types [3]

As shown in Figure 2.3, connections are first initiated by the V2I between the fixed units which are located along the road. The connection is possible by circulating the significant information related to the current position of the vehicle. This information can be received by the other vehicles in terms of movement action, direction and speed. This information helps the vehicles to take certain decisions in order to avoid certain actions. These units are also called the RSUs which apply the WAVE standard [9]. These units also employ the DSRC in order to make communication between the vehicles. In order to provide the internet access, infotainment applications and make communication in bidirectional ways, V2I uses the cellular networks like GSM, UMTS, or WiMAX.

2.5 Wireless Access Technology in VANET

There are various available wireless technologies that provide an interface to achieve the process of data dissemination. The wireless access standards can be achieved in several ways. One of the approaches is to adopt a centralised process that uses a coordinator that controls all the nodes and creates connection between them. This delivers the data to its destination in a timely manner. The second approach used here is maintaining a direct communication without bringing any other means in between [11]. These technologies can be better understood with the help of the following example:

- **Cellular Networks (2/3G):** Mobile networking is increasing at a very rapid rate leading to a vast enlargement in the area of cellular network. The emergence of new technology, i.e, 2G, mainly stresses on attaining consistent and sheltered connections that would provide the maximum data rate of 9.6 kb/sec [15]. Systems that rely on the

technology of GSM consume EDGE with a speed of 384 kb/sec and GPRS with a speed of 171kb/sec. Another 2G technology, i.e, IS-95, can provide the data rate equivalent to 141kb/sec. In order to support the issues related to the multimedia, there is a huge need for a high data rate, that led to the emergence of 3G technology [16], such as UMTS/ HSDPA, would help in providing the speed up to 2Mb/sec, and CDMA2000 that can provide up to 3Mb/sec of speed for downlink and 1.8 Mb/sec for uplink.

- WIMAX (IEEE802. 16 e/m) Technology: In the last few years, the requirement for a high data rate and reliable Wireless Broadband Access (WBA) system has been raised to a great extent. In order to accumulate the demand for using this service in applications, Quality of Service (QoS), principally for the applications that are related to the multimedia and Voice over IP (VoIP) [17], will be required. In order to satisfy the requirements related to the high data rate and trustworthy connection, WiMAX (Worldwide Interoperability for Microwave Access) has been urbanised as a priceless solution. The general structure of IEEE 802.16 relies mainly on the WiMAX standards [18].

In order to categories the WiMAX in the top list of Wireless Broadband Access systems, WiMAX serves with a set of crucial features to get rid of the issues in terms of WBA systems. One of the top classifications of Wireless Broadband Access systems is its high data rate and on the basis of this, it allows use of Multi Input Multi Output (MIMO) with Orthogonal Frequency Division Multiple Access (OFDMA) technology. This would help to provide the system with more elasticity in Up Link (UL) rate and Download Link (DL) rate. From the beginning, the standard of IEEE 802.16 includes the quality of standards in order to categorise the connections into five classes as

follows: Unsolicited Grant Service (UGS), real time Polling Service (rtPS), non-real time Polling Service (nrtPS), extended real time Polling Service (ertPS) and Best Effort (BE). After introducing a hand-off mechanism having less than 50 millisecond latencies, such as VoIP applications, that will help in accomplishing the mobility by the support of WiMAX systems on the basis of its real-time applications. A high capacity is being provided by the WiMAX that can reach up to the radius of 7 km [19].

The new standard was designed by the IEEE802.16 in order to fulfil the necessity of the International Telecommunication Union-Radio Communication/ International Mobile Telecommunication (ITUR /IMT- advanced). This will help the WiMAX technology to classify mobile network operators under the 4G- next generation.

- Wireless Local Area Network (WLAN): WLAN would help in providing a series of broadcasting at distances: 38 m and 140 m, for indoor and outdoor use respectively, by granting a speed of 54 Mb/s in its verified standard of 802.11a/g [20].

- Combined wireless access method: For the purpose of creating a Vehicular Ad hoc Network, many scenarios arise; adding together V2I, V2V Figure 2.3(c). In other words, it can be said that with the permutation of V2I and V2V, the technology of DSRC can be victimised [3].

- DSRC/ WAVE: The creation of the IEEE 802.11p standard [21] is totally based upon the IEEE 802.11a; the Dedicated for Short Range Communication (DSRC) can be measured as a technology of communication for short and medium series as well [22]. On the basis of the WAVE, the communications lie in between the vehicles having

a speed up to 120 m/h or the communication between a vehicle and roadside infrastructure unit which have a transmission series of an average of 300 m (up to 1000 m) have been recognised. With the help of the Federal Communication Commission (FCC) [11], a 75 MHz in 5.9 GHz band was segmented from the spectrum for the US in 1999. Whereas in Europe, before being altered to 5.8 GHz band, at first they had selected 2.4 GHz and this selected 2.4 GHz is equivalent to the band which is used in Japan.

Including this, the DSRC technology focuses on establishing a security application by commencing the DSRC technology that is the most significant goal of the safety application. This step was taken in order to shrink the victims and to recover in the conditions related to the traffic flow. DSRC has IEEE 802.11P as a base, which has been used to lessen the command overhead in the range of DSRC. This specific standard is known as the IEEE 1609, which has been developed for management, security and networking services [23].

According to Figure 2.4, it was judged that seven channels had a width of 10 MHz included in the spectrum of DSRC. Among these channels, safety allocation was the main reason that was allocated by the channel 178, which is known as the Control Channel (CCH). At the ends of the spectrum, another two channels were allocated for the purpose of any kind of special use, whereas for the purpose of safety and non-safety applications, another channel i.e, Service Channel (SCH), was allocated [23, 24].
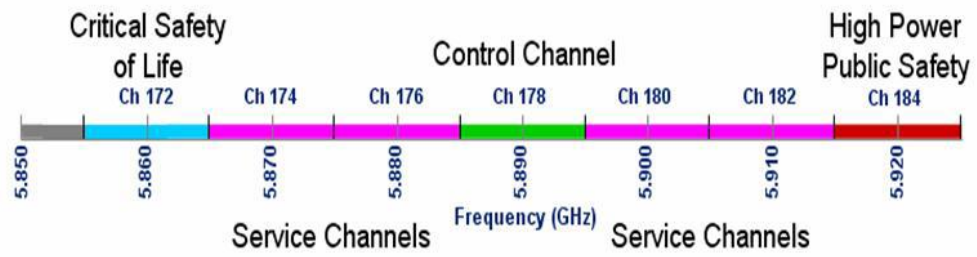
Figure 2.4 DSRC Channels Spectrum [24]

2.6 Applications in VANET

VANET consists of a variety of applications that are helpful in many ways. These applications help in discovering combinations of information that is collected from the inner and outer environment of vehicles through the help of certain devices that are already fitted in the vehicles, such as wireless sensors, GPS, radar, etc., In addition to integrating the fixed infrastructures as cellular networks and WiMAX technology [3, 15, 25, 38].
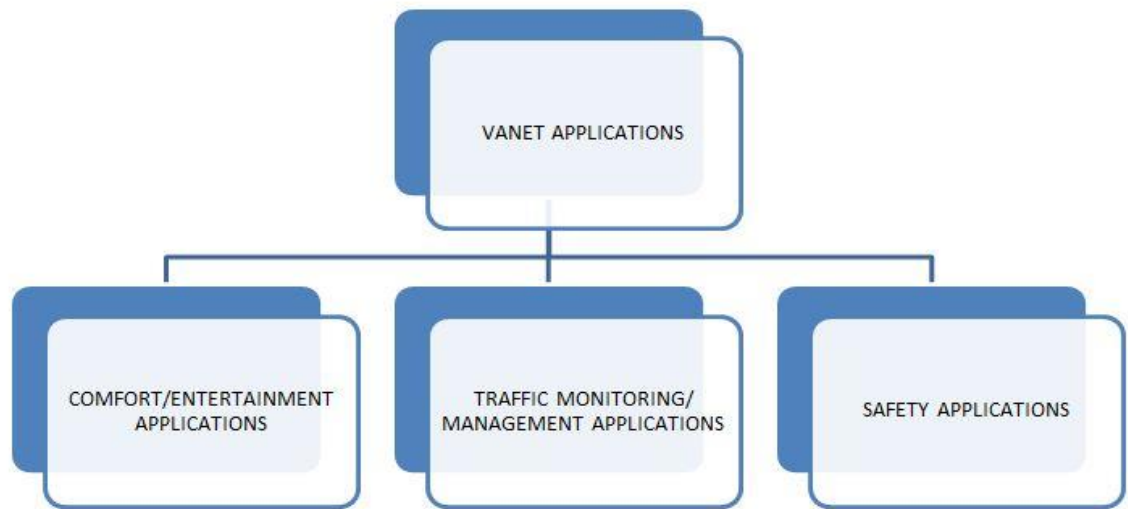
Figure 2.5 VANET Applications

In [42] applications in VANET can be described as: Entertainment / Information Applications, Traffic Monitoring / Management Applications and Safety Applications [38, 39, 40, 41] as Figure 2.5 shows.

2.6.1 Entertainment/Information Applications

The Entertainment/Information Applications, sometimes, called non-safety applications, aiming on increase the efficiency of traffic and ensuring comfortable journeys for drivers. It also focuses on informing passengers about variety of things such as: weather, nearest fuel station, restaurants menus or it could be informing them about parking space in a specific car park. Apart from all this, it also provides facilities to access internet services on the way [3, 25, 26]. As the focus of this research is more on the safety of the vehicles and drivers and avoidance of collisions on a road, therefore, the more emphasis is place on the safety applications in the next section.

2.6.2 Traffic Monitoring / Management Applications

The main aim of these applications is to improve the vehicle traffic flow by assisting and coordinating the vehicles [39]. This category can be further divided into two main categories [42]:

- *Speed Management Applications*

- *Co-operative Navigation Applications*

One of the examples in this field is Traffic Speed Camera Controls, which can be varying from one street to another according to the speed limit that will be allowed in each one.

2.6.3 Safety Applications

In 2012, the US Department of Transportation [27] specified that there have been an increasing number of people that get injured and killed in car crashes, which causes more rising expenses in healthcare to billions. However, some governments paid the attention to the growth in wireless communication between vehicles i.e VANET, specifically how to support the road safety in order to benefit these communications to avoid accidents [40, 41, 118, 119, 120].

As stated in Section 2.4.2, Dedicated Short Range Communication can be varying from the US (5.9 GHz) to EU and Japan (5.8 GHz). DSRC can support two types of communications, firstly, V2V, which allow exchanging the data between vehicles, secondly, V2I, which provide the communications with RSUs. Moreover, safety applications are based on DSRC, which contains seven channels with 10 MHz width each. As Figure 2.4 shows that channel 178 represent the safety communications.

The information thus obtained is processed and warning messages are sent to the other vehicles or RSU depending on the functions of applications. The application of wireless communication technology within the vehicles not only allows communication of vehicles with each other but it also enables the functions of several other safety applications, thereby leading to the enhanced road safety level. Furthermore, safety applications employing V2V and V2I communications can be categorised as follows [3]:

- Public safety

- Sign extension

- Vehicle diagnostics and maintenance

- Intersection collision avoidance

- Information exchange with other vehicles

The overview of categories of safety applications can be seen in Table 2.1.

The goal of this work is to design a routing protocol for emergency vehicle utilising a context-aware system approach in VANET. The application has the potential to increase road safety and prevent accidents by intersection collision avoidance, detecting the NLOS situations and issuing the warning messages in timely a fashion to other vehicles in VANET.

Safety Applications	
Intersection Collision Avoidance	1- Traffic Signal Violation Warning 2- Stop Sign Violation Warning 3- Left Turn Assistant 4- Stop Sign Movement Assistant 5- Intersection Collision Warning 6- Blind Merge Warning 7- Pedestrian Crossing Information Designated Intersection
Public Safety	1- Approaching Emergency Vehicle Warning 2- Emergency Vehicle Signal Pre-emption 3- SOS Services 4- Post-crash Warning
Sign Extension	1- In-Vehicle Signage 2- Curve Speed Warning 3- Low Parking Structure Warning 4- Wrong Way Driver Warning 5- Low Bridge Warning 6- Work Zone Warning 7- In-Vehicle AMBER Alert
Vehicle Diagnostics and Maintenance	1- Safety Recall Notice 2- Just-in-Time Repair Notification
Information from Other Vehicles	1- Cooperative Forward Collision Warning 2- Vehicle-Based Road Condition Warning 3- Emergency Electronic Brake Lights (EEBL) 4- Lane Change Warning 5- Blind Spot Warning 6- Highway Merge Assistant 7- Visibility Enhancer 8- Cooperative Collision Warning 9- Cooperative Adaptive Cruise Control 10- Road Condition Warning 11- Pre-crash Sensing 12- Highway/Rail Collision Warning 13- V2V Road Feature Notification

Table 2.1 Safety Applications [3]

2.7 Overview of Context-Aware Systems

2.7.1 Context

The word context is derived from two Latin words, 'con' meaning with or together and 'texere' means to weave. On the basis of these two words, context is defined as a comprehendible process which is undertaken to develop a meaning to the immediate environment by weaving different experiences that have been acquired over a certain time period. A number of researchers have tried to give a meaning to the word context, and felt it was a challenging process [28].

A definition of context states that context includes information about identities, locations and objects present in an environment [29]. Context is comprehended as a user's identity and present location, which analyses and represents a number of factors present in the environment [30]. Synonyms, such as background, circumstances and situation, have also been used by a number of researchers to describe the word context [31, 32]. Another researcher discussed context as the knowledge a computer system has about the environment of the user [33].

Hull et al [32] stated that context has been mentioned as an entity which defines a certain situation or environment. In terms of communication networks, context is a physical environment in the current situation. In the words of Schilit et al. context has three different aspects, where an individual is, with whom the individual is and what are the resources available to the individual [34].

Context is also stated as a state of interest connected with a specific person or place; moreover, it is also referred to as the current information about an environment

[35]. Among all the aforementioned definitions, it is difficult to choose the best possible definition; however, Dey [31] made efforts to make the definition more simple and understanding. Dey stated that context is a set of information which describes the basic characteristics of the situation of an entity. An entity can be referred to as a person, object or place which is related to the current situation, and relates to the interaction between a user and application. A user or an application can also be referred as an entity.

The most comprehensive definition of context comes from Dey and Abowd who says "context is any information that can be used to characterise the situation of an entity. An entity is a person or object that is considered relevant to the interaction between a user and application, including the user and applications themselves" [36].

2.7.2 Context sensing

A system needs to be aware of the environment in which it is processed and get the information about the environment to the users. This is known as context awareness for the system [37]. As was pointed out earlier, context is the information about the environment which the system gets from its surroundings. This acquired information is known as context awareness. This context is captured with the help of sensors. Sensors, during the course of discussion in this work, not only mean the hardware sensors, but also mean all the data resources which may supply important information to systems. As Baldauf stated; sensors can be categorised into three parts, which are discussed below [37]:

Physical sensors: Using a hardware sensor to capture any physical data, they are the most commonly used sensors. Some of the common physical sensors are listed below.

- *Light sensors:* This is the optical type of sensor which provides information about the light, such as light density, light reflection, wave length, and type of light (artificial, natural).

- *Camera:* A camera provides visual information about the environment, shape and object recognition up to a great extent. Cameras have a low cost and are easy to use; therefore, they are widely used devices.

- *Microphones:* Microphones provide the input type information, such as speaking, music and noise. Microphones with high power consumption come with the speech recognition feature.

- *Location:* Outdoor location about the user can be found using GPS and GSM, whereas indoor information can be found out using Active Badge.

- *Temperature:* In some applications, it provides valuable information, such as it is used to measure the body temperature.

- *Touch sensors:* This is a device which works only if it is touched by an object.

- *Motion detector:* This device consists of the physical mechanism and electronic sensors. This device works with a moving object which falls within its range.

Virtual sensors: virtual sensors capture information through software applications. With the help of virtual sensors, the location of students can be assessed by their activity of logging in to or out from the university campus without using any hardware sensors (for instance GPS).

Logical sensors: logical sensors are used to solve the bigger problems by using context information. Logical sensors obtain this information from both, physical and virtual sensors. For instance, the exact location of the student can be found out by using both GPS information and the logging in/ out information in the campus.

From the above discussion of the sensors, it is clear that different sensors are used for collection of the data regarding the vehicle, environment and the drivers. The physical sensors have the advantage over other sensors in terms of capturing the data in real environment during the driving. Depending on the goal of current project associated with receiving the warning messages to the destination, the physical sensors can play an important role and seems the most suitable for capturing the data from the forwarding vehicles and transferring it to the nodes near destination node in cooperatively manner. Furthermore, the architecture designed for the proposed protocol, benefits from OBU (the details viewed in Chapter 4).

2.7.3 Context Modelling

2.7.3.1 Various Approaches of Context Modelling

For achieving the goal of the context which is related to the processing and storage of the raw data, there is a need of a context model that will help to specify how

to store the raw data in the processing form of a machine. Various approaches of the context model have been summarised by [86] as follows:

Key-value model: Key- value model is considered to be one of the easiest forms of context modelling, which gives certain details such as Name: Sam, Time: 03:00 pm, Current Location: home. This model is being applied at a very rapid rate as it can be managed very easily. On the other hand, this model of context modelling lacks in potential for complicated structuring for adequate retrieval algorithms of context.

Mark-up scheme model: Mark-up scheme model consists of mark-up tags and is considered as a hierarchical data menu in which the dimensions and subjects are included. Some other types of mark-up tags are linked to the subjects of the mark-up at a very rapid rate.

Graphical model: Unified Modelling Language (UML) is a kind of language that acts as a tool of general modelling that consists of graphical tools which are more competent. Due to the generic structure of the UML, it has become possible to context the model. In order to operate an Entity Relationship model (ER- Model), only this type of unified modelling will be relevant. This derivation of an ER-Model proves to be more fruitful for relational databases in the management of building of the context system for structuring tools.

Object oriented model: A dynamic characteristic of the context has been a significant point of concern, which aims at gathering and multiple usages. Various details that are required in this model in the processing of the raw material will be

compressed at an object level, and the specified interfaces will only help in approaching the contextual information.

Logic-based model: The facts, expressions and rules are included as a context in this logic-based model, which requires various sets of other expressions in order to reach the sourcing of the concluding expression. Logic-based model is observed as having a high degree of formality in all.

Ontology-based model: Concepts and their interrelations are being specified by the ontology which defines this context. Context Broker Architecture (CoBRA) [87] system is considered as a good example in terms of the context of modelling that uses the ontology. This will also help in judging the entities by contributing the set of ontological concepts.

2.7.3.2 Salient Features of Context Modelling

The raw coordinates supplied by the location sensors actually provide the context data which can be used directly by applications [88]. For building a context-aware model, the following requirements should be fulfilled [89]:

Heterogeneity: The context model should be able to utilise different types of sensors for collection of data for downstream applications.

Dependencies: The context model needs to gather the contextual data relating to various entities and should be able to build relationships and shown dependencies among them.

Timeliness: The context histories should be captured and stored by the context models.

Imperfection: Due to the nature of heterogeneity, the context models can gather inaccurate information; therefore, the context model needs to resolve these inaccuracies.

Reasoning: The context model should have the capability to perform reasoning on the data acquired from the sensors to show the processed and refined messages to cope with the given situation.

Usability: The outcome obtained from the context model should have utility in terms of fulfilment of the objectives of the model, and should also be able to provide information about different entities included in the model.

These features are required to design the warning message propagation model utilised by the proposed CVP for this project. The context aware system will collect the data about the source emergency vehicle, by using different types of sensors, and reasoning will be performed on data to reach the outcomes which will help the vehicles on road to avoid the collision with emergency vehicles. Consequently, the context aware system is an integral part of the architecture proposed for the design of routing protocol in this project. The next section will shed light on the context –aware system.

2.7.4 Context-Aware Systems

The system consists of the capability for acquiring the operations to the current context, known as current aware systems. Therefore, this system by assuming the context of the environment, aims to be more effective and efficient [37]. In 1994, the context-aware system (CAS) was first defined by [90] as a mobile application which will provide the capability of interaction in the environment of existing information. The context-aware systems has the capability to understand, notice, interpret, respond and includes the ability to use the information related to the environment and to make this information available to the users according to their requirements [91, 92].

Users are provided the services by the applications of the CAS, the CAS classifies the three different categories of processes that information to the application of context-aware; these processes are as follows [93, 94]:

Presenting information and services to users: In order to perform services, information can be either delivered to the user or can be presented on the choice of certain actions, e.g. GUIDE in [95].

Automatic service execution: On account of a user, the system is required for conducting a service and for performing any suitable action, e.g. Teleport in [96].

Attaching context information for later retrieval: This is an application that marks the collected data items with the required context data and information, e.g. Classroom2000 in [97].

2.7.5 Architectural Design of Context-Aware Systems

Architectural design is considered to be the process which defines a technical solution (framework, architecture, components, modules, interfaces, input and output data for the system, etc) for accomplishing the system's need. As described earlier that context-aware system furnishes the important data and services to users based on the environments and contextual information. For efficient and working operations, the context-aware system incorporates the following sub-systems [98]:

Sensing Subsystem: It is designed to gather information about various contexts using the customised set of sensors.

Processing/Thinking subsystem: This subsystem employs the various processing and thinking techniques.

Acting Subsystem: this phase represents the result of the systems which in this case the suitable services to users.

In order to develop context-aware systems, various architecture has been suggested such as, the conceptual layered architecture in [99] Figure 2.6.

Application
Storage & Management
Processing
Raw data retrieval
Sensors
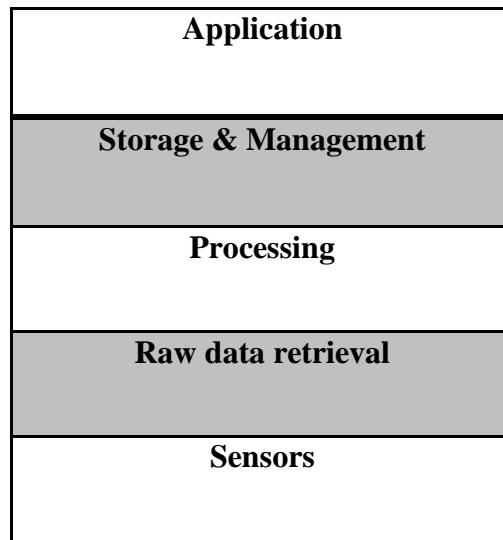
Figure 2.6: The five-layered context-aware systems Architecture [37]

The context-aware application represents the conceptual structure which consists of five levels. Sensors (physical, virtual and logical) are included in the physical layer, which is at the lowest level. The data layer is at the second level; to recover the raw context data, the data layer will be liable. In the third layer, the data which is captured is converted into valuable information, this layer is known as the processing layer. After the semantic layer, the managing and storing of the information is the liability of the fourth layer which is known as the storage layer. The name of the highest level is the application layer. This layer, for performing some definite actions, has to use the rational information from the previous layer.

The other architecture, called the Context Awareness Sub Structure (CASS) [100], is described in Figure 2.7. The middleware comprises the rule engine, interpreter, context retriever and sensor listener. The information collected from the sensors is stored in the sensor node. This information is stored in the database through the sensor listener. The context information is retrieved by the context retriever. Context retriever and sensor listener assess the interpreter services. Besides sensors, change listener and location finder have inherent communication capabilities.
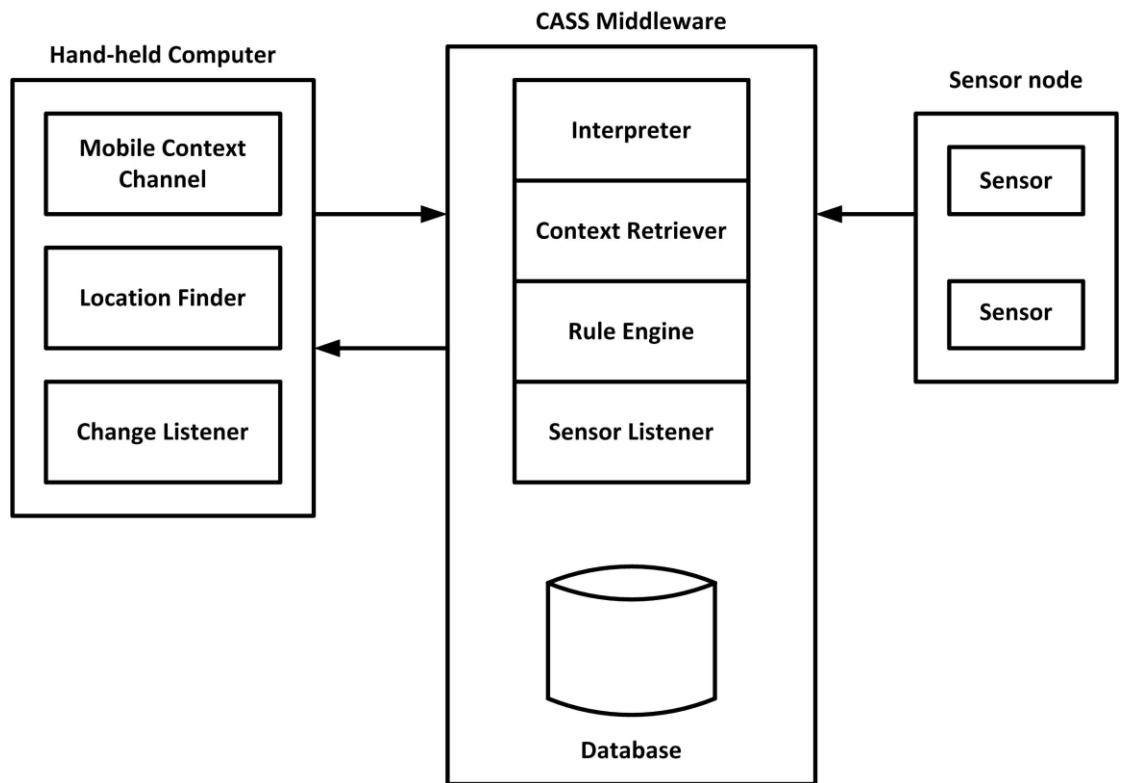
Figure 2.7: The context-awareness sub-system architecture [100]

Figure 2.8 depicts the architecture of the hydrogen project [101] which is based on three layers and located on the same device. The bottom layer is the adapter layer which retrieves the raw context data captured by the sensors. The second layer is the

management layer which supplies the context to the client applications and retrieves contexts. This layer is also known as the context server. The top layer is the application layer that allocates the appliance code.
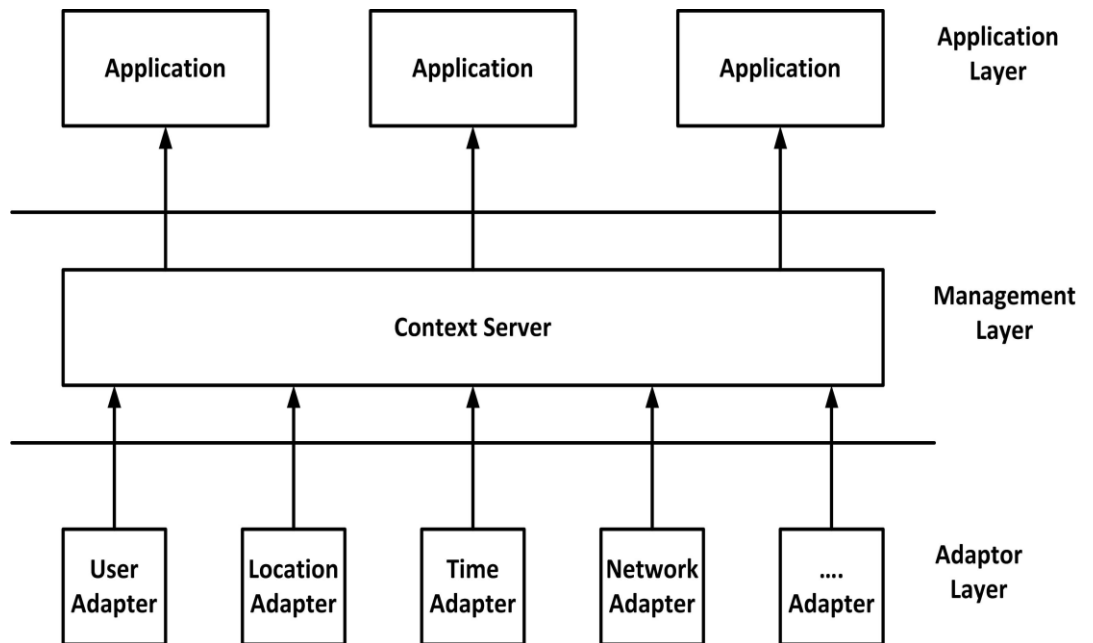
Figure 2.8 The Hydrogen Project Architecture [101]

Figure 2.9 shows the sentient object [102] which is an encapsulated object. This object has three components namely, context hierarchy, sensory capture and inference engine. This object communicates with the sensors and actuators. Sensors generate the software events and actuators utilise these software events generated by the sensors. Moreover, graphical tools are used to construct the sentient objects.
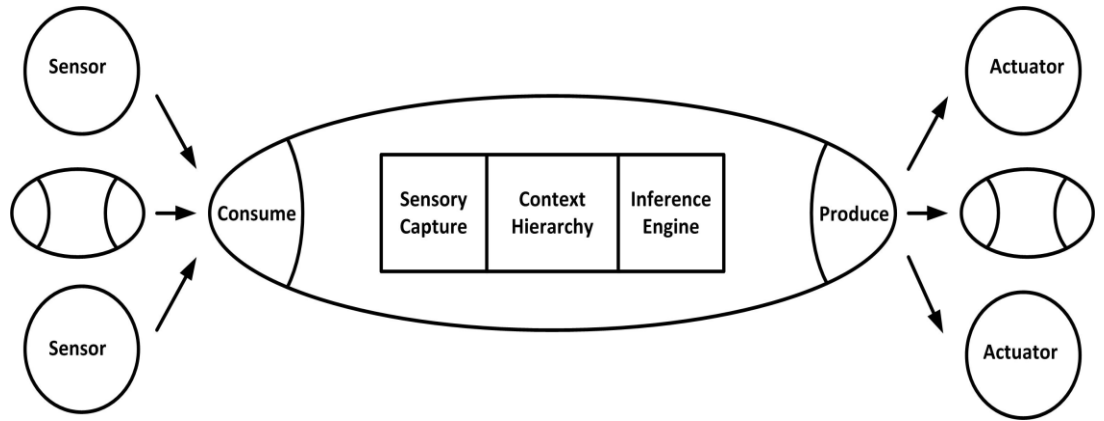
Figure 2.9 The Sentient object [102]

As described above, several context-aware systems architectures have been developed in different manners, in order to meet specific requirements. Some of them were aimed at constructing secure context-aware systems, while others sought to adapt the systems' behaviour according to their environment. Reviewing the above architectures revealed their similarity regarding the layers they incorporated (i.e. sensing layer and reasoning layer). However, they have several limitations such as: low performance processors, low storage capacities and a limited number of integrated sensors. Moreover, no architecture has been designed for a vehicle's OBU, which makes it impossible to use one of these in our system. Thus, it is essential to design a new OBU architecture for the purpose of detecting the NLOS in VANET, as the available architectures do not satisfy system requirements. Different kinds of sensors have to be integrated in order to capture information about the vehicle and the environment. The proposed architecture, which is designed to detect NLOS, is described in Chapter 4.

2.8 Summary

The overview of VANET, concept of context-aware, and context-aware systems are presented in this chapter. The focus is placed on the various techniques to model the context-aware environment along with a description of various salient features of context modelling. The main components of architectural design of context-aware system such as the sensing, data processing and decision-making phases are also presented.

An overview of wireless access technology has also been presented with a focus on applications in VANET. There are information, traffic monitoring and safety applications. The current research places focus on the safety applications due to their importance in preventing fatal road accidents.

Furthermore, the different categories of vehicle communication have been presented such as the InVC, IVC and Vehicle-to-Infrastructure communications. Different research works showed that V2I/I2V communication has attracted the research leading to resolution of issues faced by this field, while V2V communication is still facing many challenges that need to be tackled by taking further research. The challenges in Vehicle-to-Vehicle communication in VANET such as routing in VANET with obstacles preventing the effective communication between the vehicles have been presented in this chapter.

Chapter 3 discusses the challenges faced in message dissemination and an overview of routing protocols in VANET.

Chapter 3

Critical Analysis of Non-Line of Sight, Routing Protocols

Objectives:

- Challenges in data dissemination

- Factors impacting message dissemination

- NLOS types and challenges

- Overview of routing protocols

- Present a justification why focusing on Non-DTN

3.1 Introduction

Data dissemination in VANETs can be used to inform drivers or vehicles of traffic jams and to propagate emergency warning among vehicles (incidents or accidents) to avoid collisions. VANET improves the efficiency of traffic system, node mobility, extreme network density and changing topology from urban gridlock to rural traffic [43]. In Vehicular Ad hoc Network the delivery is either a single hop or multi-hop, in these situations vehicles can forward their requests to other vehicles and get responses in fractions of a second. Data disseminations have been investigated in the area of wireless sensor technique. The aim of data dissemination is to maximise the utilisation of network resources to serve the data needs of all users. In data dissemination, a single source node streams data to one or more link nodes. Many data dissemination protocols are proposed to disseminate information about obstacles, traffic conditions and mishaps on the roads [44]. Besides these there are some problems in data dissemination, for example, the vehicular network consists of a multitude of data sources and the data users which are mentioned in Chapter 2 Section 2.4; each vehicle potentially can serve as a data source and a user at the same time. Drivers' type of application, such as traffic management, situational awareness and commercial services share the same RSU [45]. Data broadcasting from a vehicle within the transmission range, which is done by flooding the network [104, 105]; in which each node receives the message and would simply rebroadcast the message without any regard to its current position or any other factors.

3.2 Challenges in Data Dissemination

In VANETs, reliable data delivery with low-latency over long distances, especially in urban areas, where several obstacles may disrupt the packets dissemination pathways, is paramount to the continuous and constant communication among the vehicles; and this is the requirement for the development of many applications, including alert of emergency situations, notifications relating to the traffic congestion and parking guidance system. In V2V communication, there are several barriers affecting the reliability and low latency of the warning messages to be delivered to the target vehicle [130, 131, 132, 133].

Important challenges in message dissemination in VANETs are discussed below:

3.2.1 High Mobility and Frequent Disconnect Topology

The issues of the frequently disconnected topology and high mobility are considered to be the main issues in VANETs. During the night in urban areas and both day and night in sub-urban areas, the density of vehicles is usually low, however, the vehicular density is high in downtown areas during rush hours in the day. These changes in network mobility and vehicular density often lead to the disconnection of the network. Furthermore, there is no single solution to deliver the data packets to all the recipients in the network [132, 134].

3.2.2 Data Delivery in Presence of Disconnection

In the case of the location of a vehicle close to the other vehicles or the RSU or in highly dense area, the disconnection does not pose a serious problem. Nevertheless, the issue of disconnection aggravates when there are several vehicles in the same area, using the same wireless communication media and requesting the same information,

along with the limited bandwidth and its usage [45, 135]. When the node in the network travels within 'the one-hop range' of the RSU, the delivery of data is carried out at the highest throughput [135]. Therefore, during the travelling of a vehicle near the RSU, it is highly desirable to extend the connection time to facilitate the higher rate of data dissemination for V2V or V2I communications [136]. Hence disconnection can reduce the capability of delivery nodes in the network to ensure the continuous data delivery to the target nodes in the network.

3.2.3 Data Distribution over the Mesh Nodes

There are several nodes in the network which form the mesh node for the distribution of data. However, it is difficult to keep these nodes connected for long times and over the desired distance to ensure the smooth flow of messages/data packets over them. A similar case can be described for the multiple RSUs connected wirelessly together to create an infrastructure mesh network which may cooperatively disseminate data to the traffic nodes, however the difficulty lies in the distribution of networks over these mesh networks [42, 137].

3.2.4 Data Passing through Different Structures is Difficult

Due to diversity in both topology and mobility of the network, it is really hard to establish and maintain different structures such as trees, grid and clustering for the data dissemination; and problems may arise due to sparse or dense network at random points in the network zone. Consequently, this situation may lead to the disruption and network partition and disconnection; if the node density is high in the network, the conventional mechanism for broadcasting the date packets may cause the broadcast storm issue [46, 106].

3.3 Different Types of Data Dissemination

Data dissemination can be referred to a process through which data packet/specific information is distributed over the different nodes in the network; this is considered to be an important component of VANET. Data dissemination over all nodes of the network simultaneously is not possible as it will consume the bandwidth space quickly, and bandwidth is another issue associated with VANETs. Therefore, [136] it is suggested to form the data aggregation scheme in a hierarchical fashion: the farther away a region, the data spread about the traffic situation will be poor. Moreover, the aggregation scheme relies on the summarised data and network capacity limits to store it; however, logically it seems a big challenge considering the constraints of limited connectivity and low data propagation speed associated with VANETs. Therefore, the data aggregation schemes are not suitable for the data dissemination in safety applications due to emergency and urgency demanded by such applications, while the data aggregation is widely used for the information/entertainment applications in VANETs. However, this drawback is reduced by applying the 'Event Suppression for Safety Message Dissemination' that aims to reduce the redundant transmissions [47, 107, 108].

The commonly used approaches for data dissemination in VANETs can be classified as follows:

3.3.1 V2I/I2V Dissemination

V2I dissemination approach involves two types of dissemination: pull-based data dissemination and push-based data dissemination. In the former, the data is transferred either from a vehicle to the fixed RSU establishing the V2I, or from the RSU

to the moving vehicles forming an I2V data dissemination pathway. This type of data communication is normally applied to develop the applications for e-advertisements and spreading the information about the road conditions. In the latter, any vehicle can communicate with the nearest RSU to query information about the specific target or location, and works on the principle of query-response model. This is used in applications used to enquire on information about the nearby restaurants, coffee shops, petrol station or parking lot [48].

The major drawback of this type of data dissemination is that it requires a lot of infrastructure to be installed along the roads for the constant communication, which is highly expensive; and low data dissemination speed and latency issues are associated with this approach as well. Therefore, this approach is not considered to be an ideal one for the data dissemination in safety applications.

3.3.2 Opportunistic Dissemination

This is a type of data dissemination strategy in which several vehicles in a particular zone rebroadcast the messages, thereby increasing the probability that all other vehicles in the network will receive the broadcasted information. However, this aggravates the situation in areas with a high density of vehicles, by increasing the load on the server, and so creating flooding and storm problems [138, 139]. Consequently it is not recommended to be used for the safety applications which require the specific information to be reached to the target vehicle in the network. This is suitable for entertainment or information applications in VANET [47, 140].

3.3.3 Geographical Dissemination

In VANETs, the topology of the network undergoes continuous changes, thereby resulting in changes in end-to-end paths of communication. This approach allows the delivery of a message to the target node by sending the message to the target node, then the next and so on until it reaches all the target nodes in the network [131]. The disadvantages of this approach includes high latency, lower success rate in terms of message delivery and broadcast storm, which make this approach less suitable for the safety applications and non-DTN applications [133].

3.3.4 Cluster-Based Dissemination

Cluster-based dissemination is based on the principle of dividing the network into several clusters and the information held by a node in cluster is not only shared with other nodes in the same cluster − intra cluster communication − but it also disseminates the specific information to neighbouring clusters. This scheme reduces the delay problem in sending the message and storm issue in the network significantly, but it requires a great deal of computational cost to connect the clusters with each other. In sparse environments, the clusters may be not located near enough to each other to establish the communication links. The solutions for facing obstacles may pose challenges in the application of such schemes with good productivity [49, 114, 115, 116, 117].

3.3.5 Peer-to-Peer Dissemination

Peer-to-Peer (P2P) data dissemination is based on the principle of communication of vehicles in V2V or V2I communication pathways, probabilistically. Whenever, the vehicle wants to share some information relating to warning messages,

entertainment information or conditions on the road, it communicates with neighbouring vehicles to release the information. In this way, in P2P solution vehicles mainly store the data and release it on the query in the network. The advantage of this type of dissemination is that it does not cause the message storm in the network and extra load on the server, however, it can decrease the bandwidth and storage capacity per node quickly, but this problem can be solved by using the cooperative caching approach as suggested [141]. They suggested that cooperative caching P2P dissemination scheme overcomes the challenges of low latency and reduction of load on sever in cooperative manner. For example, in the event of non-availability of some information in their cache, they will request information from the neighbouring vehicles or centralised control. This makes the cooperative caching P2P solution highly suitable for non-DTN Applications. Based on the advantages and suitability of the cooperative caching P2P solution for the present work, the researcher has used the cooperative caching P2P dissemination for this work.

3.4 Factors Impacting the Message Transmission in VANET

Many researchers have previously studied the various factors affecting the warning message dissemination in MANETs. However, VANETs can be distinguished from MANETs due to the special characteristics possessed by applications in VANETs. Consequently, in order to develop the application in VANETs, it is essential to take into account the most important factors affecting the dissemination of VANETs warning messages. The most prominent factors with their impact on performance of applications in VANETs are described below:

3.4.1 Number of Warning Vehicles

The safety applications used by vehicles are able to transmit the warning messages to the vehicles in close proximity, enabling the safety mechanism to be applied to avoid potential collisions and call upon the emergency services. In order to understand this mechanism, let us suppose that vehicles operate in two modes: normal mode and warning mode. When the vehicle is in warning mode, it sends the messages about its abnormal status to other vehicles in close proximity to alert them, and importantly messages are delivered to other vehicles periodically. Nonetheless, when the vehicles is in normal mode, it operates by diffusing the warning packets, and periodically sends the beacon messages to other vehicles in order to pass the information about its speed, position and services being used.

This factor holds critical importance when more vehicles go into warning mode, the more network traffic is established, thereby increasing the 'redundant rebroadcasts' which can mediate the long-lasting collisions and heavy contention in the network [142]. The warning message dissemination scheme is shown in the Figure 3.1.
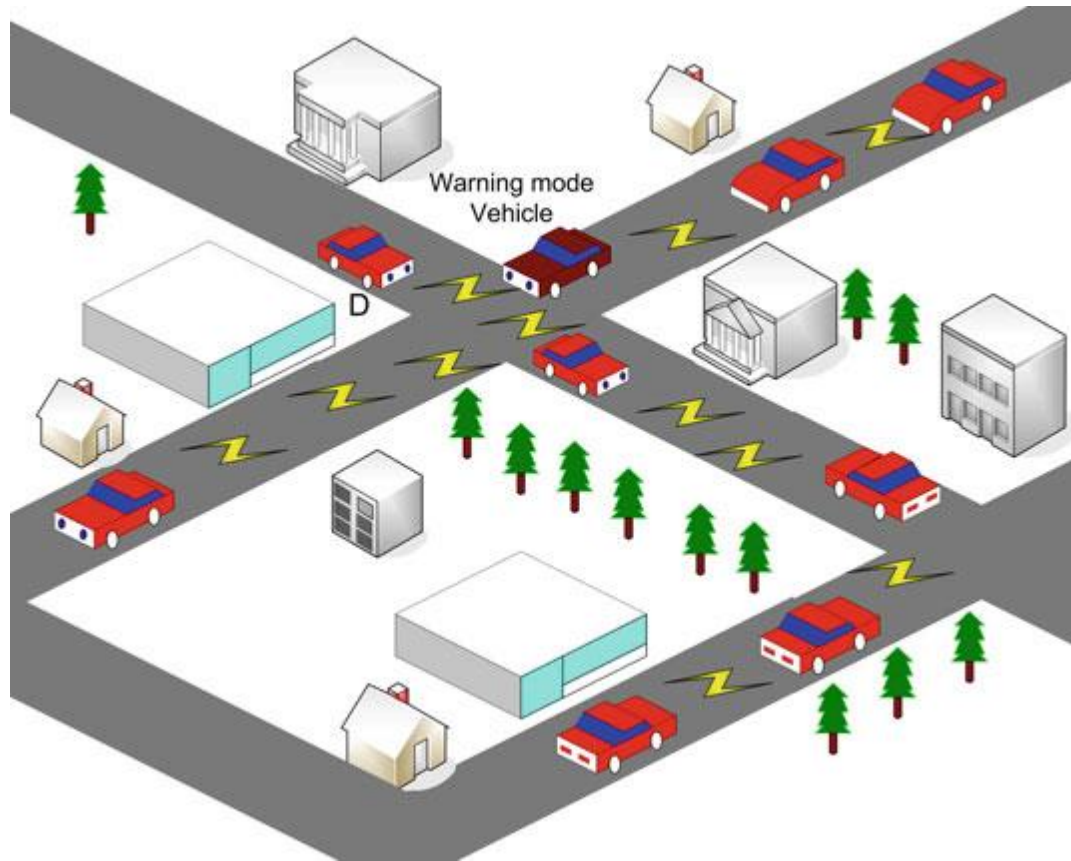
Figure 3.1 The scheme showing the dissemination of warning message in a VANET [142]

3.4.2 Density of Vehicles

The density of vehicles is unusually high in VANETs, causing the simulations work in VANETs to take quite a long time to finish. The problem faced by many simulators is scaling up the network. Most of the simulators are unable to scale the network very well, thereby leading to consumption of so much time and resources in dealing with the high-density issue during simulations of VANETs.

The previous studies showed that the high-density issue could affect the performance of VANETs in terms of dissemination of warning messages in different

scenarios [50, 51]. Furthermore some researchers [52] also concluded that vehicles could generate many other issues such as communication density, delays in messaging rate and shortening of transmission range.

3.4.3 Channel Bandwidth

The bandwidth is the term employed to denote the width of frequency band employed to send the data to the vehicles. Channel spacing is another term applied to describe the frequency difference between the adjacent allocations in the stipulated plan. The applications of various wireless technologies is expected to be used by the car industry in the near future to enable the V2V and V2I communications among vehicles and infrastructure, respectively, for example, IEEE 802.11p WAVE technology [53] which anchor 10 MHz and 20 MHz bandwidths. Based on the coding and modulation scheme, the data rates can range from 3 Mbps to 27 Mbps (3, 4.5, 6, 9, 12, 18, 24, 27) for a 10 MHz bandwidth. In VANETs, the efficiency of channel and its usage hold great importance in terms of managing the broadcast transmissions. The effective and efficient usage of transmission channel assists in reducing the overall interference, which in turn affects the performance of the broadcast reception [54].

As the vehicles are equipped with various types of application, such as information delivery application, entertainment and safety applications, and each of them uses different channel bandwidth for effective performance, this builds down to impact the channel bandwidth on the broadcast of messages to the other vehicles on the road. Similarly, this conclusion can be extrapolated to the case of Warning Message Dissemination; the channel bandwidth can impact the overall delivery of warning messages if the density of transmitters is elevated.

3.4.4 Broadcast Scheme

Broadcast Scheme is considered to be another important factor affecting the transmission of warning messages in VANETs. The intermediate vehicles serve as relay agents to transfer the warning messages to each other, thus establishing the end-to-end vehicular communication network. The issue of flooding normally is the major concern observed in applications such as traffic safety, route planning, traffic control and congestion control applications. The flooding also results in the occurrence of many other problems such as redundant broadcast of messages, collision of messages with each other (broadcast storm) and heavy channel contention [55, 106, 107, 108].

Over the last decade, researchers have tried to address the message storm problem in VANETs. Nevertheless, the most interesting approaches designed in this context are given below [56, 143, 144]:

The Counter-based Scheme: This scheme allows the application to count the number of messages received and thereby decide upon whether to inhibit the rebroadcast. This scheme is not used during the development of routing protocol for this work due to the cooperative approach taken to disseminate the warning messages to the target node in the network.

The Distance-based Scheme*:* This scheme utilises the approach of measuring the relative distance between vehicles and this information is used to decide whether re-broadcasting is necessary. This current work is based on the development of routing protocol using the cooperative approach of nearby vehicles to deliver the warning message to the vehicle under NLOS, the distance does not matter in terms of either broadcasting or the dissemination of warning message as the vehicles are supposed to

broadcast message through nearby volunteers within the communication range of requesting vehicles [111, 112, 113].

The Location-based Scheme*:* This scheme works on a similar principle as is used by the distance-based scheme. The purpose of this scheme is to determine the exact geometrical location of the vehicles in the broadcasting range which allows the vehicle to decide on continuation or disruption of the rebroadcast. Also, it allows the vehicle to estimate the coverage of rebroadcast. The current work aims to broadcast the warning messages to the vehicle under NLSO through the cooperation actions in terms of message delivery to the target vehicle. This requires the knowledge of the geometrical location of vehicles in the network; therefore, the location-based scheme is used to decide upon the need of broadcasting the warning message by volunteer vehicles to the vehicle facing NLOS.

The Cluster-based Scheme*:* In this scheme, the number of vehicles in a coverage zone is grouped into a cluster. The broadcasting of warning messages is controlled in such a way that each vehicle in the cluster (cluster head) receives the broadcast only once. This scheme will not be considered as the current work does not divide the area into clusters for message broadcasting, though a number of good protocols that have been proposed are based on this scheme [114, 115, 116, 117].

In VANETs, there are few rebroadcasting schemes developed to control the message storm problem such as '*weighted p-persistence*, the *slotted 1-persistance* and the *slotted p-persistence* [57]. The salient features of these techniques include the probability and timer based suppression of transmissions of warning messages which are reckoned to mitigate the issue of broadcast storms by setting the nodes with high priority and

allowing them access to a channel based on their urgency. However, their ability to mitigate the broadcast storm is limited as they are mostly designed for highway scenarios.

There is another scheme called 'The Last One (TLO) scheme's [58] which tries to mitigate the message storm problem by searching for the distant vehicles in the network and marking them as the only nodes in the network for rebroadcasting the warning messages. Nevertheless this scheme disregards the impact of buildings and other obstacles in the way of the sender and the recipient vehicles; therefore, it was not applied to construct the routing protocol for this thesis. Enhanced Message Dissemination based on roadmaps is another scheme designed by [50] which utilises both roadmaps and location of the vehicles to disseminate the message effectively and efficiently in 802.11p-based VANETs.

The foregoing account easily sheds light on the fact that most of the techniques and solutions are devised to address the storm problem in obstacle-free environments or line of sight situations, however, these solutions cannot be applied to the complex urban situation where plenty of obstacles in the form of buildings, vehicles and foliage can interfere with the dissemination of warning messages, unless the intermediate nodes are utilised to top forward them by overpassing the obstacles. Therefore, the current work tried to develop the comprehensive solution to overcome the storm problem and create more forwarding intermediate nodes to disseminate the warning messages in NLOS situations.

3.4.5 Message Periodicity

As previously described, vehicles in warning modes send the warning messages periodically to other vehicles in the network, nevertheless, the vehicles in normal mode operate on the principle of diffusion of warning beacons. Also these vehicles send beacons to other vehicles to communicate some important information relating to their speed, location, etc, to other vehicles. If the number of warning messages is increased in a given time, it increases the redundancy issue of rebroadcasts, message collision and channel contention. Hence, the periodicity of the warning messages is considered to be an important factor which provides a trade-off between overhead and performance.

3.4.6 The use of Mobility Model

Defining a vehicular mobility model to study context-aware VANETs is one of the major challenges. Therefore, the selection of mobility to be used for the development of routing protocol holds great importance, and that the selected mobility model should fulfil the criteria of providing a realistic and accurate description of vehicular mobility at both microscopic and macroscopic levels [59]. In order to be a realistic model and perform realistic simulation, the selected mobility model is required to provide a microscopic picture of the traffic flow by extracting the network topologies from real maps.

3.4.6.1 Justification of Selection of EstiNet as a Mobility Simulator

The mobility simulation for the current research work is performed with EstiNet [60], which has all features required to complete the simulation for this project. For example, it can show the microscopic traffic capabilities like traffic lights, junction-based right-of-way rules, collision-free vehicular movement, presentation of multi-lane

streets with options of street and lane changing, etc. Furthermore, EstiNet has the capability to import the roadmaps from OpenStreetMap [61].

In the proposed mobility simulations described the various areas having different vehicular densities. In real urban situations, the flow of traffic is not evenly distributed; for example, the points of downtowns and junctions may have a higher density of vehicles compared to other areas. Therefore, the concepts of downtown and point of interests has been utilised in this research.

There are several simulators tools which can have different capabilities to offer, such as OMNeT++ [124], NS-3 [125], Mininet [126], EstiNet [127]. Wang [60] mentioned, EstiNet has all the features required to complete the simulation for this project. For example, it can show the microscopic traffic capabilities like traffic lights, junction-based right-of-way rules, collision-free vehicular movement, presentation of multi-lane streets with options of street and lane changing, etc. Furthermore, EstiNet has the capability to import the roadmaps from OpenStreetMap. In the proposed mobility simulations described the various areas having different vehicular densities. In real urban situations, the flow of traffic is not evenly distributed; for example, the points of downtowns and junctions may have a higher density of vehicles compared to other areas. Therefore, the concepts of downtown and point of interests has been utilised in this research. Table 3.1 shows a comparison between some of these tools which was made by [60] to clarify that EstiNet is a better choice in this research.

	EstiNet	ns-3	Mininet
OpenFlow Specification	**1.1.0/1.0.0**	**0.8.9**	**1.0.0**
Simulation Mode	✓	✓	-
Emulation Mode	✓	-	✓
Compatible with Real-World Controllers	✓	-	✓
Result Repeatable	✓	✓	-
Scalability	**High** by Single Process	**High** by Single Process	**Middle** by Multiple Processes
Performance Result Correctness	✓	**No spanning tree protocol and no real-world controller**	**No performance fidelity**
GUI Support	✓ • Configuration • Observation	✓ • Observation Only • Using C++ for Configuration	✓ • Observation Only • Using python for Configuration

Table 3.1 A Comparison between EstiNet, NS-3 and Mininet [60]

3.4.7 Radio Propagation

It can be noticed that most of the simulation tools such as OPNET, SUMO, OMNET++ and NS-2 operate without inclusion of a Two-ray Model that is recommended to provide desired accuracy and efficiency for movements of vehicles [62]. However, the simulations provided by these tools do not take the presence of obstacles (vehicles, buildings) into account; therefore, they are described as overly optimistic [145]. For instance, the Two-Ray Ground (TRG) radio propagation model overpass the effects like radio-frequency attenuation effect caused by various obstacles

such as vehicles, foliage and buildings, therefore, it demands that the introduction of a new model should be taken into account for the NLOS situation. In NLOS situations, the dissemination of warning messages is highly dependent on the distance between the sender and receiver vehicles, and the nature of obstacles between them.

3.4.8 Roadmap

The road topology or roadmap is considered to be an important factor giving the description of mobility in simulation environments, as the topology is known to contain the vehicular movements. Generally, the road topology of an urban environment is represented by the graphs with vertices and edges, where the former shows the junctions and the latter represents the road elements. The user can obtain the simulated road topology randomly by making use of applications or can be extracted from the roadmap databases. However, if complex layouts are used, their processing requires a greater computational time, but the outcomes obtained through this draws closer to the real environment [50]. Most of the research work has used Manhattan-style street grids – the diagonal arrangement of streets and the highway scenarios excluding the junctions, however, the urban scenarios in their real environments are selected rarely, though they should be selected to show that outcomes obtained are likely to be comparable to realistic environments.

3.5 Issues Addressed By This Work

This work focussed on solving the critical issue of storm broadcasting, latency and detection of nodes in network facing the NLOS. The storm broadcasting is a real issue which arises from the broadcast of the message periodically by all the nodes in the

network. This can lead to the channel contention and blockage of the channel in VANET. There is already a serious issue of limited channel width in VANET. The storm problem causes the collision of messages with each other, resulting in the dissipation of packet energy, and disappearance of warning message packets before they are delivered to the destination. Similarly, the nodes under NLOS situation cannot receive the packets of warning messages from the source vehicle due to presence of nodes blocking the travel of packets from the source node to the node under NLOS situation.

Furthermore, this situation becomes even worse when the vehicles (source node) are in state of emergency and required other vehicles on the road to clear the path for them, non-propagation of packet to the nodes under NLOS situation can lead to serious road accidents between the normal vehicles and emergency vehicles. Therefore, this work considers designing the routing protocol which can detect the NLOS situation in network, ensures the delivery of warning packets from the source node to the node under NLOS, and storm problem is solved by recruiting the volunteers around the node facing NLOS situation. The volunteering nodes interact cooperatively in order to pass down the message to the node under NLOS. Thus, this work has proposed CVP, the details about which can be viewed in Chapter 5, which tried to solve the forgoing issues in VANET network regarding the dissemination of warning messages to all vehicles present in the network.

3.6 Non-Line of Sight Situation and Location Verification

Vehicle communications are vulnerable to signal interference as they travel in different environmental conditions. Physical objects and construction on the sides of the road (i.e., buildings, trees and area topography) can interfere with radio signals and prevent proper communication. Moving objects such as trucks can also interfere with communication between vehicles and could block a driver's visual and communication line of sight, creating a NLOS state, which can lead drivers to make poor judgements when changing lanes or merging onto a highway.

3.6.1 NLOS Types

Figure 3.2 shows that NLOS can be either intentional or unintentional. Intentional: malicious attacks, fake position. Unintentional: physical obstacles (trees, buildings) or moving obstacles (trucks- e.g. industrial area).

The proposed work considers the unintentional NLOS which will be based on either physical or moving obstacles [3, 7, 9].
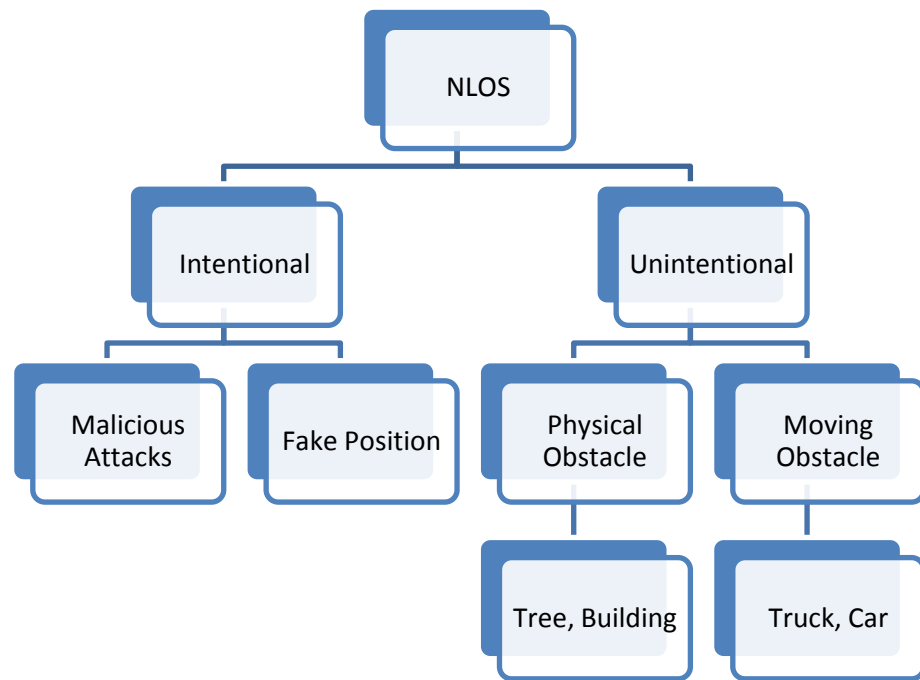
Figure 3.2 Types of NLOS

3.6.2 The main challenges in NLOS

Many researchers in the literature covered the challenges that might cause or affect the NLOS from different perspective as follows [3, 5, 7, 8, 9]:

3.6.2.1 Communication

- Signal strength

- Communication range

- Signal blockage

- Sender authentication

- Signal interference

3.6.2.2 Security

- Message forging

- Tampering with the messages

- Attacks on reply messages

- Wormhole attacks

- Invading the privacy

3.6.2.3 Location

- Verification of position of the nodes

- Reliability of message senders

- Availability

- Issues concerning with the quality and integrity of service

The current research work tries to tackle the issue of signal blockage by the obstacles in the communication of message to the vehicles under NLOS situations (hidden node). This study also tries to verify the location of the hidden node so that the warning message to be delivered to it avoids a fatal collision on the road.

3.6.3 Location Verification

Several researchers have proposed the location verification techniques for the hidden nodes in wireless networks. These approaches are generally categorised into two classes, depending on the underlying principle of propagation models: distance information methods for location verification (infrastructure-based verification methods) and the distance-free approaches (infrastructureless-based verification

method). The distance-based method such as ECHO protocol for location verification that is proposed by [146] is based on the challenge response.

The location verification methods developed by [147, 148] verify the location of the hidden node by calculating the distance of three detecting nodes from the hidden node or target node. Similarly, [149] proposed a scheme which uses some reference points around the hidden node to verify the claim of the target node (node under NLOS). The second category of the location verification – distance-free approaches – is based on the principle of utilising the distance information; and location claim are verified through the location-measuring techniques, such as angle of radio signal communicated between the detecting and the target nodes [150]. However, in comparison with the distance-based technique, distance-free schemes do not require the exact estimation of location of the hidden node, which is why they do not face the issue of localisation, especially in a sparse network. Therefore, the application of distance-free schemes (infrastructureless) is more beneficial than the distance information-based schemes [63, 151]; Figure 3.3 shows the approaches of position verification. This work is based on cooperative verification which uses an infrastructure-less environment.
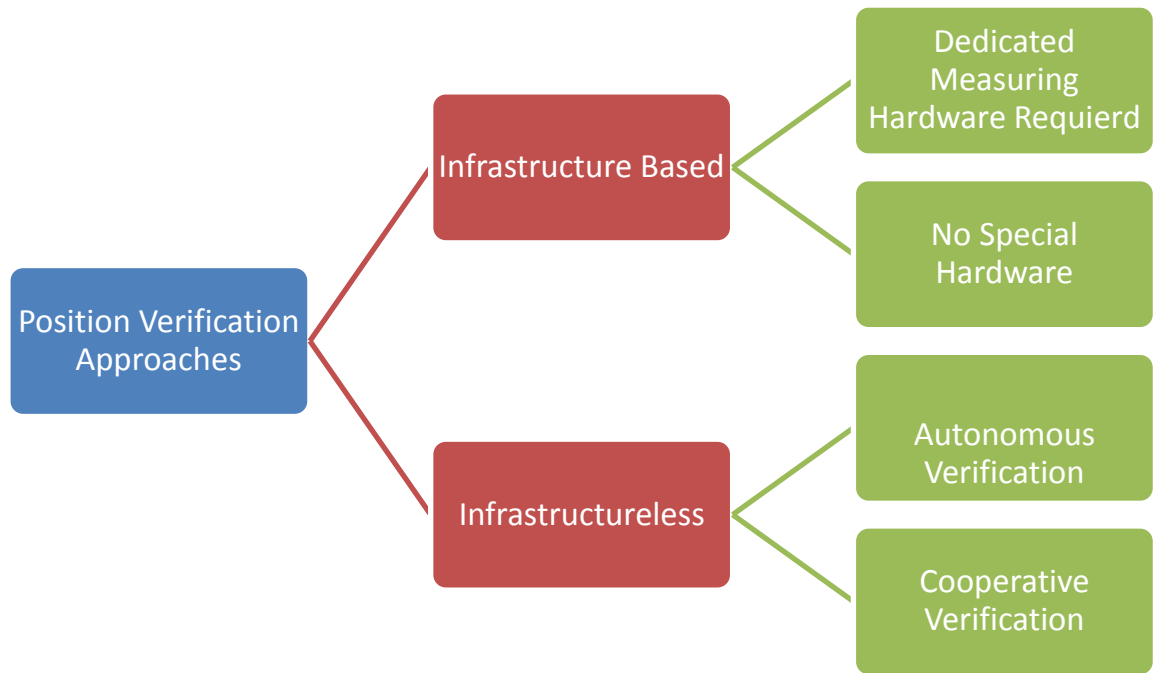
Figure 3.3 Position Verification Approaches [63]

3.7 Overview of Routing Protocols

Until now, several routing protocols have been developed for ad hoc networks [3, 8, 37], however, all of these protocols have originally been designed for MANET which is considered to be characterised by highly dynamic characteristics of the network. Therefore, these protocols cannot be directly applied to the VANET environments. Based on the area of the applications, the different routing protocols applied to VANET can be categorised into the following categories (Figure 3.4): topology-based routing protocols, position-based routing protocols or geographic-based routing protocols.
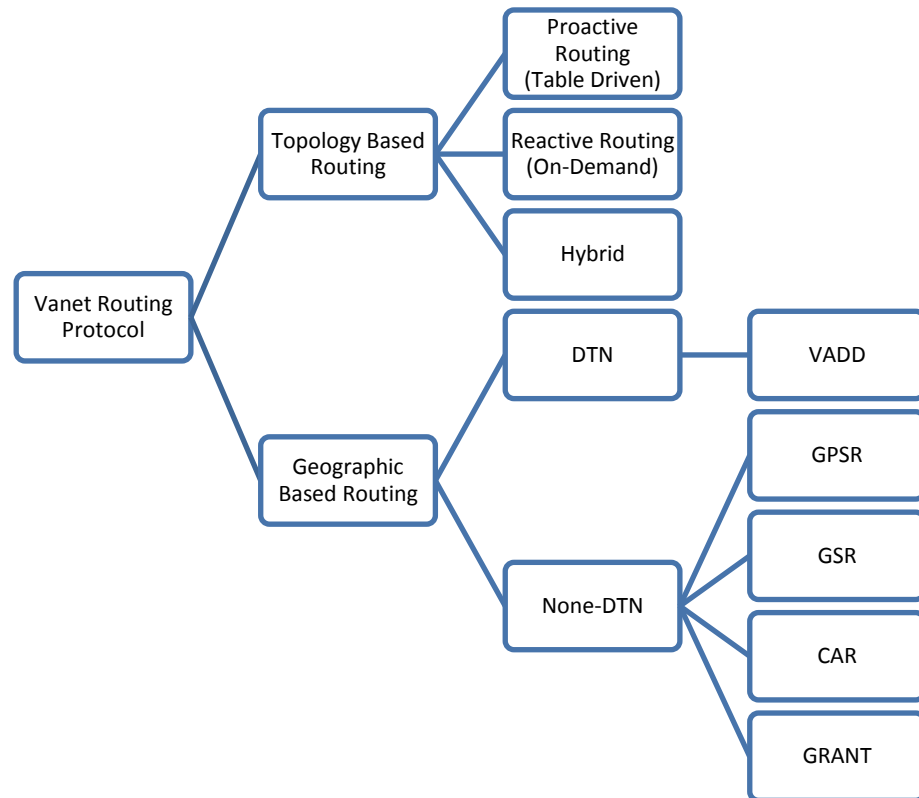
Figure 3.4 Classification of Routing Protocol in VANET

3.7.1 Topology-Based Routing Protocols

These protocols are characterised by their feature of saving information of link in the form of tables prior to delivery of data from the source node to the destination node. In order to support the functionalities of these protocols, many algorithms have been developed. Based on the network architecture, these protocols have further been divided into two categories: proactive and reactive protocols [64].

3.7.1.1 Proactive Routing Protocols

These protocols have also been termed as table-driven protocols, since all the nodes in the network store the information and network topology in the form of tables

that is sharable to other nodes in the whole network. Whenever any node has change in the network, it updates its table and delivers it to the next-hop node, thus the information is delivered to all of the nodes in the network. The flooding method is used to exchange the information to all the nodes of the work, and tables are updated periodically. The difference between the various proactive routing protocols lies in their methods of detecting the changes in the VANET environments, updating the information tables and mode of information storage in the routing tables [65, 66, 67].

In this category, there are two important routing protocols: distance vector and link-state routing protocols. The distance vector routing protocol involves the application of a 'classical Bellman-Ford routing algorithm, that allows it to maintain the list of number of hops and the destination nodes in the routing table of each node [68, 69, 152, 153]. In contrast to the distance vector routing protocol, the link-state routing protocol uses the short path first (SPF) algorithm to compute the best path from the network topology through the development of knowledge about the entire topology of the network [154, 155].

Here are the advantages and disadvantages of proactive routing protocols [156, 157, 158, 159]:

Advantages:

- These protocols do not require discovering the route as the information about the destination node is maintained in the background.

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- These protocols provide the best 'end-to-end' transmission of messages with high load costs.

- They also reduce the overhead and bandwidth consumption significantly.

- The routing table is not subject to changes in the event of link failure, which means that data to be conveyed to next-hop will be delivered without any changes.

Disadvantages:

- Poor performance is observed in the case of small VANET environment.

- They can easily provide the knowledge about the nearby nodes, but cannot supply any information relating to the distant nodes.

- With increase of network size, the issues with storage and increase in overhead are the common challenges with this type of routing protocols.

- They also increase latency issue for real-time applications in VANET; therefore, they cannot be used in real time applications.

3.7.1.2 Reactive Routing Protocols (On Demand)

These protocols were originally designed to tackle the challenges faced by the proactive routing protocols; therefore, they are called reactive. They are also called On Demand routing protocols as they only become activated when there is a demand to find a route of destination to send the message from the source. Furthermore, it creates routes between the required and requested nodes in order to deliver the message to the destination [70].

The concept of reactive routing was proposed by [70] in an attempt to decrease the bandwidth consumption and excessive information updates as observed in proactive routing protocols. The important routing techniques applied for implementation of these types of protocols are hop-by-hop and source routing. The former consists of all the necessary information required to construct the route for packet delivery between the sender node and the recipient node, and the intermediate nodes located between the source and the destination nodes. The role of intermediate nodes is to receive the information from the source and to store it in the header of the packet. However, in the case-source routing, the intermediate nodes after required to update all data received from the source for the purpose of delivering it to the destination node. This technique of packet delivery is used in several reactive routing protocols such as Ah hoc ON-Demand Distance Vector (AODV), Dynamic Source Routing (DSR) [71, 72], Temporarily Ordered Routing Algorithm (TORA) [74, 75], Preferred Group Broadcasting (PGB) [160], Single Stability Based Adaptive Routing (SSAR) [78], Junction-Based Adaptive Reactive Routing [76, 77], discussed in detail in papers [157, 161, 162, 163, 164, 165, 166]

Here are the advantages and disadvantages of reactive routing protocols [156, 157, 158, 159]:

Advantages:

- It decreases the network load by creating and maintaining only required routes of pack delivery from the source to the destination.

- It saves bandwidth to the significant level in comparison with the proactive routing.

- In order to update the routing table, on-demand flooding is used.

- In contrast to proactive protocols, it does not need to maintain the each and every path of the given network for the communication of messages from the source to the destination.

Disadvantages:

- It has high latency of route finding, since route is discovered on demand and spontaneously rather than doing so in advance.

- The disruption and discontinuity of the network can occur to the sudden and excessive flooding.

- Some protocols in this category such as AODV required extra bandwidth for the successful delivery of packets.

3.7.1.3 Hybrid Protocols

Hybrid protocols are developed in response to the issues and challenges associated with both proactive and reactive routing protocol. Architecture of these protocols is based on the routing strategies from both proactive and reactive protocols in such as a way that it will offset the issues resulting from the application of either proactive or reactive protocol [167]. For example, the network strategy of hybrid protocols involves the formation of nearby zones for the message dissemination to the target node. This strategy not only increases the network scalability, but it also decreases the route discovery overheads that may be encountered by proactive routing protocols during route maintenance to the neighbouring nodes [168, 169].

In this way, most of the routing protocols of this type are zone based, which means the network is divided into multiple zones for the dissemination of the message from the source node to the destination node [170]. Moreover, in this type of protocol, each node partitions its surrounding network into two zones: the one which is closer to the given node, called inner layer, and the other which is far away from the given node and closer to the destination node, called outer layer. Proactive approach is applied in the zone near to the given node for periodic information updates on routing between the nodes in a given network; and the process of periodic updating continues regardless of the bandwidth constrains network load and network size [171].

Thus, it can be argued that inner layer is more proactive and that it is responsible for maintaining the up-to-date and easy-to-maintain route, whereas the outer layer is more reactive and determines the need of the construction of routes based on a demand basis. Consequently, it employs a global search procedure to set up a communication link with another host with which it has no established route. The typical examples of hybrid protocols include the Core Extraction Distribution Ad hoc Routing (CEDAR) algorithm [81] and Zone Routine Protocol (ZRP) [80].

Here are the advantages and disadvantages of hybrid protocols [156]:

Advantage:

- It successfully tried to overcome the flaws resulting from the applications of proactive and reactive routing protocols.

Disadvantages:

- The drawback of such type of routing protocol is that they cannot work efficiently in the sparse environment where the packet delivery ratio is increased. Even though these protocols try to reduce the flooding issue to considerable extent, but still the flooding is reported an important challenge in the dense traffic environment.

3.7.2 Geographic-Based Routing Protocols

This class of routing protocols is regarded being highly suitable for the VANET environments, as it locates the position of the vehicle in the network for message dissemination rather than searching for the optimal route for the communication of information. In this type of protocol, the information relating to the source node, intermediate nodes, and the destination node is retained by all vehicles present in the given network [133].

These protocols perform effectively and efficiently in terms of reducing the overheads, compared to the topology-based protocols [165]. Similarly, the network performance of the protocols belonging to this category is considered to be better than topology-based routing protocols, primarily because of the creation of links between the nodes only when the message dissemination is required. There are many components associated with these protocols, including the location service, beaconing, forwarding and recovery techniques [172]. The decision of forwarding the message and selecting the best route for message dissemination to the target node lies with the source node. The position of the destination node is maintained by the source, and the position of the next hop neighbour is taken into consideration for initiation of the packet's delivery to the target node [159].

The strategy of dissemination is based on the principle of locating the immediate node by sending the periodic beacons with random jitters, the nodes included in the radio range of the given 'immediate node' act as neighbours of that particular node, and takes the responsibility of forwarding the message to their own neighbour nodes and so on. The assumption behind the working principle of geographic-based routing protocols is that each node possesses the required information about its surrounding which is easily obtained through the GPS fitted into the OBU and navigation system [157, 158, 162].

Generally in this type of routing protocol, the information about the location of the destination is received through the location services, whereas the information about the neighbours is received through the messages or beaconing. In the absence of a location server, the quorum-based location is fitted into the OBU of the vehicle or the 'fully distributed location service' can be used for this purpose. The proposed protocol for this thesis falls in the category of geographic-based routing protocol. In order to detect the hidden node, the aim of this thesis is design the routing protocol, which will locate the hidden node by using the position information of the surrounding vehicles [157, 173].

Following are the advantages and disadvantages of geographic-based routing protocols [156, 157, 158, 159]:

Advantages:

- They perform better than topology-based protocols in terms of reducing the overheads and network size.

- They are considered to be highly convenient option for a high mobility environment as in VANET.

- These protocols are known to keep the data about location of vehicles effectively and deliver the required information to the destination in a faster way.

- They are highly suitable for safety based application in VANET, and helps in preventing the accidents on the road.

Disadvantages:

- The functions of these routing protocols are highly dependent on the requirement of GPS.

- Sometimes, location services are either not available or not in the required range.

- GPS services are not functional in the tunnel environment due to unavailability of satellite signals.

The geographic-based routing protocols are categorised into two types: Delay Tolerant Network (DTN) and Non-Delay Tolerant Network (Non-DTN) [174], as shown in Figure 3.4.

3.7.2.1 DTN – Geographic-Based Routing Protocols

These protocols are also called distribution tolerant networks, as they are regarded as an effective remedy for the issue faced during the message dissemination in allowing density environment, such as the rural highways, non-peak hours such as night

conditions and sparse sub-networks in urban scenarios. In urban scenarios, the high density of vehicles, high mobility and sparse situations in certain areas of the network mean frequent disconnections are observed due to disruption of end-to-end communication between the nodes [175].

A carry-and-forward strategy is adopted by DTN protocols for successful transmission of the messages to the destination nodes in the network, for example, if the intermediate nodes are not available due to less dense situations in the network, the sending vehicle stores and carries the message in the buffer zone, unless it finds intermediate nodes which can forward the data packets to the destination node [153, 154, 176]. The best example of this strategy can be manifested during the implementation of vehicle assisted data delivery routing protocol (VADD), which will be explained in the next sub-section.

Following are the advantages and disadvantages of DTN-geographic-based routing protocols [156, 157, 158, 159].

Advantages:

- DTN routing protocols perform efficiently in the network characterised by large unavoidable delays, rapid Disconnectivity during message dissemination, huge scalability, restricted bandwidth, power constraints and high fault tolerance.

- DTN may serve as a mobile node capable of creating the routes towards other nodes once the nodes in the transmission range are found in the work,

which increases the reliability of communication and connectivity of the network.

Disadvantages:

- The restricted transmission range features each node, resulting in long delays in the packet transmission.

- Disconnectivity cannot avoided in the DTN protocol, as the data packets stored and carried by the sending vehicle may be lost or may not be delivered to the intermediate vehicle successfully due to potential long delays in finding the right intermediate nodes in the transmission range.

- It cannot detect the hidden nodes in the network, thus transmission of warning messages to the node can be obstructed by obstacles (big vehicles or buildings) that can result in serious situations on the road.

3.7.2.1.1 Vehicle associated Data delivery Routing Protocol

This protocol is based on the store, carry-and-forward strategy relying on the predicable vehicular mobility for dissemination of the message from the source node to the destination node. It considers road layout, traffic patterns and mobility of vehicles for selection of the next hop for delivery of data packets to the final node [83].

VADD is useful for many applications to be used in various scenarios such as emergency warning message dissemination and resolving situations of traffic jams. VADD assumes that every vehicle in the network is equipped with the digital maps, traffic statistics (vehicle speed and vehicle density), and street level maps for sending

messages wirelessly and selecting the road with higher speed to decrease the delay in transmission of warning messages [153].

Here are the advantages and disadvantages of VADD routing protocol [156, 157, 158, 159]:

Advantages:

- VADD is designed to significantly reduce the issues in VANET such as problems of data delivery and latency in packet delivery.

- VADD outperforms GPSR (with buffer), DSR and epidemic routing protocol

- It is considered to be suitable for multi-hop delivery of the packets to the destination node.

Disadvantages:

- VADD is not suitable for the network suffering from continuous changes in topology and high traffic density such as observed at intersections and urban scenarios.

- Large delays in the delivery of packets to the destination node are reported for this protocol, especially under conditions of highly dense traffic environments.

3.7.2.2 Non-DTN Geographic-Based Routing Protocols

The basic principle which forms the basis of the greedy approach is that a node in a network delivers the data packet to its closest neighbours around the destination node. However, if the forwarding node is unable to find the closest neighbour to the

target node than itself, it is said that packet has reached its local maximum at the given node, as it has attained the maximum local progress at that given node. Therefore, these protocols are suitable for the urban environment with high mobility and traffic density, as they require a pair of vehicles in order to establish the connection. The typical examples of such protocols include Greedy Perimeter Stateless Routing (GPSR) and Greedy Routing with Abstract Neighbour Table (GRANT). The proposed Cooperative Volunteer Protocol for this thesis belongs to the category of Non-DTN routing. The detailed layout and mechanism of CVP will be described in Chapter 5.

3.7.2.2.1 Greedy Perimeter Stateless Routing

GPSR is one of the best examples of Non-DTN geographic-based routing protocols, which utilises the data relating to the closest neighbour nodes to the destination for the delivery of packets efficiently. The knowledge about the positions of the destination knowledge and intermediate nodes are maintained within the routing metrics used by this protocol, thereby making it a stateless protocol. The protocol is able to function in two modes: greedy forwarding and perimeter mode [84].

When the forwarding node has some intermediate nodes closest to the destination node, the greedy mode is switched on, so as to deliver the data packets to the intermediate nodes for forwarding them to the destination node [155]. Nevertheless, in case the intermediate node is not available, which is closest to the destination node, the greedy modes is switched off. Then the perimeter mode is switched on to forward the data packets to the vehicles moving in perimeter unless they find some intermediate nodes closest to the destination, then the greedy mode is restored to disseminate the packets successfully [160, 177].

The concept of the perimeter mode switching follows the right-hand rule with the starting vector. For example, if the greedy mode is switched to the perimeter mode at node *x*, a virtual vector is mapped from the intermediate node x to the destination node D. The forwarding of packets by node x to the next hop is performed through the edge of the vector anti clockwise from the vector. The data packets will be shifted back to the greedy modes as the delivery of packets to nodes closer to node D is executed; otherwise they will be dropped at the completion point of loop [157].

Following the advantages and disadvantages of GPSR routing protocol [156, 157, 158, 159]:

Advantages:

- The greedy mode of forwarding data packets to the destination keeps the existing and current positions of the forwarding nodes in the metrics, which assist in reducing the distance to the destination and information is transmitted to the destination in the shortest period of time.

- Decisions of forwarding data packet are carried out by the protocol dynamically.

- The protocol needs to remember and interact with the next-hop only for the successful delivery of data packets.

Disadvantages:

- The implementation of GPSR protocol is executed by drawing a planar graph; otherwise the cross link scheme terminates the forwarding process by creating the routing loops causing a drop of packets.

- Issues such as obstacles in the form of buildings or big vehicles may cause the disruption in the process of creating a planar graph, therefore the inaccuracies and inconsistencies in the planar graph may lead to the failure of GPSR in the case of the NLOS situation.

- The information about the mobile destination node in the network is never updated in the 'packet header of the intermediate node'.

- In VANET environments characterised by the high mobility pattern, the stale information in relation to the positions of intermediate nodes is often retained in the neighbour table and sending nodes, causing the saturation of messages in storage places of the routing protocol.

3.7.2.2.2 Geographic Source Routing Protocol

The GPSR was not suitable to be applied to overcome the radio obstacles in the way of the packets and the destination node. Consequently, GSR was designed to overcome this challenge [173]. This utilises the road layouts and maps in order to discover the shortest possible way to deliver the packets to the destination node.

It works well in the dense environment of urban areas and also uses road layout for discovering routes. GSR uses Reactive Location Services (RLS) to know the location of the destination. For the effective functioning, it combines the principle of the geographic routing with road topology knowledge. This protocol makes use of the simple graph algorithm for finding the shortest route to the destination node and identification of destination is marked with the packet delivery point [178].

3.7.2.2.3 Connectivity-Aware Routing Protocol

This scheme is position-based routing which is based on the microscopic model developed and implemented by [171]. This protocol works well in the inter-vehicle communication in dense city environments and highway scenarios. CAR protocol was developed in order to solve the issue of breakage in the end-to-end connectivity in VANET. The main principle of operation of this protocol is to keep the source and destination connected, even when the shortest path is not available. This task is accomplished by utilising the 'route discovery process' before the dissemination of real data to the destination node. This is due to the fact that the shortest path may suffer disconnectivity or disruption in the network, whereas the long path remains connected [156].

Here are the advantages and disadvantages of CAR routing protocols [156, 157, 158, 159]:

Advantages:

- It does not face issue of local maximum as is observed in the case of GPSR.

- It does not require the digital map for the path discovery.

- The packet delivery ratio of CAR protocol is higher than GPSR, which shows the ability of this protocol to find the shortest path for the delivery of data packets to the destination node.

Disadvantages:

- During the message dissemination phase, unnecessary nodes can be chosen as an anchor.

- When the traffic environment undergoes massive changes due to high mobility characteristic of VANET, it faces some issues in adjusting the different sub-paths in the network for discovering the optimal routes.

3.7.2.2.4 Greedy Routing with Abstract Neighbour Table

This is a very efficient and effective non-DTN protocol, which works on the principle of extended greedy routing where each node in the network has knowledge of its neighbouring nodes, giving each node a broad vision to take decisions regarding the selection of the best route for avoiding the local maximum situation. For selection of next forwarding hop E, the following parameters are used: multiplying the distance between the node N, distance of E from the destination, the shortest path between the E and N, and the charge per hop for multi-hop neighbours. The choice of only hop E offering the shortest path between E and the destination and E and the node N is made as a next hop for warning message dissemination [158, 179].

Interestingly, GRANT divides the plane into several small areas; and each area contains only one representative hop. The representative hop determines the number of neighbouring hops and chooses the suitable one for message dissemination to the destination node. This protocol adopts the propagation model assuming that there are radio obstacles in the urban scenario, disallowing the hops to communicate with each other. Therefore, it has the smallest path length and number of packets recovered per route than the traditional greedy routing protocol [156, 179].

Here are the advantages and disadvantages of GRANT routing protocol [156, 157, 158, 159]:

Advantages:

- The extended greedy routing scheme adopted by GRANT performs well in urban environments with many obstacles such as buildings and trees.

Disadvantages:

- It floods the smallest areas in the plane of the network, resulting in short-range flooding.

- The important performance metric such as packet delivery ratio is not included in its absolute performance metric; therefore, the true performance of GRANT cannot be validated.

- The performance evaluation of this protocol has been done on the static traces, which means its application to VANET environments with high mobility characteristics is not well established.

- The inaccuracies in packet delivery ratio and overheads are not measured for GRANT.

3.8 Why Focus on Non-DTN Networks?

The protocols described above (DTN protocols) were originally designed for the MANET, and their application in the VANET environment does not give the best results, due to the dynamicity of VANET. The geographic-based routing protocols are considered to be more appropriate for VANET than the topology-based routing protocols.

Therefore, most of the routing protocols that are developed for VANET used the greedy routing strategy and assume that every node in the network keeps the knowledge about its surroundings and destination. However this assumption fails in case of the hidden node in the network; where the other nodes cannot communicate with it due to the presence of obstacles. Emergency vehicles approaching an intersection in urban areas or moving on the highway can, if the hidden nodes are disseminating the warning message, cause fatal collisions between the emergency vehicles and the vehicles hidden by any obstacles. In such situations, only the cooperation of vehicles with knowledge of emergency vehicles with other vehicles and the use of greedy routing strategy can be employed effectively to locate the hidden node and subsequently deliver the warning message to it. Therefore, the focus of this thesis is placed on the non-DTN type routing protocol rather than DTN type routing protocols

The current research aims to devise a unique routing strategy called the extensive greedy routing, as used by GRANT protocol, combined with a cooperative approach to locate the NLOS situation in urban scenarios and disseminate warning messages to hidden nodes or the node facing the NLOS situation. Thus the proposed protocol will be called Co-operative Volunteer Protocol and will fall into the category of Non-DTN routing protocols due to utilisation of the greedy routing strategy. The detailed mechanism of the proposed CVP discussed in Chapter 5.

3.9 Summary

In this chapter, a comprehensive analysis of the literature relating to the various protocols provides an overview of the concepts of broadcasting schemes and challenges

in VANET broadcasting environment. This chapter described in detail the challenges in data dissemination in VANET. Also, the different types of data dissemination are elaborated along with factors impacting the message dissemination in VANET. Moreover, the chapter introduced the NLOS and the challenges needed to be tackled in NLOS. Signal blockage and location verification are considered to be important challenges in the NLOS situations. The existing routing protocols are designed for MANET, so their suitability in VANET is challenged in many aspects, such as the topology-based routing protocols being more suitable in the MANET environment than the VANET one. However, position-based routing protocols are more suitable for VANET due to their strength in coping with issues like mobility in VANET.

The geographic-based routing protocols have expressed high performance for several situations, such as highly dense environments in urban areas. Nevertheless, the Non-DTN routing faces some challenges in communication with the hidden nodes, which can impact on their performance in the urban environment with a plethora of obstacles in the form of trees, buildings and vehicles of various sizes. This is the motivation of focusing on Non-DTN networks to solve the issue of communication with the hidden nodes through the development of robust routing protocol.

Chapter 4 presents the novel OBU architecture of the proposed protocol.

Chapter 4

Context-Aware System On Board Unit Architecture

Objectives:

- Present a novel OBU non-line of sight detection architecture in VANET

- Describe the three phases of the proposed architecture which designed based on the concept of CAS

- Define the proposed OBU architecture's components

4.1 Introduction

As mentioned previously in Chapter 2, the proposed architecture will utilise the five-layered context-aware system's framework (Figure 4.1) in order to make the system more intelligent, aware of the surroundings event and cost effective. The OBU architecture which has been presented in this thesis will be used in every vehicle in the system, in addition to a Warning Message Byte (WMB) – warning message data packets (which will be described in Chapter 5) that will inform the system about upcoming emergency events in order to deal with it separately. The next section describes each component in the system and how they interact with each other to reach the goal of the system by reducing the delays for emergency vehicles crossing an intersection and avoiding the storm broadcast problem in order to prevent fatal accidents from occurring.

Application	Acting Phase
Storage & Management	Thinking/Processing Phase
Processing	
Raw data retrieval	
Sensors	Sensing Phase
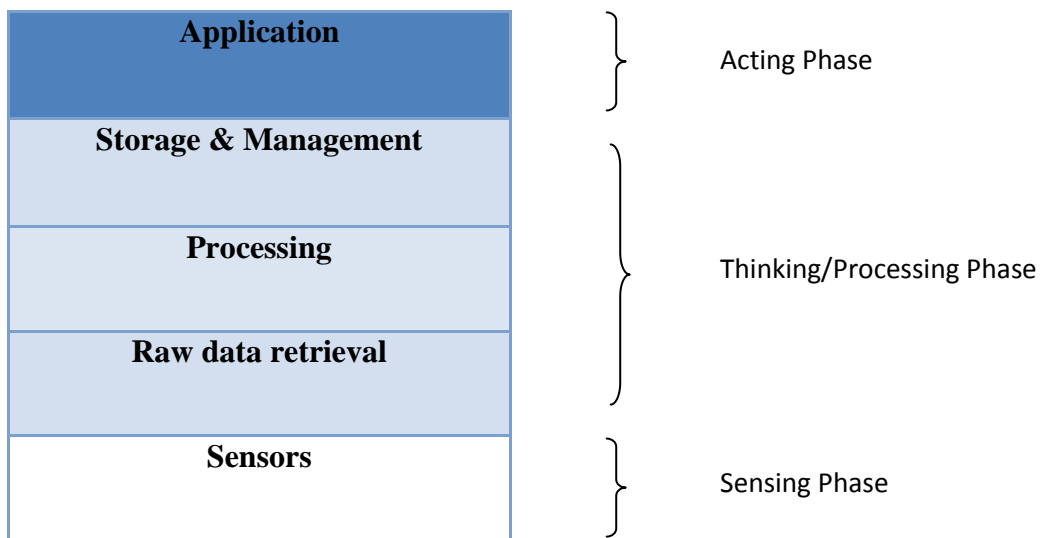
Figure 4.1 The Five-Layered Context-Aware System's Framework [37]

4.2 Architecture Based on CAS

The proposed architecture consists of three main phases as shown in Figure 4.1.

4.2.1 Sensing Phase

This phase is representing sensing layer in context aware system's framework (the proposed architecture). It represents the gate of the system and is responsible for gathering the raw data by collection from different sensors in order to process it in the next phase. There are three types of sensors: Physical sensors, Virtual sensors and Logical sensors, as described in Chapter 2 Section 2.7.2. the proposed architecture does use a variety of sensors as follows Figure 4.2:
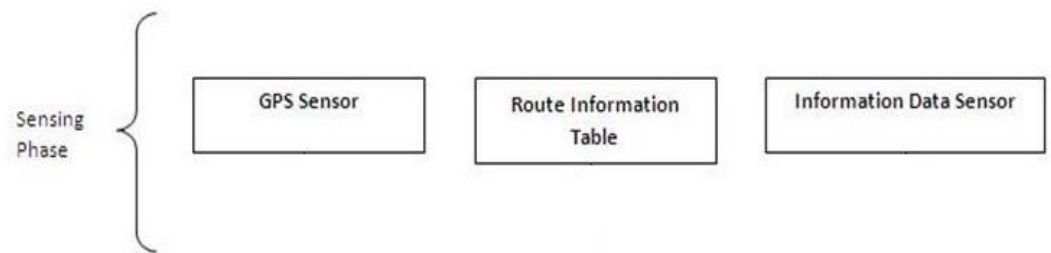
Figure 4.2 Sensing Phase

4.2.1.1 Global Positioning System

Determining the exact position is so critical in VANET; GPS will be used to find out the general information about the vehicles such as, speed, location and direction [3]. GPS represents the physical sensor that collects physical data.

4.2.1.2 Information Data Sensor

A virtual sensor that gathers data from a software application works only in an emergency event by adding an emergency header to the packet (WMB). Dealing with emergency broadcasts separately will benefit by reducing the delay and responding faster than dealing with it among other broadcasts. Also, this will help to enhance reducing broadcast storm problems. These sensors detect the approaching emergency vehicle through using their unique frequency channel. This sensor also captures the information from surrounding nodes, process them quickly in order to avoid the unnecessary collection of packets in certain areas of network, which can cause the broadcast storm issue.

4.2.1.3 Route Information Table

Each vehicle has its own routing information table, which is a table that contains all the information for the surroundings vehicles (speed, location, and direction), in order to send it to the processor to determine whether there is a NLOS condition or not, by using an NLOS Detecting Unit which will be discussed later. RIT will be used in two different scenarios: intersections and road disseminations (highway).

4.2.2 Thinking/Processing Phase

The processing phase is the core for the proposed system, representing three layers in the context-aware system's framework, these are: raw data retrieval, processing and storage. This phase directs the system what to do next by interpreting the raw data into action, in order to start the CVP to notify hidden vehicles about the upcoming events. The details of this phase can be found in Figure 4.4 at the end of the chapter.

4.2.2.1 Location and Direction Unit

This part is responsible for getting the general information about the emergency vehicle that sent the dissemination broadcast and all other nodes in the system by indicating location and direction. Using GPS will help to get this information. This unit is located in the OBU of all the nodes, and will detect the location and direction of the emergency vehicle and the hidden node.

4.2.2.2 Emergency Dissemination Unit

This part is responsible for receiving the raw data from the Information Data Sensor (emergency sensor) in order to interpret it. Getting serious emergency broadcasts separately will give it high priority and faster response. This unit contains one unit as follows:

4.2.2.2.1 Intersection & Road Coverage Control Unit

Crossing an intersection is one of the most dangerous situations for emergency vehicle mobility, it is so critical to cross it safely without any delay which will affect the vehicle arrival time. Using RIT will help to control intersections by knowing the position for every vehicle in the network. This unit will deal with road dissemination to detect if there is a NLOS situation or not. The unit is responsible for sending the WMB-Req in order to check the possibility of any hidden nodes in the system.

4.2.2.3 Storage Unit

This part represents the system database, which stores any information which other components in the system can access, in order to process that information, which

will enable the system to make the suitable reaction in the next phase. This unit contains the maps for both roads and intersection in the following unit:

4.2.2.3.1 Road& Intersection Maps

In the main storage unit there are pre-loaded maps for the road and all the intersections in it. After getting the direction information about vehicles in the system, this unit will help to determine on the maps where every vehicles will be heading and try to avoid fatal accidents from occurring.

4.2.2.4 Non-Line of Sight Detecting Unit

This part is responsible for all the tasks in the system. It is the core part of the proposed architecture, and is responsible for detecting whether the vehicle is in NLOS or not by comparing its RIT with the emergency vehicle's RIT to check if there is any vehicle not in the original RIT meaning there is a high chance it is in an NLOS position which will send it to the next phase to make a suitable response. The processing in this unit will decide whether to send the packet to the Directional Dissemination Unit (DDU) to start the voluntary process or ignore it (which will be explained in the third phase).

4.2.2.5 Power Supply

This part is controlling all the power in the system.

4.2.3 Action Phase

Once the system has got the raw data and sent it to the processer, it gets to the final stage which is the fifth layer in the context aware system's framework. This phase represents the result of the system by sending a directional message to the intended vehicles to notify them about the upcoming situation (Figure 4.3). Then the CVP

triggers the result by sending the WMB to notify the hidden nodes about the upcoming events. Chapter 5 will explain this mechanism in detail.
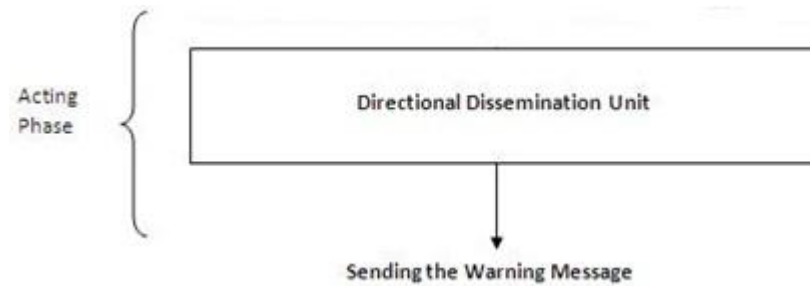
Figure 4.3 Acting Phase

4.2.3.1 Directional Dissemination Unit (DDU)

This unit will send the voluntary package (WMB-Rep) to the vehicles that are in NLOS conditions after getting the confirmation from the emergency vehicle. Directional dissemination helps to reduce the storm broadcasts problem by allocating the broadcasting to one sender.

Finally, Figure 4.4 shows a good explanation of how the OBU architecture's components interact with each other.
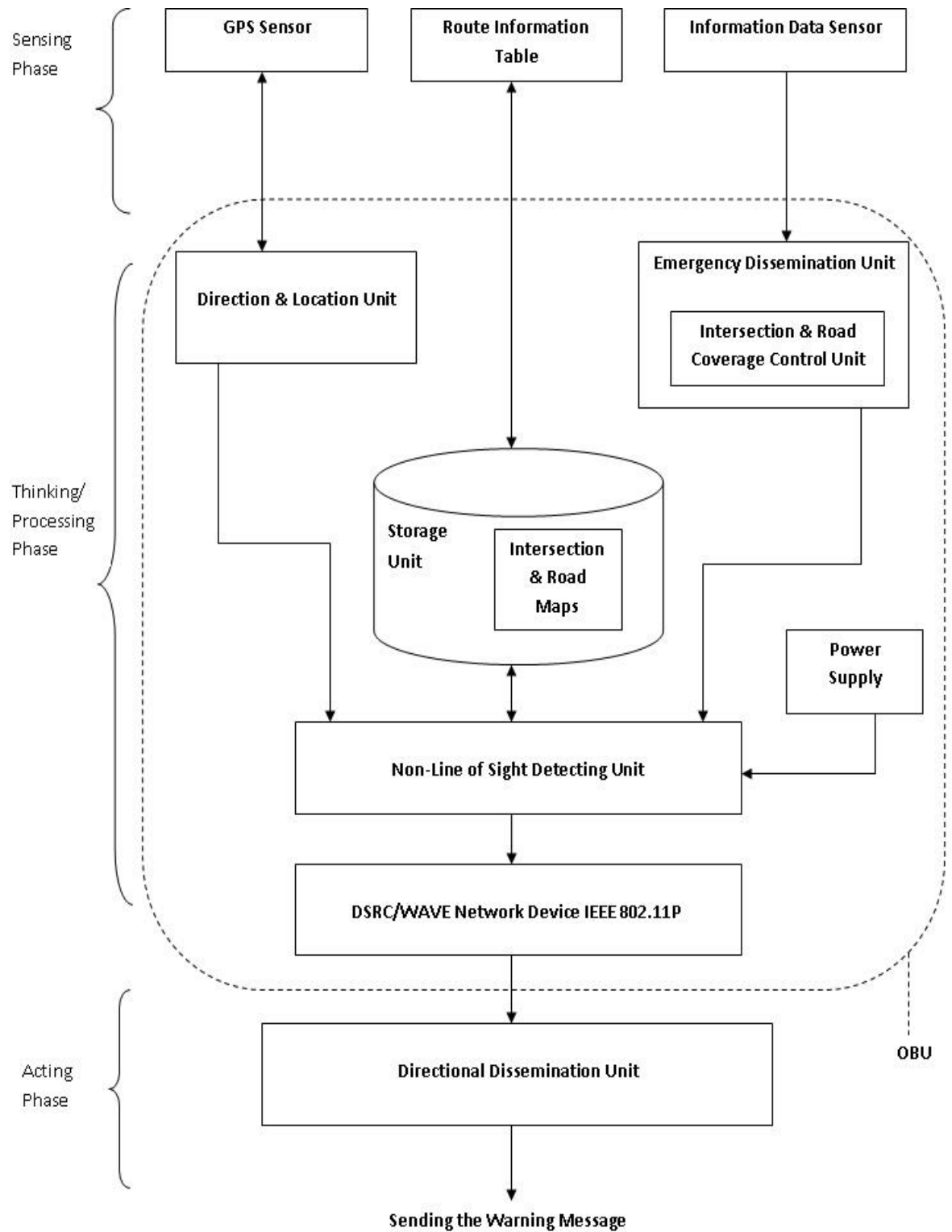
Figure 4.4 OBU Architecture Based on CAS

4.3 Justification why using this architecture

As described earlier in Chapter 2, several context-aware systems architectures have been developed in different manners, in order to meet specific requirements. Some of them were aimed at constructing secure context-aware systems, while others sought to adapt the systems' behaviour according to their environment. Reviewing the earlier architectures revealed their similarity regarding the layers they incorporated (i.e. sensing layer and reasoning layer). However, they have several limitations such as: low performance processors, low storage capacities and a limited number of integrated sensors. Moreover, no architecture has been designed for a vehicle's OBU, which makes it impossible to use one of these in our system. Thus, it is essential to design a new OBU architecture for the purpose of detecting the NLOS in VANET, as the available architectures do not satisfy system requirements. Different kinds of sensors have to be integrated in order to capture information about the vehicle and the environment. The proposed architecture, which is designed to detect NLOS, is described in this chapter.

4.4 Summary

A novel OBU architecture in VANET has been presented in this chapter, which has been designed by using the concepts from a context-aware system. The architecture has been divided into three phases: sensing phase, processing phase and acting phase. Together it comprises a five-layered conceptual framework. The motivation behind the development and design of this architecture is to deliver the warning messages to the hidden nodes successfully through effective detection of NLOS situations on the road in order to avoid accidental situations taking place on the road.

Chapter 5 illustrates the detailed mechanism of the proposed CVP and the functions of the various components of the CVP.

Chapter 5

Co-operative Volunteer Protocol

Objectives:

- Define the objectives behind developing the proposed routing

  protocol CVP

- Describe the mechanism of the proposed routing protocol

- Present detecting of NLOS phase

- Describe how RIT help to detect NLOS in the proposed protocol

- Present packet delivery phase

5.1 Introduction

A novel protocol for the V2V communication in VANET is proposed and presented in this chapter. Over the past few years, researchers have made considerable advances in terms of advancing the boundaries of VANET by developing and evaluating the new routing techniques and protocols [83]. However, the V2V communication domain has been largely ignored compared to the V2I domain, resulting in the generation of research gaps in the area of development of ad hoc networks. V2V communication in VANET is infrastructure-less, so it is much cheaper than the V2I type of communication which is much more expensive due to massive expenses incurred during the installation of the required infrastructure. Moreover, the change of nodes and the probability of utilisation of various nodes in the mobility model of V2V type of communication can be easily executed, which makes it the perfect choice for developing the new V2V communication protocol and establishing the links among nodes in a realistic environment. Consequently, the most important function of the routing protocols in VANET is to establish and maintain a stable and robust routes between source node and a destination node. During the design of this new routing mechanism, the most important consideration is to create a routing protocol with capability to prevent issues occurring from NLOS situations, thereby providing a guarantee that the next-hop node will follow the right trajectory on the road within a specific period of time [103].

As described in Chapter 3, the increased message drop ratio and the message storm issue serve as major impediments to the mobility in VANET, thereby by giving rise to the congestion arising from traffic backlogs and traffic control volume that is

necessary to maintain routes. The channel contention and collision of messages resulting in packet dissipation are the outcomes of problems faced by mobility nodes in the network in order to access the messages. Therefore, efficiency and responsiveness of the routing mechanism for detection of NLOS situation is the ultimate goal behind designing the CVP which is further aimed to reduce the warning message dissipation by increasing the packet delivery ratio and route stability.

The approach proposed in this chapter utilises different sources such as intersection roadmap, navigation system and the GPS system, routing information table (RIT) and warning sensors in order to obtain the information in relation to the speed, location and direction of vehicles, and subsequently activating the warning path in the protocol for dissemination of warning messages. This will ultimately result in timely delivery of messages to the target vehicles and thereby make the road safer for travellers. The proposed routing mechanism intends to create an effective route between the destination node under NLOS situation and source node. In addition, this reduces the flooding issue and minimises the overheads effects and link breakage rate.

The proposed model for warning message dissemination (CVP) detects the NLOS situation and delivers the warning message to the non-receiver node in the network by utilising the intermediate node (mediator node) to rebroadcast the message to those vehicles situated out of the coverage zone or the broadcast being blocked because of an obstacle. As mentioned in Chapter 3, there are several routing protocols which have been designed for emergency message dissemination to increase the reachability and to overcome storm problems. However, none of them is applicable to NLOS in particular, thus there is a need to develop the routing protocol to disseminate

the emergency messages to those vehicles without having to provide for accessing the message due to some obstacles between the sender and the receiver nodes. The basic purpose of this proposed routing protocol is to deliver the warning messages effectively and efficiently to those vehicles facing the NLOS situation in the network by using a novel technique, "Co-operative Volunteer Protocol" (CVP). The development of efficient routing protocol is the main challenge which needs to be addressed in order to deliver the warning messages successfully to vehicles under NLOS situations; and this is the main aim of this work.

The proposed protocol has been designed to increase road safety by reducing the number of accidents and fatalities caused by vehicular crashes. The utilisation of communication technology is regarded as a vital step for improving the safety and security status-quo on the roads.

Nevertheless, the application of wireless communication helps in prevention of road accidents by disseminating the warming messages to vehicles to inform them about the probability of collision so that they can take the corrective measures to avoid the fatal situations on the road. For example, information is communicated to the nodes/vehicles for avoiding the accidents on road; such as data relating to bad weather, traffic jams and emergency vehicles (police vehicle, ambulance) approaching from the other side of the road, blockages of roads due to accident or maintenance of roads. This type of information communication can be executed in different ways, for instance, to use vehicles to act as repeaters to exchange the information with vehicles in close proximity. This is also called V2V communication (more details can be found in Chapter 3 Section 3.3), in V2V communication, the information exchange is based on

the use of vehicles as carriers of messages for other vehicles, which is executed through DSRC based on IEEE 1609 standards of WAVE family [109, 110]. This consists of four standards, one of which is IEEE 1609.3 and that is responsible for networking services such as routing issues. Also, the information can be exchanged between vehicles through RSU establishing the V2I communication. Moreover, disseminate the message by involving both vehicles and RSUs, which called a Hybrid approach. For instance, utilising V2I type of communication on the availability of infrastructure in the specific area; however, when the vehicles enter into a zone without infrastructure, it utilises the V2V communication to disseminate the warning messages to other vehicles, without the requirement of additional infrastructure. This work is based on V2V, which allow some vehicles in the system to act as a repeater to rebroadcast the warning message whenever an NLOS has been detected.

5.2 Co-operative Volunteer Protocol

In density network and due to NLOS situations because of obstacles such as buildings, trees or vehicles, the need of V2V communications arises due to the high expense of installing the needed infrastructure, especially in rural areas [12]. Therefore, the proposed work will be based on infrastructures-less systems i.e. V2V communications, which means some vehicles must act as a repeater to assure that warning messages will reach every vehicle in the network to avoid fatal accidents occurring. One of the assumptions here is that every vehicle in the system is equipped with GPS (Global Positioning System), NS (Navigation System) and can exchange RITs (Routing Information Table), in addition to periodic messages which will be sent all over the network regularly, in order for the proposed protocol to process all the

information that has been gathered to detect the NLOS to send a warning message in time.

The main purpose of designing this protocol is to solve NLOS using a mediator node, which acts to deliver the warning message in time to the hidden node, and then reply to the emergency vehicle that it is clear to pass the intersection. Moreover, using CVP is very important in safety application, with the need of Non-DTN (Delay Tolerant Network) routing protocol issues, which is based only on position. In contrast, DTN-based routing protocol cannot be utilised in this research due to the carry and forward mechanism which cannot be applied in the proposed protocol in order to the delay that might occur because of this issue as mentioned earlier in Chapter 3.

5.3 CVP Mechanism

In this section, mechanism of CVP with focus on various actions are described. This section shows the two stages of the protocol: Detecting the NLOS and Packet Delivery.

5.3.1 Detecting Non-Line of Sight

Each node in the network sends periodic messages to its neighbours including position, velocity, direction and emergency status, which is supposed to be saved in the Routing Information Table and be exchanged with its neighbours. Therefore, after acquiring these data, each vehicle will acquire the data about its neighbour and the neighbours of the neighbour's node, which will be extracted from the RITs. Each vehicle in the network will perform scanning periodically after every 10 seconds for the inconsistency in its neighbour stored list; this means that the RIT will be used to check

for possible NLOS situations in its surrounding traffic network using (Algorithm 1: NLOS detecting).
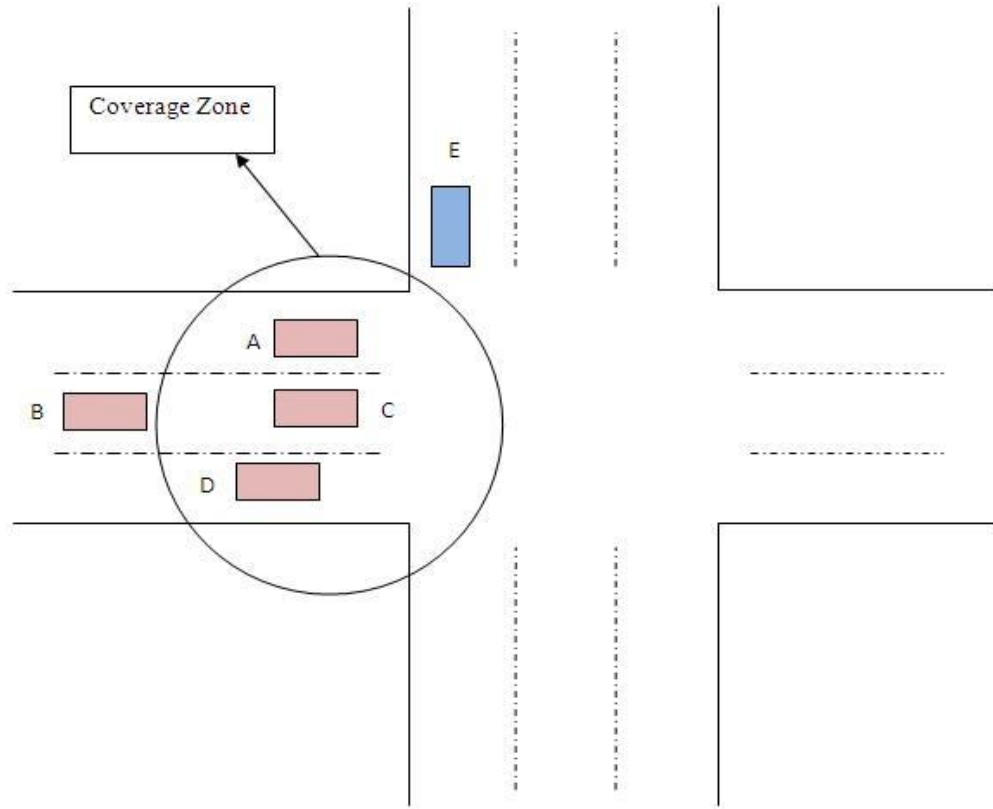
Figure 5.1 Car B being out of the coverage zone

Actually, the RIT table sent with the packet of the previous sender is compared with that of the receiver, and if inconsistency in RIT is detected, this may be due to two scenarios, either the node being out of the coverage zone or being under NLOS due to an obstacle as shown in Figures 5.1 and 5.2, respectively. Both of these scenarios demand different actions to ensure the communication of vehicles to vehicles under NLOS. In case of the node being out of the coverage zone Figure 5.1, the vehicle will not appear in the RIT, which means it is not in the surroundings area; therefore, it will give the opportunity for another vehicle to detect the NLOS then the CVP will be triggered. In case of detection of NLOS Figure 5.2, it confirms the NLOS for itself and

action of CVP will be triggered using (Algorithm 2: the CVP trigger). In this case, the receiver node declares itself against NLOS by triggering NLOS status based on (Algorithm 1: NLOS detecting). Concurrently, the node also piggybacks the NLOS query in the transmission of next warning beacon interval.
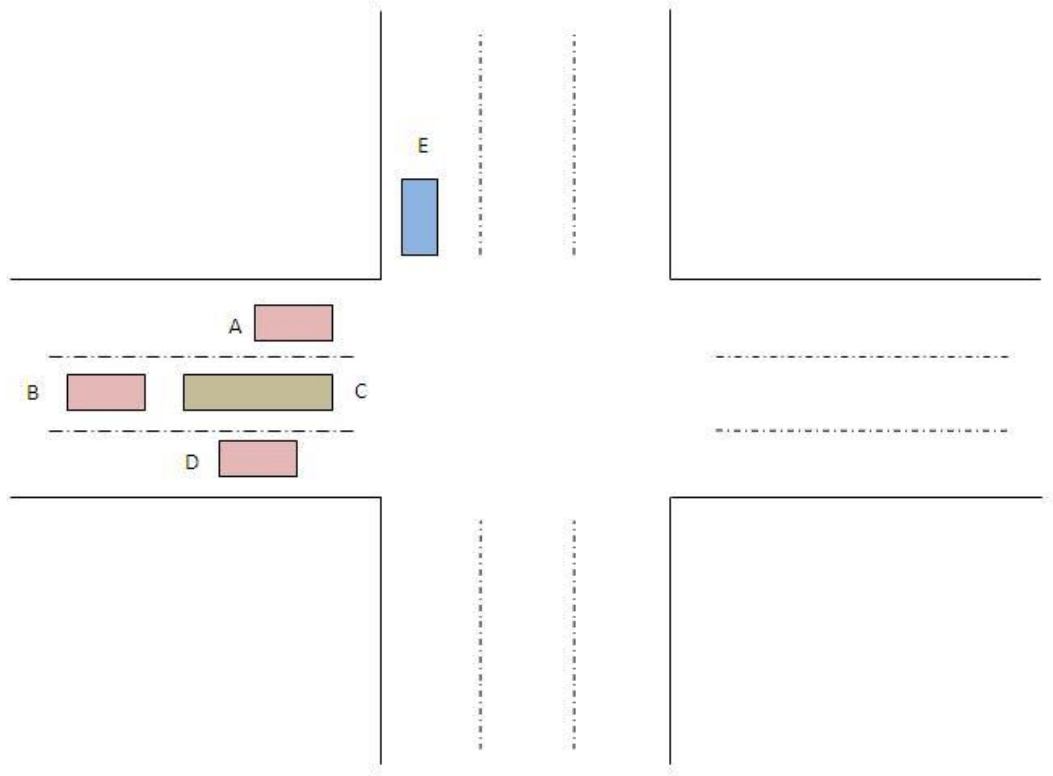
Figure 5.2 NLOS (Intersection with a truck obstacle)

5.3.1.1 Routing Information Table

As the system deals with infrastructure-less environments with the need to detect the NLOS by any volunteer vehicle, this detection is based on the comparison of RITs. As [121] stated that the RIT will show a history of all activities being performed by each node in the network. It will store a record of all the neighbours and their neighbours which will enhance location verification in order to detect the NLOS

situation. This section will take a look at how the RIT will be created and how the comparison will be performed according to the CVP.

The emergency node E (Figure 5.2) sends the warning message to the vehicles approaching the road intersection. Every node is supposed to have its own RIT (Tables 5.1-5.4) which will hold general information about its neighbours such as ID, direction, distance from the road intersection and position in the lane and most importantly, indication of the nodes that will get the packet and highlighting those nodes which are in neighbourhood but they did not receive the warning packets due to some NLOS situation in the network.

Table 5.1 shows how the node E's RIT will look in the proposed scenario in Figure 5.2 which stated that nodes A and B are in the coverage zone and will get the warning message.

NODE E			
ID of (neighbour nodes)	Distance from the intersection	Direction	Lane (position)
Node A	x	y	L1/L2
Node B	a	b	L1/L2

Table 5.1 Routing Information Table for Node E. (The values for distance direction and lane positions are assumed here in the table for nodes A and B. The values x, y, a, b are repeated as assumed values for the RIT tables referred to later on)

Tables 5.2, 5.3 and 5.4 show the RIT for nodes A, B and D respectively. While, node C acts as an obstacle which prevents communication between A and D.

NODE A			
ID of (neighbour nodes)	Distance from the intersection	Direction	Lane (position)
Node E	x	y	L1/L2
Node B	a	b	L1/L2

Table 5.2 Routing Information Table for Node A

NODE B			
ID of (neighbour nodes)	Distance from the intersection	Direction	Lane (position)
Node E	x	y	L1/L2
Node A	a	b	L1/L2
Node D	c	d	L1/L2

Table 5.3 Routing Information Table for Node B

NODE D			
ID of (neighbour nodes)	Distance from the intersection	Direction	Lane (position)
Node B	x	y	L1/L2

Table 5.4 Routing Information Table for Node D

After getting the warning message, each node will get node E's RIT which will be compared with its own RIT in order to check for any hidden node in the system. The comparison process for node A is shown in Table 5.5. Whereas T=True, which means LOS communication can be achieved, while F=False, which means there is no direct communication with this node.

NODE A		
ID	E RIT	A RIT
Node E	-	T
Node A	T	-
Node B	T	T
Node D	F	F

Table 5.5 The Comparison Process for Node A

Apparently, the table did not show any indication of hidden nodes or NLOS, both RITs show that they can build LOS communication with each other and with node B. On the other hand, neither of them can locate node D.

However, after getting the comparison process for node B Table 5.6 shows that nodes E and B have direct communication with each other and with node A. But from the table it can be seen that node E has no direct contact with node D. Meanwhile, node D is in the LOS of node B, therefore, CVP will be triggered to solve the NLOS issue that has occurred in the system because of node E having no direct communication with

node D, being out of its coverage zone or under NLOS. So a fatal accident can occur if there is failure to get the warning message in time. In this scenario, the NLOS occur because the obstacle (node C) prevented the communication from occurring between nodes D & A, and D & E.

NODE B		
ID	E RIT	B RIT
Node E	-	T
Node A	T	T
Node B	T	-
Node D	F	T

Table 5.6 The Comparison Process for Node B

5.3.1.1.1 Trigger of CVP by RIT data in node B

Here assumption is that nodes facing NLOS will appear to be missing in the RIT table, and the detecting vehicle (A) will automatically pass the data down to other neighbour node (B) for comparison and verification of information in RIT tables of A and B. The vehicle B being in direct line of sight with D will confirm to the vehicle A and E that vehicle D did not receive the packet; and B will volunteer itself to deliver the packet to D. In this way, RIT tables of all concerned nodes in the network will share the information about the neighbours nodes and find the missing nodes on RIT, detect them

and suitable vehicle with direct line of sight (which is B in this scenario) with the missing node will transfer the data to the node facing NLOS situation.

CVP will allow B to trigger the rebroadcast process rather than waiting for E to assign the job to it. To avoid storm problems, B will notify E about the situation to check if there is no other node will do it. Once E received that, it will add the new node to its RIT to notify other nodes about the new changes to avoid duplication. This notification will be based on the three handshake technique, which needs acknowledgment of receiving the packet which will enhance the robustness in the CVP as will be discussed later in this chapter.

5.3.1.2 NLOS Detection Algorithms

If a node detects NLOS in its transmission range, it constructs warning message bytes (WMB), which can assume two forms: WMB-req and WMB-rep. The former is the request from nodes experiencing NLOS which also tries to verify the current situation of traffic in the respective neighbourhood whereas the WMB-rep is the reply to the cognate query. From the requesters standpoint, if the receiver receives the multiple queries regarding the nodes experiencing the NLOS in the same area, the repliers reply collectively once to all of these queries instead of relying on an individual basis in order to avoid the storm issue and communication channel contention. For example, if two nodes are moving close to each other and experiencing the same state of NLOS, they may raise the NLOS alarm regarding the same area, therefore, only a single reply for both of them is needed. The format of both WMBs is given as follows:

Request:

$(RR//((req_{id1}, pos_{start}, status), (req_{id2}, pos_{start}, status), ...,((req_{idn}, pos_{start}, status))))$

Reply:

$(RR//((rep_{id1}, pos_{start}, status), (rep_{id2}, pos_{start}, status),........(rep_{idn}, pos_{start}, status)))$

Here RR represents the request or response based on the contents of the request or response.

In the above communication the request or response is presented in triplets containing unique ID, starting position of the respective area and the Emergency status. In order to inform the surrounding vehicles about the upcoming events. The response is generated in the same manner.

Algorithm 1. NLOS Detecting

---

1. Assumption: two adjacent statuses for neighbourhood are saved in interval $[t_{i-1},$ $t_i]$

2. **For** N1 to Nn **do** check coverage zone

3.   Check consistency of two consecutive states

4.   **If** (N_{Ev}) then construct WMB for the respective Node

5.   Set WMB

6.   Break

7.   **Else** no action

8.   **End if**

9. **End for**

10. **For** N1 to Nn **do** NLOS Detect

11.   **If** (N_{LOS}) **then** wait()

12.   **If** WMB received **then**

13.   Break

14.   **Else** send info to mediator node

15.   **End if**

16.   **End if**

17. **End for**

18. **If** RIT = missing node **then** trigger NLOS

19.   **Return** $Status_{NLOS}$ = TRUE/FALSE

20. **End if**

5.3.2 Packet Delivery Phase

In this section, delivery of packets from the source node to the destination node explained, which constitutes the packet delivery phase.

5.3.2.1 Communication in NLOS

When a node detects the NLOS situation through the data stored in RIT maintained by each vehicle in the network, it triggers CVP, which piggybacks WMB through the next beacon to its immediate neighbour in both directions. The neighbours, after reception of the WMB, perform the plausibility checks to find the vehicle under NLOS, and also each node will perform checks of NLOS situation in its own area and areas under question. In the case of issuance of such NLOS situation by the receiver node, then it will wait for the response from another node having clear LOS to the area under question. If the receiver already has LOS to the node under NLOS, then it constructs WMB-rep and communicates back to the requester(s). There is also the possibility that the surroundings vehicles have clear LOS to the requested area. In that case, the request is forwarded by the neighbour vehicle with a timestamp. The overall scenario has been implemented through Algorithm 2, given below:

Algorithm 2. Trigger CVP

1. Assumption: two immediate statuses for neighbours are saved in any interval $[t_{i-1}, t_i])$

2. WMB received with RIT

3.   **For** N_1 to N_n **do**

4.   Compare RIT for the same area for direct comm.

5.   **If** report is issued already **then** Break

6.   **else if** (NLOS in the same area and are under request shows same node info) **then**

7.   Construct WMB-rep

8.   Forward the node info to the requester

9.   **else if** (NLOS in neighbour's list) **then**

10.   Forward the information at hand with timestamp

11.   **End if**

12.   **End if**

13.   **End if**

14.   **End for**

15. **Return** CVP Triggered

5.3.2.2 Acknowledgement of receipt of WMB

In case of reception of WMB by the node under NLOS (N_{NLOS}), it will issue the reply to the requester N_{LOS} confirming that the WMB is received and action is taken according to the contents of the request. The N_{LOS}, according to the protocol, will send the verification message to the originator of the request, which is an emergency vehicle in our case, to let N_{EV} know that WMB has been delivered to the N_{NLOS} and action has been taken accordingly. The following Algorithm 3 describes the whole scenario:

Algorithm 3. Acknowledgement receipt of NLOS communication
1. Assumption: two immediate statuses for neighbours are saved in any interval [t_{i-1}, t_i])
2.   Verify the reception of WMB-req by N_{NLOS} do
3.   Update the RIT
4. **if**
5.   The requester node not in communication range then
6.   Break
7.   **else if** N_{NLOS} in communication range
8.   Send WMB-rep to N_{LOS},
9. N_{LOS} update the RIT and
10.   WMB-rep to N_{EV}
11.   **End if**
12. **End if**
13. **Return** WMB Received
14. **Return** NLOS Cleared

The overall process of NLOS detection and solving the NLOS situation is described by the following Algorithm 4.
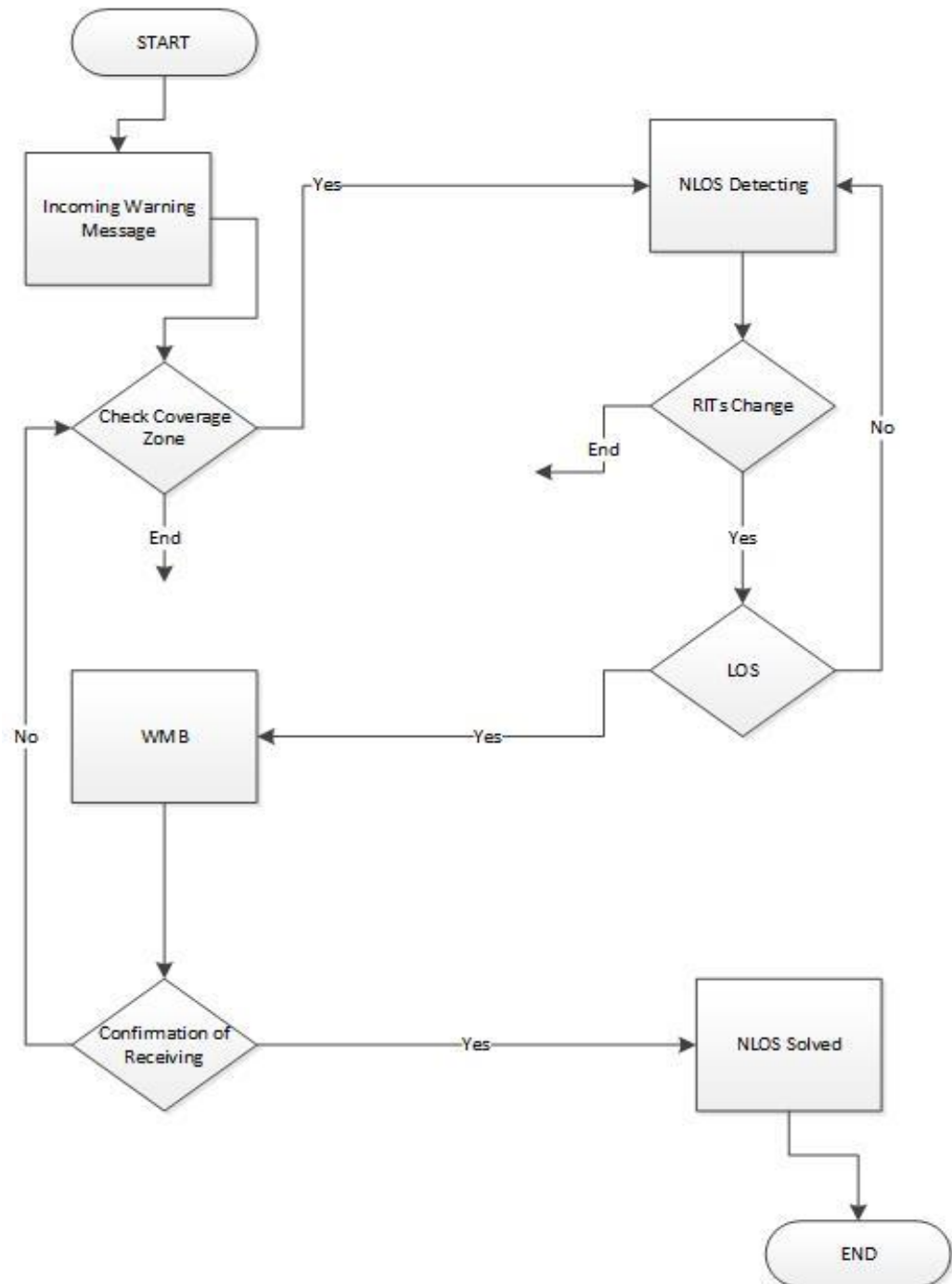
Algorithm 4. NLOS Detection Process

5.4 Assumptions/Hypotheses

The following assumptions have been made for constructing the CVP and interpretations of its working principles

- The simulation is performed in virtual environment rather than real life situation to validate the functions of CVP

- At least one vehicle will act as a mediator node to start the voluntary process on behalf of the source node

- The RIT tables are generated in OBU of all vehicles for purpose of comparison and detection of missing nodes

- The missing nodes in the RIT is considered either a node facing NLOS situation or in non- coverage zone.

- The data generated in the RIT of one vehicle will be automatically shared with neighbouring vehicles

- RIT tables will be updated periodically after every 10 seconds to take into account of new nodes and existing nodes

- The RIT will contain data regarding distance of vehicles from the intersection, ID of neighbouring vehicles, direction and lane positions of neighbouring nodes/vehicles

5.5 Summary

A novel routing protocol has been proposed and presented, which is designed to work efficiently and effectively to deliver the warning messages to vehicles experiencing NLOS in both highway and intersection scenarios. A proposed protocol called CVP is a step forward to improving the ITS and safety applications; furthermore it assumes that nodes in the traffic network can contribute towards delivering the message to the target node through a cooperative mechanism. This becomes realistic when the traffic dynamics and behaviours of nodes in real traffic scenarios are taken into account with the availability of up-to-date navigation systems and GPS.

Utilising the information regarding the behaviour of vehicles on the road and their role in improving the performance of the routing protocol cooperatively in VANET, CVP exploits the cooperation approach adopted by vehicles to communicate with each other to disseminate the knowledge and detection of NLOS in VANET. Through this, each vehicle has the knowledge of the questioned node shared it with other vehicles, and volunteer nodes transfer the warning message to the node under question. The novelty of CVP lies in minimising the utility of bandwidth, avoiding storm problems arising from retransmission and solving the hidden node issues by detecting it through a cooperative approach, by exploiting the information relating to the speed, position and direction of the nodes during the communication process. The mechanism for detection of NLSO situations has been developed and nodes commutating with the node under NLOS has been presented as well. Four algorithms have been used to validate the mechanism of the routing protocol. In summary, the CVP

and its mechanism described in this chapter provide the criteria to implement two phases of the CVP: detection of NLOS and the packet delivery.

Chapter 6

Simulation and Evaluation Using EstiNet Tool

Objectives:

- Justification of using EstiNet

- Description of simulation scenarios

- Show the simulation metrics and result

- Present the validity and performance of the proposed protocol

- Case study

6.1 Introduction

The behaviour of the nodes in the network is unpredictable and uncertain, mostly due to the greater degree of obscurity associated with the context prediction about the VANET behaviour. Furthermore, VANET is under research area and needs a plethora of research activities to unfold its subtleties, therefore, the research cost and complications in the authentic measurements cause further issues in the identification of nodes behaviour in the VANET field. According to Tarek [122] "There are three ways to model networks: formal analysis, real life measurements and simulation. The dynamic nature of ad hoc networks makes them hard to study by formal analysis. Some formal techniques that have been used in static networks include Petri nets, stochastic processes, queuing theory, and graph theory. None of these is especially well suited to study the dynamic networks. Since the nature and mechanism of ad hoc networks are poorly understood. Therefore, most scenarios falling in this category still demand research. However for scenarios that are already known, e.g. military networks, extreme uncertainties and dynamicity are expected. Thus, use of real life measurements is certainly costly. The commonly used alternative is to study the behaviour of the protocols in a simulated environment."

Furthermore, the simulation technique is considered to be a more powerful technique for evaluating and experiencing the efficiency of the network behaviour, even where there are complex conditions present in the networks such as a high mobile nature of the nodes and a variety of sizes of network areas, and that is capable to offer more flexibility than the physical gadgets in the fixed area. The better and more flexible control over the parameters and values of the protocol, iteration running and change of

variables are some other advantages achieved through the simulation process, which result in the determination of performance of network parameters in the best possible way.

6.2 Simulation Environment

Simulators are becoming popular based on their ease of use and the strong programming model support. It really helps the researcher or application developer to focus only on the research issue and not on the simulator features [123]. The simulators usually have the stack of algorithms and transmission protocols to choose. This reduces the developer's effort to a great extent. Some of the simulators allow the researcher to plug in the algorithm module, which is also of great help. The simulator must be capable enough to help developers to visualise all the layers of WSN communication, the physical layer, data link layer and the network layer details [60, 129].

6.3 Description of Simulation Scenario

The simulation scenario comprises a multi-hop VANET, where the performance of CVP technique is tested. CVP is designed with the intention of a non-delay tolerant protocol that transmits the warning messages to the other vehicles on the road. The transmission efficiency is improved by this protocol by means of the following metrics: the vehicle density, the distance of source to the destination and the available bandwidth. While the NLOS situation is detected by the application of RIT in the sensing bed of the protocol. This multi-metric protocol is obtained by each node in the network and is employed to locate the neighbouring node that is the candidate for receiving the next forwarding node. The proposed protocol presented in this thesis is

self-configuring and can easily adapt to the changing density of vehicles in the network in real-time scenario.

Several simulations employing the EstiNet Network simulator have been carried out. Basically, the simulation work can be performed by using two types of simulators: traffic simulators and network simulators. However, the objectives of the current study require the combination of both traffic and network simulations integrated within a single simulator – a hybrid simulator. EstiNet is such a simulator which fulfils the requirements of being a hybrid simulator. EstiNet version 8.1 supports various features of VANET, thereby being the obvious choice for the simulation of traffic and network nodes. Furthermore, it consists of standard IEEE 802.11p, and offers simple and accurate methods to design the VANET's realistic scenarios. The strengths of EstiNet simulator compared to the other simulators have been shown in the Figure 6.1, (note: the old version of EstiNet was called NCTuns).
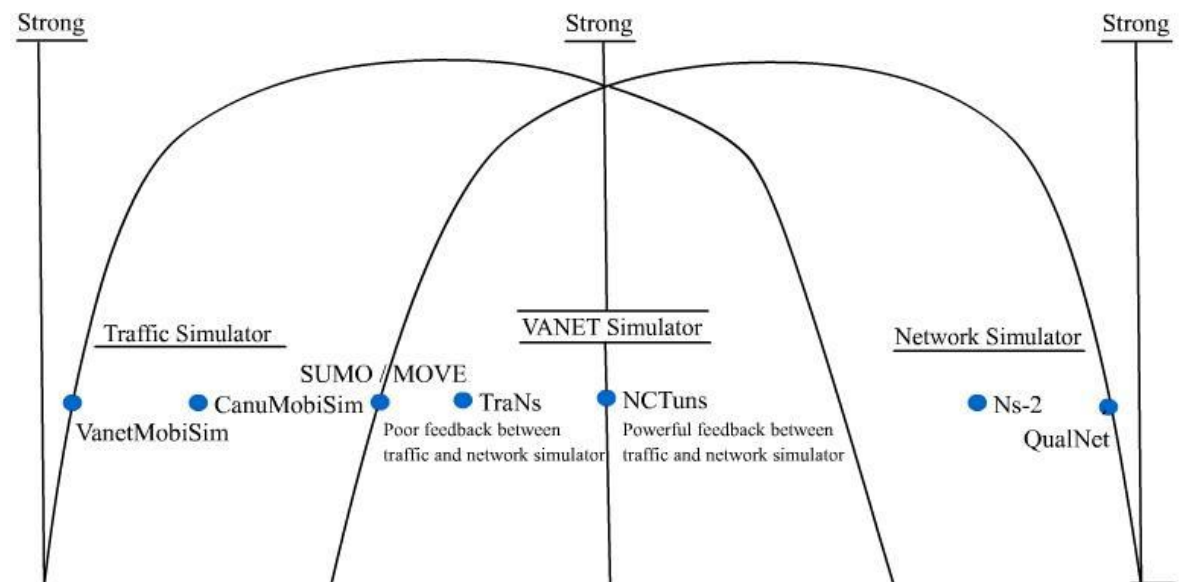

Figure 6.1 Strength relations between various simulators [180]

In this research work, two scenarios including highway and intersection are considered for the simulation. Production of NLOS situations is due to tall buildings and double-decker buses frequenting the roundabouts during busy hours of the day. Furthermore, a highway is selected to do the simulation to apply the protocol to highway scenario. Each scenario will be discussed later in this chapter.

Version 8.1 of EstiNet on Fedora 17 Linux has been employed to simulate CVP protocol. The purpose of simulation of CVP mechanism is to evaluate it and compare it with other routing protocols. The rationale behind the selection of the EstiNet Simulator for this work is related to the range of salient features of EstiNet which distinguishes it from other simulators as shown in Table 3.1 (Chapter 3). EstiNet is an easily expandable and modifiable simulator with several embedded functions and features required to complete the simulation work for this thesis.

For the simulation, four arbitrary vehicle densities have been considered: 37, 76, 110, 160 cars per km^2. Each of these densities represents the different situations during a daytime, for example, early morning, morning/afternoon and rush hours (7 am-8.30 am, 4 pm-6 pm). The main purpose of utilising the arbitrary different density values is to identify if the variations among the obtained outcomes originating from the CVP depends on the density of the scenario. The higher density at the intersection means that there is higher probability of availability of next-forwarding hop that will in turn help to reduce the number of packets discarded; however, the transmissions of data would become more susceptible to interference.

Furthermore, in simulation model 37-160 vehicles are considered to be present and mobile within the boundaries of the simulation perimeter, and capable of detecting the NLOS by comparing the RITs in the surroundings area of the vehicles on a highways or intersections. Each simulation is carried out for 270 seconds. The speed of the vehicle is supposed to be in the range of 30-70 mph, and peer-to-peer communication pattern is employed in simulation. All these simulations settings are presented in the Table 6.1. The performance of the proposed protocol is evaluated by using the following metrics: overhead, packet delivery ratio, delay in data delivery, neighbour awareness, response time and channel capacity utilisation.

Parameters	Values
Simulation area	1,500 m x 1,500 m
Routing protocol	CVP, GRANT
Transmission range	200 m
EstiNet version	8.1
MAC Layer Protocol	IEEE 802.11p
Network size	37, 76, 110, 160
Traffic type	Constant Bit Rate (CBR)
Warning packet size	512 B
Bandwidth	12 Mbps
Simulation time	270 s
Node speed	30 miles. 70 miles
Mobility generator	OpenStreetMap

Table 6.1: Setting of parameters and values for simulation

6.4 Simulation Metrics and Results

The simulation results of the CVP, as described previously, were obtained through the EstiNet Simulator version 8.1, in order to evaluate the performance of this protocol, by using the performance metrics defined in subsequent subsection. The results of CVP were compared with those of GRANT which is considered to be a standard routing protocol in VANET and ad hoc networks.

GRANT is simulated under the same conditions and scenarios as were used to simulate the CVP in order to obtain a justifiable comparison. The performance of GRANT has been selected for comparison with that of the proposed CVP, because both GRANT and proposed CVP share similarity in aims and mechanism. It is used for the detection of obstacles in urban area, and the proposed CVP also aims to detect NLOS situations in urban areas. Both protocols use the extended greedy mechanism for forwarding the messages from source vehicle to the target vehicle. Both routing protocols works in Non-DTN environment, therefore, the comparison of performance of the proposed CVP with GRANT can show the extent to which the latter can perform better than the former in terms decreasing delay in warning messages and other performance parameters evaluated in succeeding sections of this chapter.

6.4.1 Simulation Metrics

Six different performance metrics are used to evaluate the performance of CVP, which are described briefly below:

1- Warning Messages Delivery Success Rate: This metric represent the total number of packets delivered to the destination node successfully, including the packets forwarded

among the nodes to reach the destination node. The goal of using this metric is to determine the efficiency of the routing protocol in terms of successful delivery of packets.

2- Overhead: This metric represent all of the control packets issued during the transmission in order to process the successful delivery of data to the destination node.

3- End-to-End Delay: This metric is used to measure the time delay required to forward the data packet from the source node to the destination node; and this includes the time taken to process the data during the retransmission and buffering operations.

4- Neighbour Awareness and Location Verification: This metric is useful in NLOS situation when packets delivery is failed to those vehicles behind obstacles, and measures the capability of the proposed routing protocol to detect the NLOS situation in the network successfully. The goal of using this metric is to evaluate the performance of the CVP to detect the vehicle under NLOS and verify the location using the cooperative approach. When the source detects the number vehicles in surroundings matching with those within its communication range, the neighbour awareness rate is said to be 100%.

5- Channel Utilisation: This metric measure the performance of routing protocol in terms of generating the number of messages and the channel capacity occupied by them. The goal of this object is to evaluate the CVP scalability and efficiency of the cooperative approach used to transmit the packets to the destination.

6- Request Processing and Response Time: Average processing time is the time taken from the generation of request from the sender to the receipt of reply from the other vehicle in the network.

6.4.2 Simulation Results

6.4.2.1 Neighbourhood Awareness and Location Verification

When a vehicle or building disrupt the communication channel, the packets cannot be delivered successfully to the vehicles behind the obstacles. The vehicles in NLOS situations cannot be detected by the system. Therefore, neighbour awareness is important, which can be achieved by verifying the location of the questioned vehicle. In other words, a negative impact is cast by obstacles on the neighbourhood awareness rate. The simulation is performed to detect the NLOS situation both in highway and intersection scenarios. Data showed that the proposed protocol is able to successfully identify the NLOS situation by increasing the neighbourhood awareness rate. The updates about the neighbour depend on the reception of the forwarded packets, which can be disrupted by the presence of obstacles between the node forwarding the packet and the node under NLOS situation. In comparison with GRANT, the use of the proposed protocol increased the neighbourhood awareness rate. Simulation data obtained from GRANT is inconsistent as it has some network performance issues that impacted the performance and limited its use. Using CVP increased the neighbourhood awareness rate by up to 89% with the application of RIT table which is able to verify requests whenever a verification reply is found to be inconsistent. The proposed protocol is able to detect the NLOS situation in the questioned neighbourhood by comparing the number of detected neighbours and number of surrounding vehicles within the packet dissemination range. The RIT table is updated if the verification reply is received that the node under an NLOS situation exists. The CVP recognised the

NLOS situation and kept sending requests to determine whether the target neighbour still existed before deleting the record.

Figure 6.2 shows the average awareness rate of various densities with 20% obstacles included in the simulation. The findings reflected that improvement in detection of NLOS is achieved using the proposed protocol.
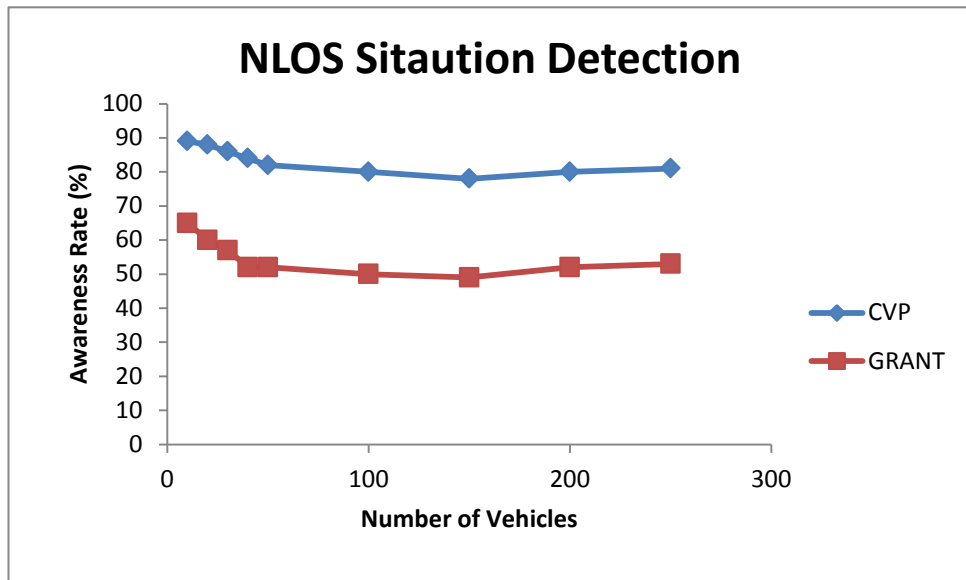
Figure 6.2 Neighbourhood Awareness

6.4.2.2 Channel Utilisation

The proposed CVP mechanism is based on the cooperative approach that requires an exchange of warning messages among the neighbouring nodes in the network. The estimation of the volume of message exchanges and the space used by them in the communication channel bears on the efficiency and effectiveness of the model designed to disseminate the warning messages to the target vehicles. The packet payload size used during simulation experiments is 150 B, which includes the messages relating to location information and request information about the node under NLOS

situation. The findings obtained from the simulation experiments showed that the average channel utilised by the packets generated during the experiments is found to be less than 9% of the total available channel capacity of 12 Mb/s (Figure 6.3).
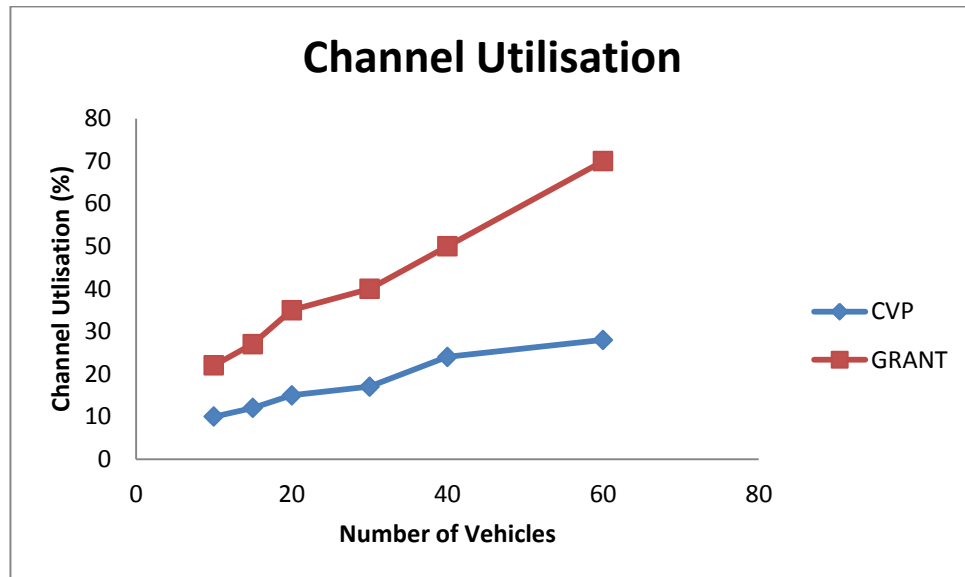
Figure 6.3 Channel Utilisation

In comparison with GRANT, CVP protocol showed 20% less utilisation of space of communication channels owing to the cooperative approach adopted by CVP. The cooperative approach allows the generation of packets from one vehicle to another based on requests from each other, thus each node does not transmit multiple packets in a given time space, allowing the utilisation of less space of the communication channel. Figure 6.3 shows the comparison of cooperative and non-cooperative systems, and it can be clearly observed that in the absence of a cooperative approach, the channel bandwidth can be quickly saturated, as each node has to issue its own verification request, particularly in high density areas.

6.4.2.3 The Time Delay of Data Delivery

In this section, the end-to-end delay for the CVP has been simulated and measured for two scenarios: network size and data packet size, the comparison is made with the GRANT protocol of which performance is evaluated using the same conditions and scenarios.

Network Size

Figure 6.4 shows the influence of the number of nodes in the network on the time delay of data delivery. It can be seen that with an increase in the number of nodes in the network, the end-to-end delays decreases, which assures the delivery of packets to their destination nodes within as much short duration as possible. This is because the protocol guarantees the dissemination of packets to the destination through a cooperative approach. In the high node density area, the packets are forwarded quickly due to availability of more intermediate nodes mediating the forwarding action on the warning messages issued by the source. Furthermore, it can be observed in the figure that GRANT's performance starts decreasing then it slow down with the increase in the number of nodes, indicating the negative impact of increasing node density on the performance of GRANT, primarily because of the non-cooperative nature of the protocol and selection of next-hop node based on its position. During the selection of forwarding node based on the location, GRANT tries to depend on the vehicles on the perimeter (perimeter mode) if nodes in the local neighbourhood become thin or unavailable. That is not considered to be efficient in terms of delivering the message successfully to the destination, thereby leading to a loss of packets in switching to perimeter mode. However, in comparison to GRANT, the novel feature of the proposed

CVP works more efficiently in the high-density node and low-density areas due to availability of cooperative nodes assisting in forwarding the warning messages to those nodes under NLOS situations.
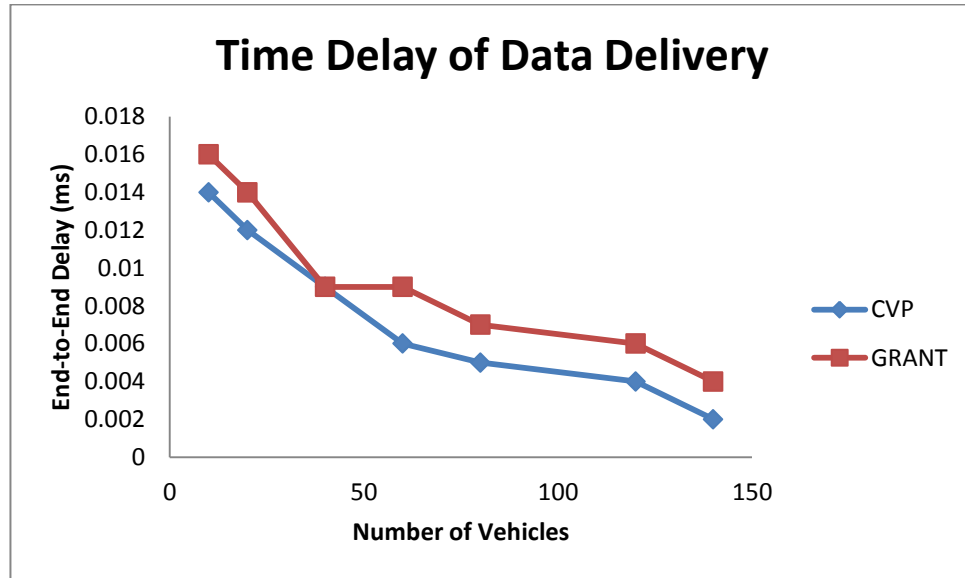
Figure 6.4 Time Delay of Data Delivery (Network Size)

Data Packet Size:

In the data packet size, the pattern of end-to-end delay has been shown in Figure 6.5. The performance of GRANT in the case of increasing packet size increases significantly then slow down in comparison with CVP which continues to deliver the warning messages in less time even when the data packet size is higher. With an increase in the data packet size, the CVP shows a further reduction in the delivery of data to the mediator nodes in the network, while the retransmission of messages by nodes in GRANT environment result in an increase of time delay. However, the decision about forwarding the packet to the next-hop node is based on the immediate

availability of volunteer nodes that accurately transfer the message to the next-hop, this leads to the delivery of warning message to the nodes under NLOS situation.
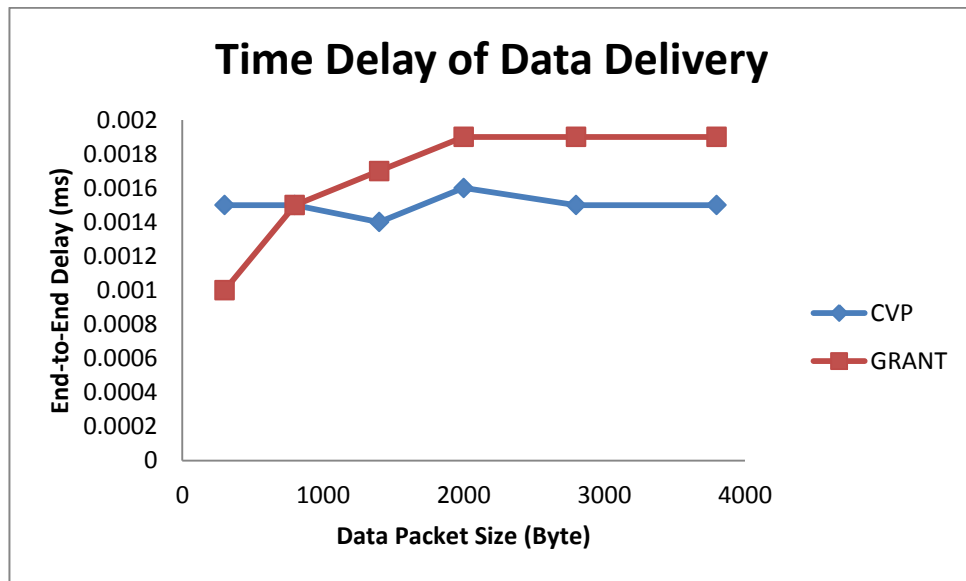
Figure 6.5 Time Delay of Data Delivery (Data Packet Size)

6.4.2.4 Overhead

In this section, the overhead has been measured against two scenarios: network size and data packet size, and comparison were made with the GRANT protocol which has been evaluated against the same scenarios and conditions.

Network Size:

The graph in Figure 6.6 shows the overhead (number of packets sent through the network) against the number of nodes, and it can be observed that the number of overhead is increased with an increase in the number of nodes in the network, primarily because of the enlargement of the network overhead packet caused by the number of nodes. The proposed protocol produces less overhead compared to the GRANT, mainly due to the generation of single packets by single nodes as each node finds volunteers to

transmit the warning messages, thereby avoiding the retransmission of the warning messages by all the nodes in the network. However, GRANT does not operate on the principle of a cooperative approach for data transmission, which leads to generation of more messages including the retransmissions. This salient feature of the proposed protocol facilitates the avoidance of the collision of messages to the target destination under NLOS situation.
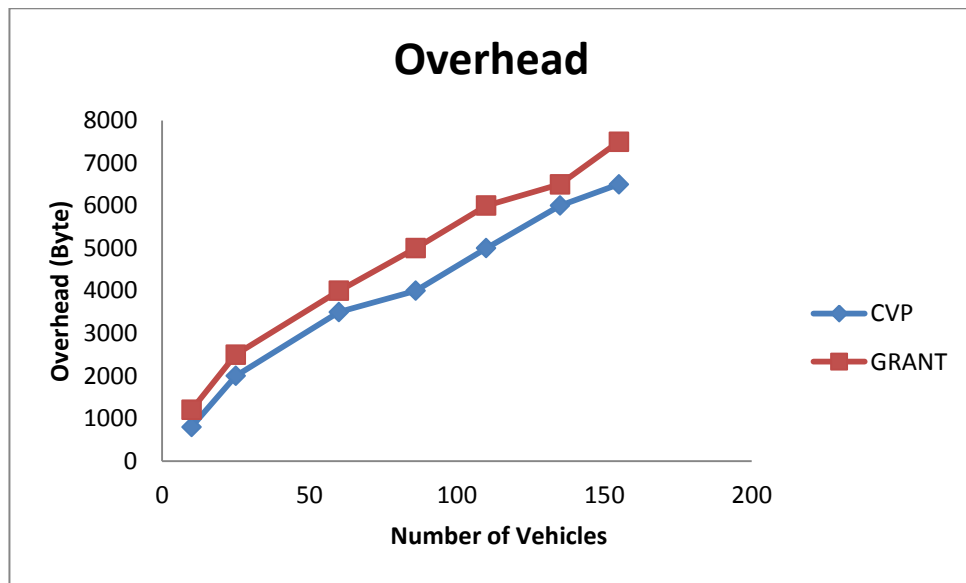
Figure 6.6 Overhead (Network Size)

Data Packet Size:

The effect of variation in the data packet size on the overhead is shown in Figure 6.7. It shows that with an increase in the data packet size, the overhead does not change, this is because of that fact the increase in data packet size causes more effect on the consumption of bandwidth, which leads to the creation of channel contention during wireless communication. Additionally, it can also be seen that CVP performs better than GRANT, which is derived from the fact that it is based on the cooperative approach in

order to choose the next-hop node for transmission of warning messages to target under NLOS situations. In this way, using the cooperative approach to reach the target results in the reduction of aborted attempts to deliver the warning message to the target under NLOS situation.
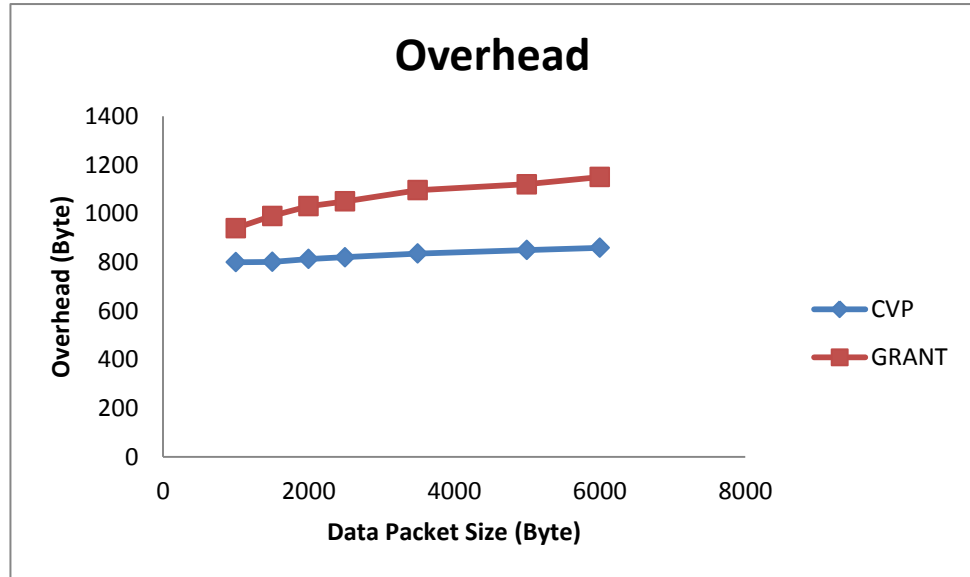
Figure 6.7 Overhead (Data Packet Size)

6.4.2.5 Warning Message Delivery Success Rate

In this section, the warning message delivery success rate has been measured for the CVP using two scenarios: network size and data packet size. The performance of the CVP is then evaluated by comparing it to GRANT, which has been evaluated based on the same scenarios.

Network Size:

The performance of the CVP with the GRANT has been compared in terms of efficiency of delivering messages to the target under NLOS successfully, in order to test the influence of the variations in the number of vehicles and the vehicular distance on

the measurements. Figure 6.8 depicts the relationship between the number of packets delivered and the number of nodes in the network. Firstly, it can be seen clearly that a makeable increase in the efficiency of delivery of warning messages occurs when the number of nodes in the network increases; the reason for which is the availability of more volunteer nodes and a reduction in the disconnected areas between the nodes. The existence of more voluntary nodes in the network creates more intermediary nodes that make it possible to transmit the message in end-to-end fashion to the target destination under NLOS. Hence, the warning message is efficiently delivered to the target destination, thereby avoiding any collision between the source (emergency vehicle) and the vehicle under NLOS situation.

Figure 6.8 Warning Message Delivery Rate (Network Size)

Furthermore, after comparing the efficiency of data packet delivery by CVP, it is found that CVP performs better than GRANT, even in low density areas of the network. This is due to the fact that CVP is based on the cooperative approach through which

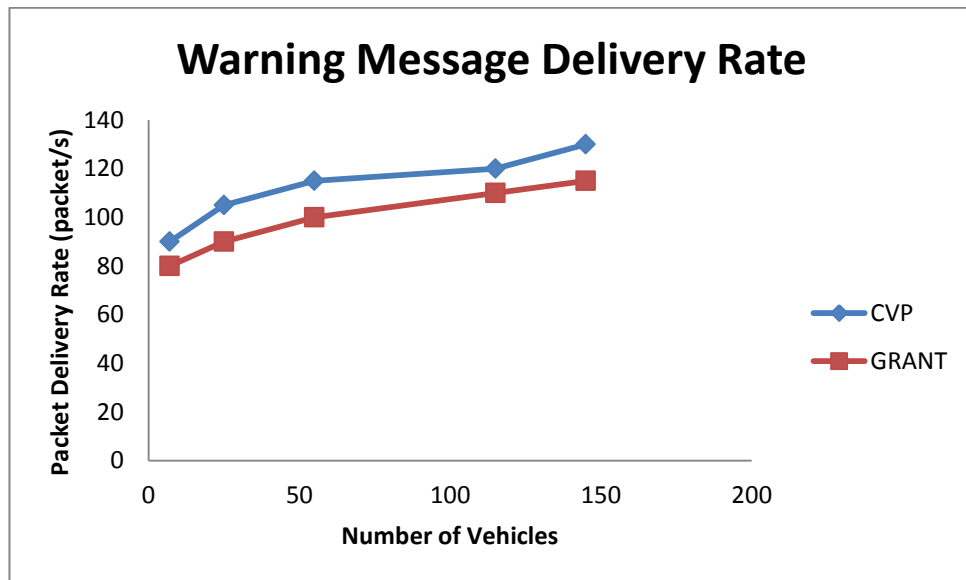volunteers are recruited to deliver the message to the next-hop and finally to the destination node, thereby reducing the possibility of packet drop dramatically. The cooperative approach also ensures the reliability of CVP as the node in LOS and near to the node under NLOS situation receives the message through the intermediary or voluntary nodes with greater reliability compared to the GRANT. Additionally, these data also reflect that CVP is able to promise a greater degree of reliability in terms of delivering the packet to the destination node, even with certain areas having a low number of nodes, which fits with the designer's objective engaged in developing the CVP protocol.

Data Packet Size:

The graph in Figure 6.9 provides information about the relationship between the data packet size and the number of packets delivered to the destination node in the network. The efficiency of the data delivery slightly decreases, and then sharply increases up to 1,500 data packet size, after that it shows the decreasing trend again. This latter decrease might be due to the consumption of bandwidth as the packet size increases, causing the issue of contention in the communication channel; the bandwidth in VANET is already limited which exerts extra constraint on the protocol developers to design the protocol by taking the bandwidth size into consideration.

In comparison with GRANT, however, the proposed CVP presents a higher performance in terms of delivery of the data packets to nodes under NLOS situation. This because of the exploitation of the aspects of the cooperative nature of the protocol for forwarding the data packets to the nodes under NLOS condition through the recruitment of volunteer nodes in the neighbourhood.
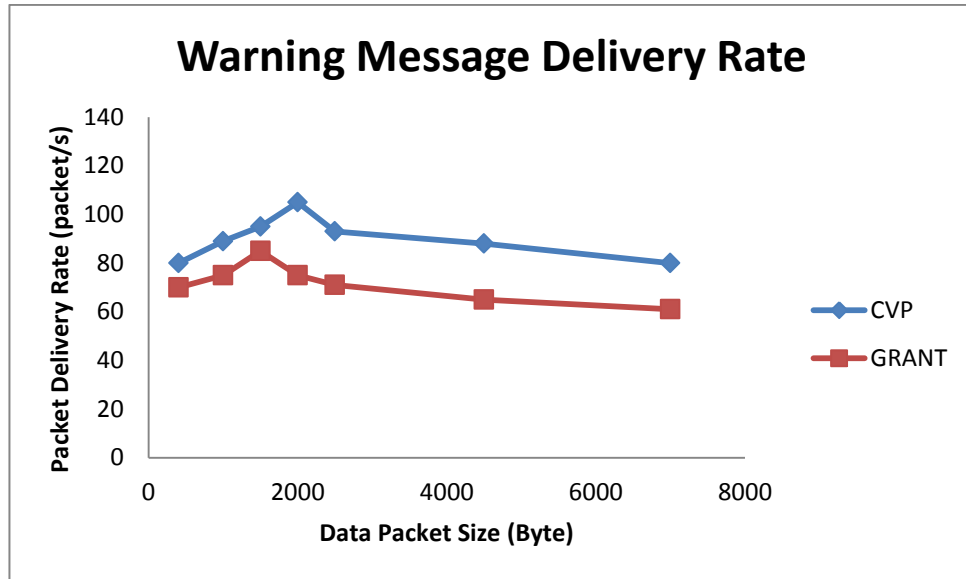
Figure 6.9 Warning Message Delivery Rate (Data Packet Size)

6.4.2.6 Average Processing Time for Request Verification

In this section, the average processing time for request verification has been measured for the CVP using two scenarios: network size and data packet size. The evaluation of the CVP's performance is then done by comparing it to the GRANT which has been evaluated under the same conditions. Average processing time is the time taken from the generation of request from the sender to the receipt of reply from the other vehicle in the network.

Network Size

The performance of the CVP in comparison with GRANT is evaluated by taking the nodes in the network. The simulation results have been depicted in the Figure 6.10. It shows that with the increase in the network nodes, the average processing time is increased. This increase is more pronounced in GRANT compared to the CVP, showing that latter is more efficient in processing the request between the sender and receiver

vehicles in the network. The increase in the time taken to process the request is due to the accumulation of increased number of processed and queued messages in the case of high density in the vehicle. The CVP showed better performance compared to the GRANT due to the cooperative approach which prevents the message contentions issue to considerable extent.
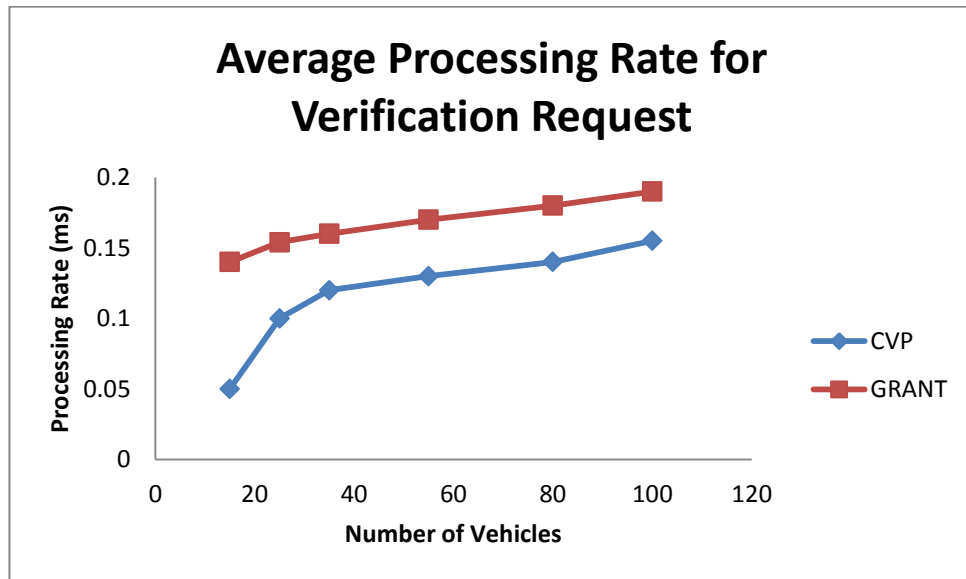
Figure 6.10: Average Processing Rate for Request Verification (Network Size)

Data Packet Size

The performance of the CVP is also measured against the data packet size parameter, and is compared with the GRANT. The results obtained from the simulation experiments revealed that if the data packet size increases, the average processing time also increases, which is due to the higher consumption of bandwidth within the VANET. VANET already face the challenge of limited bandwidth, the increase in data packet sized likely causes the message contention, packet collisions and dissipation of

the packet energy. Taken together, these factors can increase the average processing time. However, the average processing time of the CVP is observed to be lower than that of GRANT, which is because of the fact that nodes in the network in vicinity act as volunteers to transfer the messages to the target vehicles and consequently the reply to the request of the sender vehicle is made quicker than GRANT which does not utilise this principle during the execution of its function. Thus these results show that CVP can outperform GRANT with increasing trend of data packet size as shown in Figure 6.11.
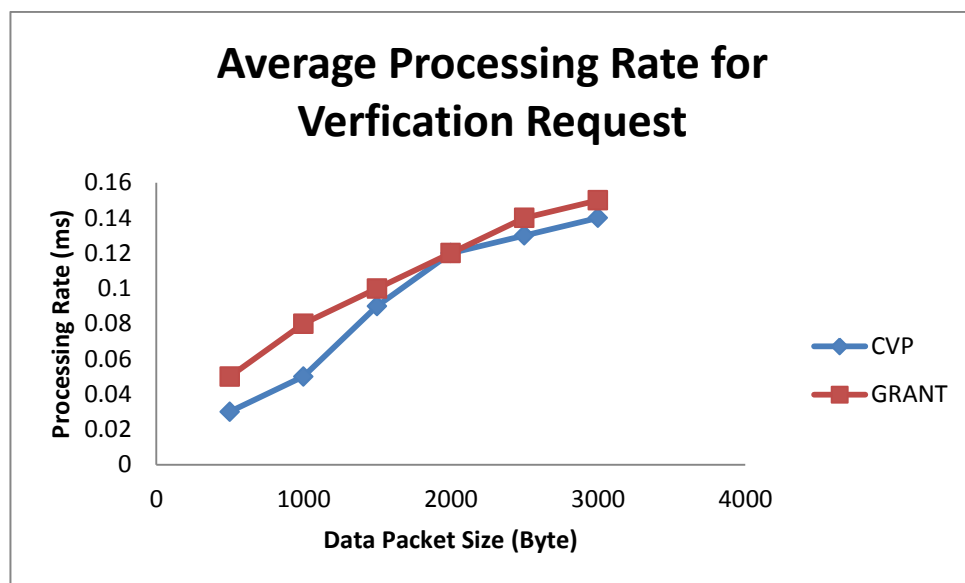
Figure 6.11: Average Processing Rate for Request Verification (Data Packet Size)

6.5 Case Studies

In this section, an evaluation of the mechanism of CVP, with a focus on the efficiency of delivery of warning messages to the vehicles facing the NLOS situation, and with the reduced time delay and overhead. A case study of an emergency vehicle with the warning system is introduced with two scenarios: the first one will present the efficiency of CVP in delivering the message to the vehicle facing an obstacle in the form of a building at an intersection in the urban area scenario. While the second one will show the application of CVP to deliver the warning message to the vehicle facing an obstacle in the form of some other vehicle disrupting the path of communication between the questioned vehicle and the emergency vehicle. The warning messages issues by the emergency vehicle at the intersection or on the highway are received by the vehicles in communication range, and then request the mediator or volunteer nodes to transmit the packets to the vehicle facing NLOS situation. In this way, the cooperative approach in message dissemination is the main thesis of the proposed CVP protocol.

6.5.1 Case Study 1: Intersection Scenario

In this scenario, the vehicle has multiple paths and directions to go such as at roundabouts/intersections where more than one exit, exist as shown in Figure 6.12. The emergency vehicle needs to send the warning message to other vehicles coming from other legs of the intersection. Some of the vehicles do not receive the warning messages due to presence of an obstacle between them and source. The mediators (vehicles) will act as volunteer nodes in the network and implementation of CVP will ensure the

delivery of warning messages to vehicles near the intersection or roundabout facing the

NLOS, in order to avoid any potential accident situation on the road.
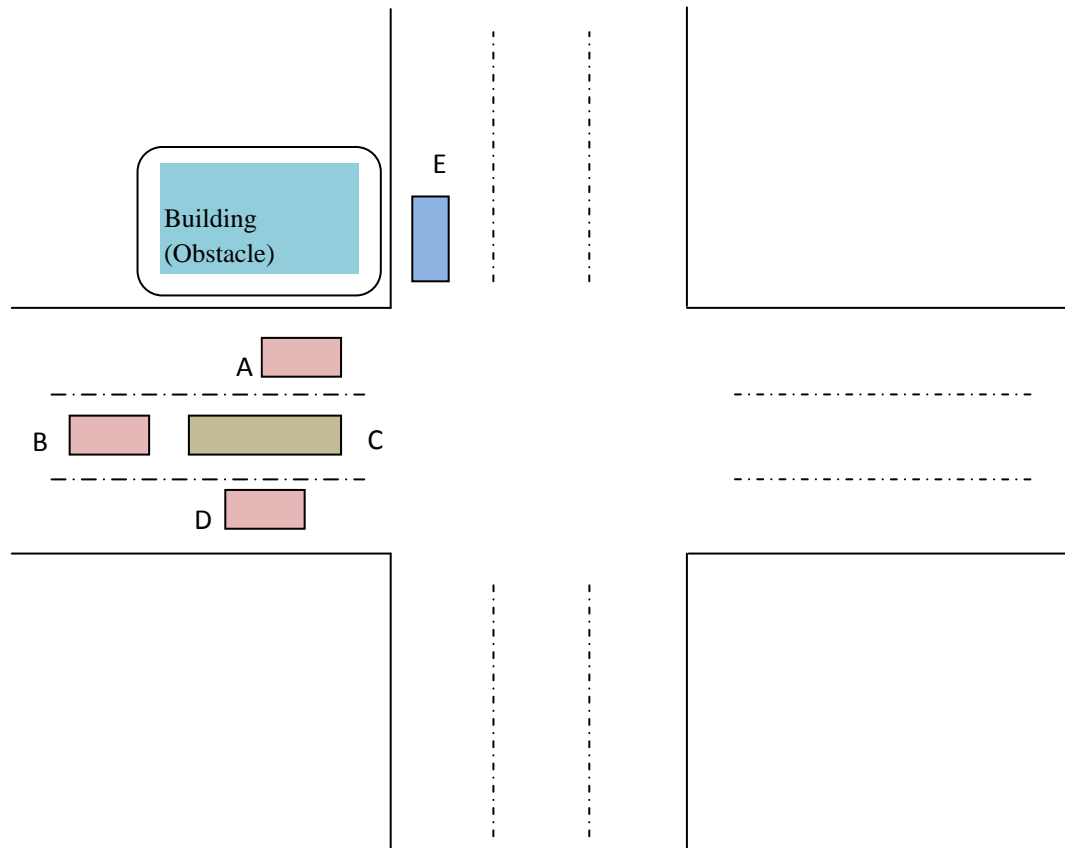
Figure 6.12 Case Study (Intersection Scenario)

Hence, the illustration of the situation with an NLOS situation in the work and how the

CVP help to solve this situation by sending the messages to the vehicles under NLOS

through the selecting of the volunteers in the network having LOS situation with respect

to nodes under NLOS. In the given case study, the emergency vehicle E broadcasts the

warning messages to the vehicle while approaching the intersection to clear the way for

the safe passage of the emergency vehicle. Vehicle A, which is in range of E, receives

the message and in response to this delivers the message to vehicles which is in the

surrounding area of it to request their operators to slow down their speed to let the E

pass through the road safely. Vehicle B compares the RIT tables generated through CVP from other vehicles within the same range, and marks the vehicle D as the node which did not receive the message due to presence of truck C or building (obstacles) disrupting the direct communication path between E and D. In order to deliver the message to D, vehicle B sends the directional warning message to D, and confirmation of message delivery to D will be done by using the hand-shake technique between B and D. Concurrently, B will notify E about the presence of D and delivery of the warning message to it through the aforementioned technique.

6.5.2 Case Study 2: Highway Scenario

This scenario reflects the situation where the emergency vehicles want to change lane to turn to some different directions. For that purpose, the lane where the emergency vehicle wants to move to should be clear and vehicles already changing lanes are required to clear a path for it. An NLOS situation may occur due to the presence of trucks and buses in the questioned lane which could disrupt the direct communication between the emergency vehicle and the vehicles facing the obstacle. The proposed CVP can transmit the message successfully on this highway scenario to detect NLOS and clear the path for the emergency vehicle.
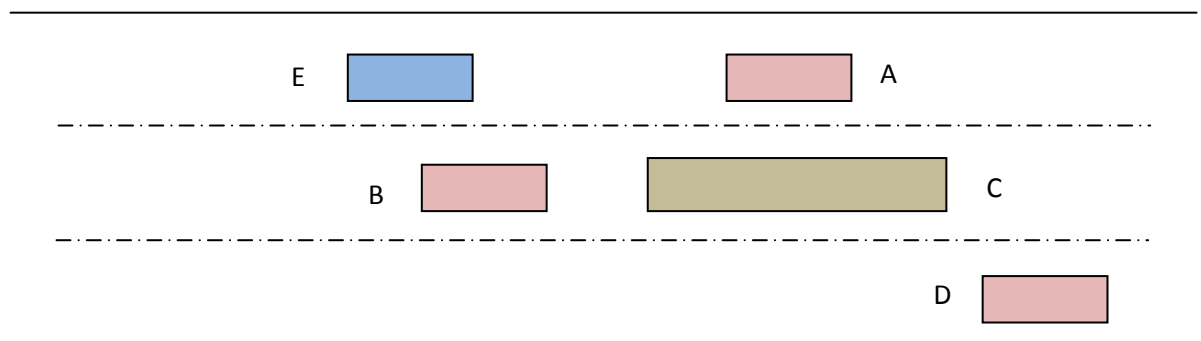
Figure 6.13 Case Study (Highway Scenario)

In the given case study, in Figure 6.13, the emergency vehicle E broadcasts the warning message to change lanes to the surrounding vehicles and vehicles A and B receive the warning message. However, when the vehicle B compares its RIT table with the RIT table generated by vehicle E, it find outs that vehicle D is missing in that due to being under NLOS situation. Actually vehicle D is in front of truck C, which obstructs the communication path between emergency vehicle E and vehicle D. After detection of vehicle D under NLOS by vehicle B, the CVP is triggered to transmit the warning message to vehicle D so that it can change its lane to clear the path for the approaching emergency vehicle E. After D changed its lane, vehicle B sends notification to E for successful delivery of the warning message to D and clearance of the path for emergency vehicle E through the use of the hand-shake technique.

6.6 Summary

A novel routing protocol mechanism in intersection and highway environments has been evaluated in this chapter. The performance of CVP has been evaluated using an EstiNet simulator in order to demonstrate the efficiency of the proposed CVP routing protocol. The comparison of the performance of the proposed protocol is made with the standard routing protocol called Greedy Routing with Abstract Neighbour Table (GRANT) that is applied to decrease the warning message delay in disseminating the packets to the desired destination node facing NLOS. The performance evaluation of GRANT is carried out using the same conditions in EstiNet as were used for the proposed routing protocol CVP. After comparison of experimental results obtained from EstiNet for both CVP and GRANT, it is showed that CVP has performed better than GRANT in various scenarios and under many tests.

Furthermore, in order to show the validity of the CVP, different case studies have been presented with a focus on the emergency vehicles (ambulances and police vehicles). Two scenarios have been introduced as two case studies, representing the CVP in two modes.

Scenario one represents the emergency vehicle approaching the intersection and triggering CVP to locate the NLOS situation and to solve the situation by cooperatively forwarding the message through the vehicle close to and in NLOS situation with the vehicle under NLOS. This ensures the reduction of storm problems by selecting only the vehicle in NLOS with the node facing NLOS in the network, thus saving bandwidth and retransmission of the warning messages, causing the channel contention issues.

CVP successfully detected the node under NLOS in the intersection scenario and delivered the warning message to it as well.

Scenario two presents highway condition when the emergency vehicle tries to change lanes and broadcast the warning message for path clearance of the questioned lane. CVP selected the node closest to the node under NLOS and through this the warning message is disseminated to the node under NLOS. On completion of this action, the emergency vehicle is notified.

Chapter 7

Conclusions and Future Work

Objectives:

- Summarise the work in the thesis

- Show the achieved aims

- Propose the future work that follows from this thesis

7.1 Summary

VANET is a special case of MANET, which casts an important impact on wireless communications on the roads, being used to develop the safety applications that require VANET for maintaining the comfort and safety for drivers and passengers on the road. The alarming increased numbers of fatal accidents resulting from collisions between emergency vehicles and normal vehicles, especially at intersections in urban scenarios, have caused governments and car manufacturers to focus their attention on the research and development of Intelligent Transport Systems (ITS), in order to decrease the percentage of fatal collisions occurring on the roads. Undoubtedly, VANET has become an important and essential player in the development and support of intelligent transportation systems.

The work that has been accomplished in this thesis will be summarised in this section. In Chapter 2, there were a brief introduction of MANET and VANET, including the characteristics of VANET and challenges faced by researchers in the development of safety applications in VANET. Furthermore, a comprehensive introduction and illustration of VANET is presented covering the two important communications in VANET: V2V and V2I; and the characteristics of two major types of applications in VANET – information or entertainment applications and safety applications. The information applications are useful in providing drivers with information and entertainment, for instance, drivers can get information about the nearest fuel station, the current weather conditions, the situation of traffic congestion and flow on the road ahead, and the information relating to restaurants, food menus and prices. However, the second type of application called safety applications alerts the

drivers about hazardous situations on the road, dissemination of messages about the potential accident situations ahead, detection of the NLOS situations, and dissemination of vehicles under NLOS situation. Following this, the challenges and requirements of the development of applications in VANET were fully elaborated.

Similarly in Chapter 3, the concepts about the dissemination of warning messages have been discussed with a focus on the delivery of warning messages to the vehicles under NLOS. The comprehensive discussion about the challenges faced in data dissemination in VANET has been discussed, followed by the different types of data dissemination considering the cases of V2V and V2I communications in VANET. Following this, the factors impacting the message dissemination in VANET were fully discussed, including broadcast schemes, message priority and cooperative message dissemination which lies at the heart of this discussion.

Following this, an extensive literature survey on the routing protocols in VANET is given, which actually presented the classification of routing protocols. Furthermore, the discussion on the various types of routing protocols with critical analysis in comparison with the proposed routing protocol is provided in Chapter 3 as well. For instance, topology-based protocol is presented with its suitability more to the MANET-based application than to the VANET-based applications, and the position based routing protocols are more suited to the VANET application than to the MANET applications owing to the constrained road topology and the high mobility features. Therefore, it is concluded in Chapter 3 that protocols designed for MANET applications cannot be used for the development of applications in VANET, and thus the high

demand for the development of efficient routing protocols with increased probability of delivering the warning messages to vehicles in NLOS is always required.

In addition, the classification of routing protocols introduced in Chapter 3 also clearly demonstrated that there are two main categories in the position-based routing protocols including a Delay Tolerant Network and a non-Delay Tolerant Network, and both of these classifications depend on the measurement of vehicular density in the network; and many examples of both categories are elaborated with their characteristic features, advantages and disadvantages. Many protocols for DTN were described where the number of vehicles is critical for dissemination of messages to the neighbouring nodes in the network. However, the development of non-DTN based protocol is challenging; the concern of this thesis falls in the non-DTN category, where high numbers of vehicles are present which can provide voluntary nodes for the delivery of warning messages to the vehicles under NLOS.

Furthermore, in Chapter 3, the preliminaries regarding the management of routing protocols were presented, describing the two important key ideas of the research, including the management of dissemination of warning messages to the vehicles under NLOS in order to avoid fatal collisions between vehicles in the normal and emergency modes. The element of cooperation among vehicles for message dissemination is concluded to be an important factor compared to the periodicity of messages in VANET for the present work.

The OBU architecture is illustrated in Chapter 4, that is based on the principle of a cooperative approach for the dissemination of warning messages to the target node in the network, thereby organising the broadcasting of warning messages to the target

vehicle cooperatively rather than periodically in VANET in order to decrease the bandwidth consumption and avoid the storm problem in the network, that ultimately led to reduction of overheads produced

Chapter 5 presented the design of CVP for both intersection and highway scenarios, along with the mechanism of message dissemination by CVP, how the comparison of the RITs is made in order to detect the NLOS and the packet delivery to the target vehicle under NLOS. Chapter 5 also introduced the algorithms for the detection of NLOS and packet delivery to NLOS, which formed the basis of function of CVP in emergency conditions at intersections and on highways.

Chapter 6 presented the validation results of CVP using simulation techniques to evaluate the performance of CVP; for this purpose, the simulation environment and parameters specific to that environment were identified and set to the suitable values. An EstiNet simulator is employed to conduct the simulation for this work. The simulation outcomes clearly demonstrated the better performance of CVP in terms of overheads, packet delivery ratio, neighbourhood awareness, channel utilisation and response time, compared to the GRANT protocol. Following this, the descriptive analysis revealing the effectiveness of the new proposed CVP routing protocol is discussed. Following this, the two case studies were introduced to prove the validity of CVP, the first case study highlighted the dissemination of warning messages at intersection located in urban areas, and it is shown that CVP could successfully be applied to the given scenario. Meanwhile, the second case study showed the application of CVP in a straight highway scenario.

7.2 Achieved Objectives

The research problems highlighted in Chapter 1 were solved as follows:

❖ Presentation of a new routing management by designing the new routing protocol for the detection of NLOS situations on the road at intersections in urban scenarios.

❖ The dissemination of warning messages broadcasted by the source vehicle (emergency vehicle) to the target vehicle facing the NLOS situation.

❖ CVP achieved the target of successful dissemination of warning messages to vehicles under NLOS through cooperatively delivering messages to vehicles under NLOS, through which the vehicles in LOS to the vehicles under NLOS volunteer themselves to deliver the packets to the NLOS, thereby solving the NLOS situation successfully.

❖ It has been shown that CVP can operate in two modes: intersection scenario in which a vehicle is hidden by a bus, truck or building, thereby preventing an access of warning messages from the source emergency vehicle to the vehicle hidden by some obstacle; and the highway scenario in which the location of the target node under NLOS is hidden by some other vehicle (bus, lorry, truck) or foliage along the highways, CVP effectively detected the NLOS and is triggered to solve the NLOS using the cooperative approach for message delivery to the target vehicle.

❖ Furthermore, the aim of reducing the storm issue in the network is achieved through the reduction of rebroadcast of warning messages by utilising the principle of a cooperative approach of message communications in VANET.

❖ A novel architecture is proposed based on the context-aware system and is designed to deliver the warning messages from the source vehicle to the target vehicle under NLOS cooperatively in VANET.

7.3 Research Limitations

The limitation of this research is due when there is no vehicle will act as a volunteer node in order to start the voluntary process or there were no vehicles in the coverage zone to detect the NLOS situation (hidden node), which will cause a threat to the emergency vehicle passing an intersection or changing lane in the proposed scenarios.

7.4 Future Work

Vehicular Ad hoc Networks have been considered an interesting and ever-evolving research area in the field of wireless communications and networking, whereby it attracted the attention of a large number of researchers. However, there are still many challenges relevant to this field, which need to be solved and overcome. Currently the focus has shifted towards the solution of issues related to the delivery of messages to the target vehicles, avoidance of storm problems and channel contention in VANET.

Based on the work accomplished in this thesis, future work can be undertaken in the following directions:

❖ The proposed CVP protocol is applied only to a single leg of the intersection, however, it can be extended to all four legs of the intersection, through which it

should be validated whether or not it can efficiently transmit the warning messages to the vehicles facing NLOS in each and every leg of the intersection.

❖ The proposed CVP is evaluated using a one-way traffic scenario. It can be extended to the scenario having traffic lanes with traffic flow in opposite directions. Its effectiveness needs to checked to use the vehicles in opposite lanes to serve as volunteers to deliver the warning messages to vehicles under NLOS in any of the traffic lanes on the road.

❖ The security part of the CVP needs to be improved in order to use its modified version for the security applications. It must be noted that CVP may give false signals. Thus the security aspects need to be validated for the proposed CVP.

❖ The sensors that were used to collect the data, their efficiency and effectiveness can be enhanced by the development and incorporation of the security interpreter unit which can convert the sensory data into a machine-readable format. This can be accomplished by using modelling techniques such as ontology.

❖ The CVP can be further developed through incorporation of more sophisticated sensors for the accurate collection of data.

❖ This CVP can be tested in real-life scenarios on the road for its validity and use in vehicles, so that it can be optimised for vehicles to avoid collisions in real life scenarios. This can be done by performing some field experiments using the experimental vehicles or sample vehicles on the road, and real data provided by CVP from the real road experiments can be used to infer its performance in real life situations.

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