Utilising In-vehicle Information to Detect Traffic Conditions in Vehicular Ad-Hoc Networks

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Copyright Statement

Dedicated to my love mother, my love wife and to my sons (Qais and Aws) for their endless love and support throughout my studying.

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All Praises be to Allah Almighty who enabled us to complete this task successfully and our utmost respect to His last Prophet Mohamed (Be blessed upon him).

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Supporting every worker is an understanding family, or nothing would ever get written or done! I am obliged to express gratitude to my

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Abstract

IN the last decade, cooperative vehicular network has been one of the most studied areas for developing the intelligent transportation systems (ITS). It is considered as an important approach to share the periodic traffic situations over vehicular ad hoc networks (VANETs) to improve efficiency and safety over the road. In addition to the uses of ITS, VANETs will contribute in service access, cooperative driving, entertainment and navigation for cars of the future. Vehicle to vehicle and vehicle to infrastructure communication are two distinct avenues that make possible efficient delivery of messages through direct wireless transmissions in traffic regions. Furthermore, promising quality of communication performance is desirable for a communication system composed mostly if roaming participants; such a system needs to be dynamic, flexible and infrastructure-less. Thus VANET architecture is a natural fit for ITS. However, there are a number of issues in exchanging traffic data over high mobility of VANET, such as broadcast storms, hidden nodes and network instability.

Therefore, vehicular traffic efficiency applications have been investigated recently using VANET. This aspect of research is primarily concerned with increasing the traffic awareness over roads. In this thesis, a novel model, Efficient Traffic Conditions Detection

(ETraCD) is proposed to detect the traffic conditions utilising vehicles' characteristics and in-vehicles sensors information to evaluate traffic situations that are gathered from the nodes (vehicles) in VANET.

The model revolves around the core idea to what extent we will be considering the traffic characteristics between groups of cars rather than individual cars. This does not concern the physical transmission of data but the data processing in the network. More precisely, vehicles are clustered into traffic groups based on the similarity of sensors's data. ETraCD (a) divides the situations of vehicles into clusters, (b) designs a set of metrics to get the correlations among vehicles and (c) detects the traffic condition in certain areas. These approaches have been simulated in NS3 network simulator to investigate the performance of stability of the network, latency, and the accuracy of traffic situations detection.

The proposed model applies V2V clustering paradigm for detecting traffic conditions, it has been implemented and its features investigated through simulation runs. It shows the benefit of using the vehicular sensors informations such as ABS, windscreen lights and so on based on V2V communication to provide an efficient traffic conclusion in urban environment. Experiments also show improved overall performance when compared to previous protocols.

Publications

1. Ayman Abufanas, Richard Germon and Evtim Peytchev. Road Traffic Condition Detection - Wireless Networks Models Review. Second International Proceeding Symposium on Sustainable Mobility 28-29 May 2014 Conference Centre, *Chinese Academy of Sciences*, Beijing, China.
2. Ayman Abufanas (2015). Poster presented in the College of Science and Technology, Nottingham Trent University, 9th Science and Technology Annual Research (STAR) Conference on 7th-8th May 2015.
3. ABUFANAS, A. and PEYTCHEV, E. , 2015. Detecting Traffic Conditions Model Based On Clustering Nodes Situations In VANET. Proceedings of the 29th European Conference on Modelling and Simulation (**ECMS**), Albena, Varna, Bulgaria, 26-29 May 2015. *European Council for Modelling and Simulation.*
4. Ayman Abufanas (2016). Using SUMO for simulation of in VANETs, Modelling and Visualising Traffic Simulation Models. Impart Workshop, Nottingham Trent University Conference Centre , February 2016.
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Abbreviations

MANET	Mobile Ad hoc Network
VANET	Vehicular Ad hoc Network
MAC	Media Access Control
HIHE	HeuBNet6 Intelligent Heuristic Engine
NS3	Network Simulator III
DSRC	Dedicated Short Range Communication
ITS	Intelligent Transportation System
IVC	Inter-Vehicle Communication
MNAD	Managed Network Address Directory
IVC	In-Vehicle Communication
ND	Neighbour Discovery
ACK	Acknowledgement Message
DIFS	Distributed Inter-frame Space
CTS	Clear To Send
ETraCD	**E**fficient **Tra**ffic **C**onditions **D**etection protocol
COC	**C**ontent **O**riented **C**ommunication Protocol
TCDA	**T**raffic **C**onditions **D**etection **A**lgorithm
ECODE	Efficient Congestion Detection Protocol
TCP	Transmission Control Protocol

3G/4G	Third, Fourth Generation of Mobile Telecommunication
TEM	Time Expired Messages
DTN	Delay Tolerant Network
UDP	User Datagram Protocol
WMN	Wireles Mesh Network
NGSS	Navigation global satellite system
OBU	On-board unit
RSU	Road side unit
OSI	Open system interconnection
GPS	Global positioning system
WMN	Wireles Mesh Network
HTC	Hazard Traffic Cluster
PD	Participation Duration
TD	Traffic Density
TC	Traffic Cluster
TS	Traffic Situation

Contents

List of Figures

List of Tables

List of Algorithms

Chapter 1

Introduction

1.1 Overview

In this chapter, we overview the background of this research to provide appropriate context regarding intelligent transport applications. We then present the motivation of this research along with main issues specifically tied traffic evaluation systems. We then introduce the contributions of this study. Finally, the last section of this chapter summaries the structure of this thesis.

1.2 Introduction

The number of vehicles on roads is increasing day by day over the world. Some figures from the agency of driver and vehicles licensing (DVLA) state that about 100,000 new registrations of vehicles just in the first quarter of 2016 [3]. In the same period, vehicle usage grows by 2.5 per cent to 36.7 million in the uk. These figures have influenced on life safety of people and participially vehicles' passengers.

Due to serious issues caused by the dramatic rise of vehicles usage in term of traffic safety management such as increasing the rate of car accidents, traffic congestion, and so on, finding solutions for issues of traffic control and roads management has become significantly important in order to utilize the full capacity of all roads. In addition, the lack consideration of travel safety may also increase number of traffic accidents. For instance, approximately six million accidents are recorded annually in the United States alone and the same study shows that in the 2007, thousands of people have died and were injured in China due to cars crashes [4].

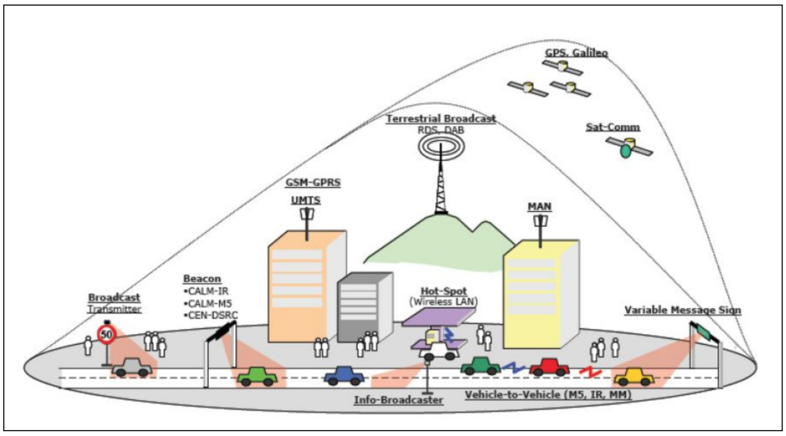

Figure 1.1: ITS architecture [1]

Consequently, researchers have focused on different approaches that take control over the traffic issues, one of the ways is to gather, spread and utilise roads and traffic information using wireless communications among vehicles. Therefore, many research has been conducted to develop the Intelligent Transport Systems (ITS) to lessen the problems and to assist drivers to avoid potential congestions or hazard roads on their current routes. For instance, (Bishop,2005) [5] states that the integration of ITS with telecommunication and transport data technologies will provide reliable forecast information to travellers and as a result to enhance the safety and efficiency of the roads. In fact, the idea of combining telecommunication with transportation control systems was established in public in the 1939 by General Motors [6]. Historically, it was most advanced concept to knowledge at that time. They attempted to describe the benefit of utilising basic communication between vehicles and the infrastructure in order to improve traffic control even at somewhat high velocities. Several findings such as some reviewed by Dabbous and et al [7] associated with this field are still influential till our current time. These attempts are under-utilised so far in term of traffic management systems where every vehicle can be considered as an independent node in an ad-hoc form [8].

1.3 Vehicular ad-hoc network

The new wireless tobology, which is discovered by communication among vehicles, is known as a Vehicular Ad-hoc Network (VANET). Vehicular network, as a special case of the mobile ad-hoc network (MANET), is considered as one of newest technologies that have developed dramatically in the last decade. The association of Computing Machinery (ACM) was first coined it in an international workshop on Vehicular Networks [9]. It aims to improve travel safety, traffic knowledge, and also pedestrians information services by utilising from communication between cars and the infrastructure or direct communication among cars. Although VANET is a special kind of traditional MANET, most MANET's techniques can be inherited to VANETs. However, the latter has some unique characteristics such as high mobility (speed), rapidly changing form and short link lifetimes which makes the MANET's features somewhat difficult to apply.

The solutions to MANETs were built for networks with more stability and lower mobility than typically observed in a VANET. Even though mobility tends to be higher in VANETs, they are fixed and deterministic since each vehicle is bound to the path it travels on. This fact amongst several others has led to the ground of this research. Thus, The use of Information and Communications Technology (ICT) in ITS requires the development of an advanced communication model that enables all participants in the traffic to talk to each other. There are European projects focusing on different types of ITS information systems' paradigms, known as the vehicle-to-Infrastructure (V2I) communications, which develop models for message delivery to/from cars and the vehicle-to-vehicle (V2V) communication for enabling cars to exchange data. V2V research is still lagging behind in developing a stable wireless communication environment [10][11].

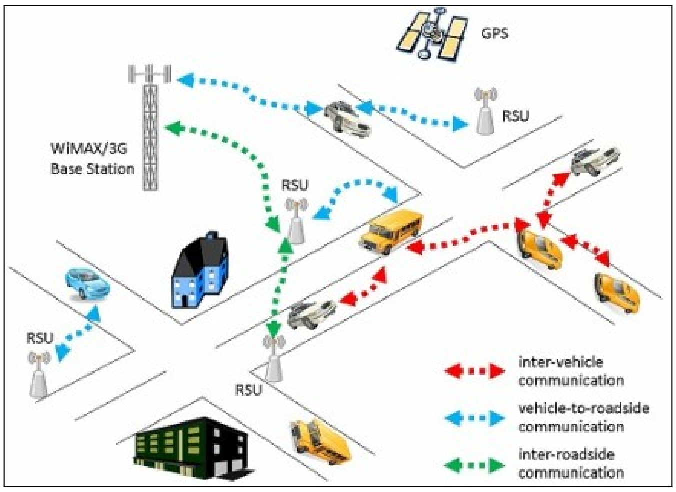

Figure 1.2: VANET Concept

Figure 1.3 illustrates the architecture of vanet including these types of communications. Currently, VANET-based wireless networks are a natural fit to intelligent information transportation system (ITS). In fact, currently, several recent relevant ITS applications still require fixed infrastructure. Particularly, the communication part between vehicles and road side units is defined as Vehicle-to-Infrastructure (V2I) communications. Although, it helps for several solutions for any traffic safety challenges, many questions rise about V2I method, because it has faced several issues such as the cost of sufficient infrastructure, scalability, and reliable connection [8] .

According to these circumstances, researchers and commercial projects have moved to focus on a different architecture of ITS applications, known as the V2V communications, which focus on direct message delivery between nodes (vehicles) [12].

- Self-Organisation: The nodes participating in the network do so without the aid of a central management system. This lack of a central management system or central infrastructure can lead to poor network management and poor utilisation of network resources [9].

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

- Standards: A lot of work has gone into acceptable standards for both software and hardware in VANETs. Many researchers include requirements that may prevent auto manufacturers or other researchers in implementing their proposals [9]. In this research, the aim is to use existing mechanisms to achieve efficient traffic detection distribution in the network, all standards already proposed by organisations such as ETSI and IEEE will be used without significant changes.

1.4 Problem specification

Recently, Most of the current traffic conditions evaluation applications rely on concept of building a direct communication between mobile nodes in MANET and existing infrastructure unit, which immediately raises arguments about the integrity, availability, required hardware and so on. When we perform a collaborative ad-hoc network, the existing approaches which rely on somewhat infrastructure may require the high cost. Therefore, there is a need for proposing a model that is decentralised, self-organisable, and does not rely on the network infrastructure, but the exchanging of traffic data between the vehicles will help the region definitions to identify traffic conditions.

Regarding the short-time traffic condition detection is a significant application for controlling the traffic safety and driving guidance in ITS. Previous studies evaluating traffic detection method observed inconsistent outcome whether traffic conclusion is reliable or not. Some of them had disadvantages of a) relying on infrastructure equipment, which raises issues of cost and availability in reality. And b) traffic prediction methods that have been recently used depending only on geometric characteristics of roads, vehicles movement data and not considering driver's behavior concurrently. Some studies consider V2I communications to gather data then detect traffic status of roads. Also, they have not taken individual vehicle's sensors data (e,g. ABS, Brake light data, etc.) into account to improve the performance. In contrast, very Few studies have noted the significance of the status of every individual vehicle in order to deliver a reliable traffic evaluation using V2V communication scheme [13]. However, to the best of my knowledge, it is the first time that taking individual traffic sensors data into account in order provide a strong similarity

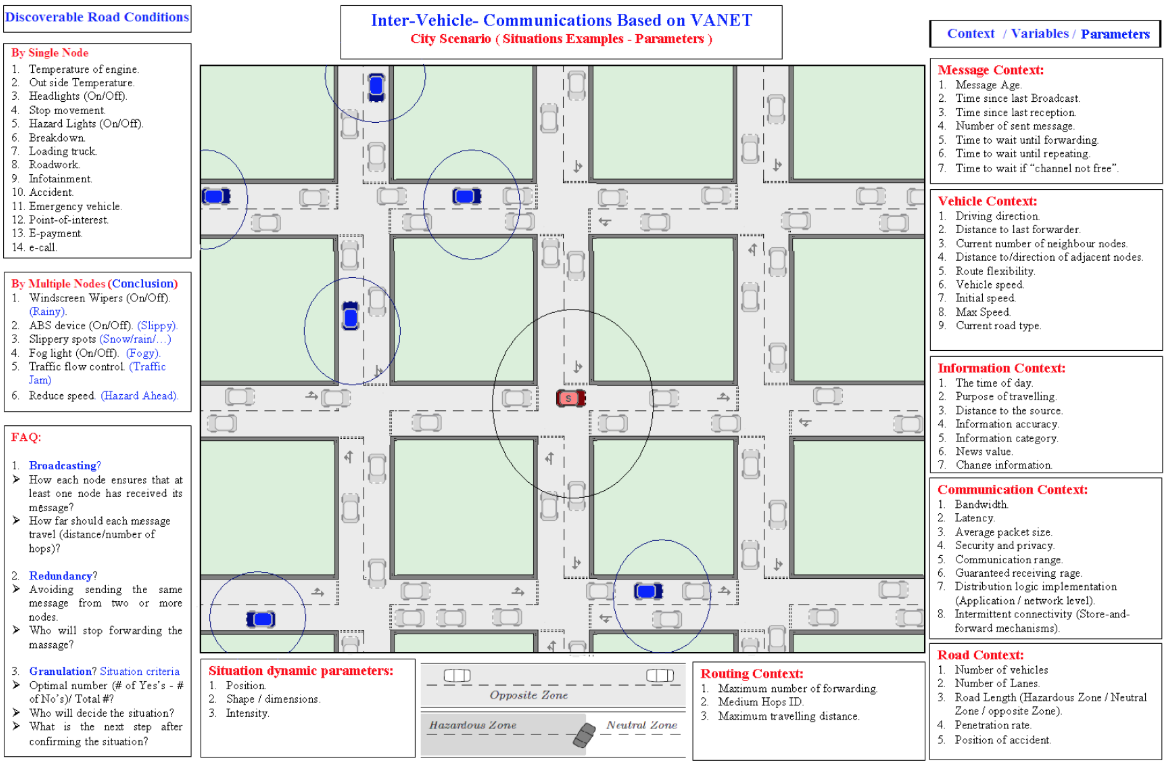

Figure 1.3: City scenario - (case study)

correlation among vehicles then analyse it and evaluate it in the area of interest.

Given the disparity in both methods, it is evident to see that introducing an approach extends deeply to consider individually traffic movement data along with cars' sensors data based on certain criteria. For example, should all adjacent vehicles participate in the same traffic conclusion? Is possible to detect multiple traffic statuses happen in the same area? Etc. This research proposes a novel model by combining individual car's sensors information along with characteristics of car's movements. Then the model converts the low-level individual vehicles' data, which are gathered by vehicles in which they are located, into high-level of traffic conclusions. As a result, collaboration among vehicles will be more intelligent than previous traditional approaches such as those that rely on infrastructure to analyse the gathered data. Moreover, this work aims to critically investigate the effects of utilising vehicle's sensors data in order to deliver an efficient traffic condition detection model through clustering paradigm for vehicular environments.

1.5 Objectives of the research

This study is focused on evaluating the gathered traffic data through utilising vehicles' sensors data in city scenarios where the traffic characteristics may be more sensitive to sudden incidents because of the high density of vehicles over the roads. The research provides an overview of vehicular network communications and the potential approaches, which may apply to VANET environment. After which a study is carried out to identify what traffic factors influence on vehicular network communication. This will lead to conduct experiments using those factors to gather data to be used in designing and building our model for identifying traffic conditions in VANET. The objectives of this study are:

- To study the state of the art of vehicular ad-hoc network paradigms and traffic evaluation technologies.
- Investigate factors associated with road traffic characteristics may affect on vehicular network communcation.
- Investigate the influence of utilising of individual vehicles situations on the traffic evaluation performance.
- Investigate VANET dissemination and gathering traffic data methods.
- Test the impact of using In-vehicle sensors data on the detected traffic conditions

- Design and implement algorithms for gathering traffic data, evaluating the gathered data, and method of expanding and merging detected traffic conclusions respectively.
- Develop and implement a model for detecting traffic conditons through clustering in vehicular ad-hoc networks.
- Investigate the viability of the proposed model against existing existing protocols through a series of experiments.

1.6 Original Contributions

The original contributions of this thesis are:

- **Investigating and identifying extra factors could be derived from In-vehicles sensors to improve the performance of detected traffic conditions in VANET:** this approach involves the investigation of how utilising individual vehicles' status data (defined in the thesis as In-vehicle sensors data) such as ABS control, Windscreen Wipers, Brake light, etc. and taking traffic data such as speed, direction, and position into account can help to improve the performance of detected traffic conditions zones of the urban environment. Following this investigation, experiments to gather the effects of the aforementioned data will be performed.
- **Novel algorithms for identifying traffic conditions by utilising V2V communications and, cooperative traffic data gathering and through intelligent traffic clustering approach:** the new algorithms is for a) each vehicle share and gahter traffic characteristics including In-vehicle sensors data from other vehicles within transmission range and define a cluster that reflects traffic situation of vehicles in the area of

interest. A specific criteria will be applied in order to identify traffic situation cluster. Then b) Each vehicle in such traffic situation zone will evaluate the gathered data in order to come up with traffic conclusion of the detected cluster. Finally c) algorithm for expanding the traffic conlcusions in order to inform other vehicles in different regions.

- **Design of *E*fficient *Tr*affic *C*onditions *D*etection Model (*ETraCD*):** the algorithms described above are employed in the design of a new model. it is designed through a concept of developing dynamic traffic clusters. It is an active aware model for evaluating real-time traffic situations based on vehicle-to-vehicle communication. It is designed to detect the vehicles that have similar traffic characteristics through clustering in a city scenario. *ETraCD* identifies and reports the traffic conditions of each cluster, in order to be recognised by the real-time traffic efficiency applications in traffic control centre. Through designing this model, following are achieved;
  - Defining rules for how each vehicle performs its duty in terms of gathering traffic data and identifying traffic situation zone.
  - Defining rules of how the detected traffic situation zone are evaluated and provide conclusion of such situation.
  - Ensuring that the model can expand the detected traffic conclusions to another areas in city scenario.

1.7 Structure of the Thesis

In this section, we provide a brief guide on the research structure through presenting the main contents of the chapters of this thesis, as follow:

- **Chapter one**: introduction to ad-hoc network and intelligent transport systems was introduced. Challenges of traffic conditions detections applications have been presented with special characteristics of VANET toplogy. Moreover, research motivation and contributions to the knowledge were also stated in this chapter.

- **Chapter two**: it presents the VANET domain and its architecture, its standards and applications as well as establishing the required parameters for better performance in the vehicular topology. In addition, the chapter introduces the existing traffic condition detection technologies, as they are within the general field of this study. It also introduces traffic condition evaluation protocols in either V2V or V2I communication topology and related work which uses traffic information through different approaches and methods. This knowledge delivers appropriate assumptions and the scope of this research.

- **Chapter three**: it introduces the general design for detecting traffic condition using the VANET environment. It also presents various data dissemination and gathering methods, which may be utilised in identifying traffic situations. A detailed look at the In-vehicle sensors data and they increase the accuracy of the detected traffic cluster in our model. This implies to a brief discussion about factors that affect on wireless communication in VANET. Finally, it concludes possible metrics for measuring such traffic conditions detection protocols.

- **Chapter four**: it presents an explanation in detail of the proposed algorithms of the model for identifying traffic conditions for vehicle to vehicle communication technology (*ETraCD*). The chapter discusses different possible scenarios and cases, which can be detected by the proposed model. It also introduces multiple algorithms for gathering traffic data, evaluating the gathered data, and expanding conclusions of clusters that the model delivered. Following, execution mechanisms of ETraCD are introduced in that chapter.

- **Chapter five**: the new model is designed and implemented in network simulators. It includes the setup of simulation parameters for the conducted experiment. Finally results of the model performance and the comparison analysis are discussed in this chapter.

- **Chapter six**: it reviews the outcome of the undertaken work in this research and highlights the main objectives achieved. It also introduces some vital recommendations and suggestions through discussions of the future directions of this research.

Chapter 2

Related Work

Outlines:

- Ad-hoc Networks.
- VANETs Architecture and Standards.
- Applications of VANET.
- Traffic Evaluation Technologies.
- Traffic Evaluation in VANETs.
- Simulation Techniques in VANET.
- Summery

Related Work

2.1 Overview

The first part of chapter two is a general review of Ad-hoc networking, and their types. Then the chapter discusses first the topology of vehicular ad-hoc network (VANET) and its architecture in order to gain the background of the study reported in this thesis. Second it presents wireless communication technologies and standards are used in vehicular environment. Variety of applications may be provided in VANET field are also covered in this chapter. Those applications are whether for safety, traffic management or entertainment purposes

In addition, the second part of this chapter starts with section 2.6, it is a brief discussion about the existing approaches for real-time traffic evaluation. The chapter then covers traffic conditions detection and evaluation approaches in such network and outlines traffic detection issues in section 2.7. The section lists most related traffic conditions detection protocols existing in the literature discusses their advantages and drawbacks. Moreover, a brief text of the challenges face traffic efficiency applications in ITS is presented in section 2.8. While section 2.9

presents the high-level based architecture of the proposed model. Consequently we can gain a critical review of previous protocols in VANETs which are aimed to bring a conclusion of the traffic conditions over roads. Classification of traffic efficiency protocols are also included according to their functionality and to point possible scenarios of these protocols.

2.2 Ad-hoc network

An ad hoc network is defined as a cooperative engagement of a group of mobile nodes without the required services of any centralized access device or any existing infrastructure [14][15]. From this definition, it is clear that two most important characteristics of ad hoc network is principally a cooperation between devices (nodes) and the independent management. This section will present a brief overview of ad hoc network types, architecture, the standards and current approaches, and their applications.

2.2.1 Ad-hoc network types

Wireless Mesh Networks (WMNs); it is a general tobology of ad hoc networks. Simply, it is a mixture of mesh routers and mesh clients or devices, as shown in Figure 2.1. Mesh routers that are linked to their clients are also connected to each other in a multihop form, hence it results to a stable network. Some mesh routers have the capability to act as Internet gateways. Recently, the wireless mesh networks are quickly developed to offer coverage for few miles of connectivity, and as such, are more qualified as a solution for metropolitan area network. As a result of the possibility of including extra mesh routers, it provides more coverage in a region [2][16].

In addition,the characteristics of WMNs have been develped qiuckly by researchers and examined in terms of the performance and stability. Transceivers based on the IEEE 802.11 standard have been used in WMNs because they are inexpensive and easy to implement. Moreover future research still continue to utilise other standards such as WiMAX[2][17] and 3G/4G in order to develop WMNs over IEEE standards.

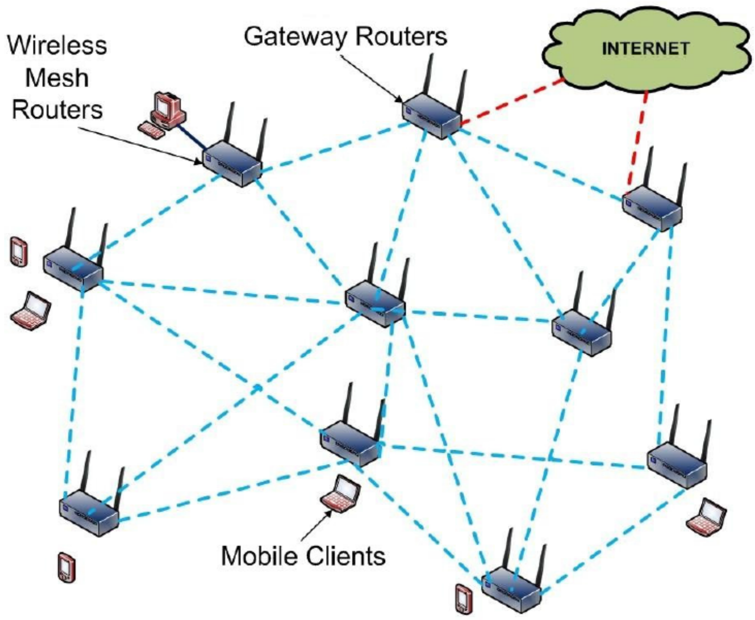

Figure 2.1: Mesh Network Form [2]

Mobile Ad-hoc Networks:

Mobile Ad hoc Network (MANET) is special case from WMN in terms of general topology, but clients (nodes) in MANETs tend to be fully mobiles within the network. Both are similar in communication tecnologies to establish the network. Importantly, because of the mobility of node, it could be a real challenge to build a reliable backbone as in WMNs. Therefore, all nodes in a MANET are self organised to manage communication by establishing routing protocols for sending and receiving messages among nodes[18][16], whilst the limitation of node's heterogeneity is taken into consideration. Recent reseach on

MANET is focussing on develping routing prtocols and mobility models. A special form of MANET it is called Vehicular Ad hoc Netwok (VANET) when vehicles that over roads represent nodes in the network.

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2.3 VANETs Architecture and Standards

According to the characteristics that shown in figure 1.3, the architecture of VANET can be classified into categories in term of communication nature; a) vehicle to vehicle communication (V2V), b) vehicle to infrastructure (V2I) and c) inter-roadside communication (I2I) [11], which is the communications between RSU and other infrastructure units such as traffic control centre. Since the limitation of availability of a reliable infrastructure or not widely deployed due to setup costs or geographical nature in some regions [19][20][21], vehicles are almost involved to communicate to each other. Because of traffic data are collected by on-board unit that is implemented in the vehicles, it leads to be the solution key to notify other vehicles about the traffic status or help traffic control centre in this area.

Considering that V2X safety systems requires reliable, scalable, and cost-effective promising technological framework. The wireless communication standards should offer the reliability and the required quality of service (QoS) regarding connectivity and bandwidth. In addition, in term of funding the infrastructure of vehicular wireless technology and its maintenance, economic and cost-effective issues should be considered [22][21][23]. The reference standard that organise the communications among vehicles is the IEEE 802.11p [24][25]. It also known as Dedicated Short Range Communication (DSRC), is reliable wireless local area network (WLAN) standard designed for traffic safety applications.The following two subsections briefly present an overview of DSRC/WAVE standard and its protocol stack in V2X environments.

IEEE 802.11 series standard of WLAN offers a higher speed of transmissions but shorter distance dependence on verity of cellular network types. IEEE 802.11 standard is developed to cover physical and MAC layers specifications for wireless connections among static, dynamic and mobile clients within a certain area (Ma and Jia 2005, Li 2013).

2.3.1 Vehicular Network Architecture

This section illustrates the architecture of Vehicular networks. Generally, guide of VANET framework can be built through three main domains as shown in table 2.1: 1) ad-hoc domain, 2) Infrastructure domain, and 3) In-vehicle domain. Figure 2.2 classified VANET into four main communication categories under those domains, and they are closely linked as main VANET key components for any specific field[26][27].

Different wireless access scheme is included depending on the scope of the VANET framework. Navigation global satellite systems (NGSS) and cellular networks, such as 2G version and above, are applied on infrastructure domain. IEEE 802.11a/b/g/n/ac and Bluetooth wireless standards are used to the In-vehicle domain [28], whereas IEEE 802.11p standard is fully applied on the ad-hoc domain. However, two or more wireless access approaches could be included in the same VANET application.

Table 2.1: VANET's domains

Domain	**Wireless access**	**Client type**
Ad-hoc domain	Wi-fi (*IEEE 802.11p or IEEE 802.11a,b,g*)	V2V (*On-board unites (OBU)*) or V2I (*OBU and RSU*) [29]. OBU create ad-hoc network which provide communication among vehicles (*nodes*).
Infrastructure domain	NGSS, Cellular networks (*2G, 3G, ..etc.*). Wired connection also available among RSU to control centre	*RSUs* and wireless hotspots (*HT*), which represent infrastructure side, are connected to *OBUs* that equipped in vehicles.
In-vehicle domain	Wireless conncetion via short range communication such as IEEE 802.11 standards or Bluetooth	Application units (*AUs* such as phone cells) are connected to OBU

- **Vehicle-to-infrastructure (V2I)** or vehicle-to-roadside unit communication is a mixture of both ad-hoc domain and infrastructure domain. Although it is considered as warning messages platform, RSUs may also share updated weather, advertisements or an entertainments information with nearby drivers. High bandwidth is configured in V2I between vehicles and RSUs. As a result, high data rates can be provided through such V2I applications even when a high peak of traffic information. If we would take varied broadcast speeds, it is potential for RSUs to

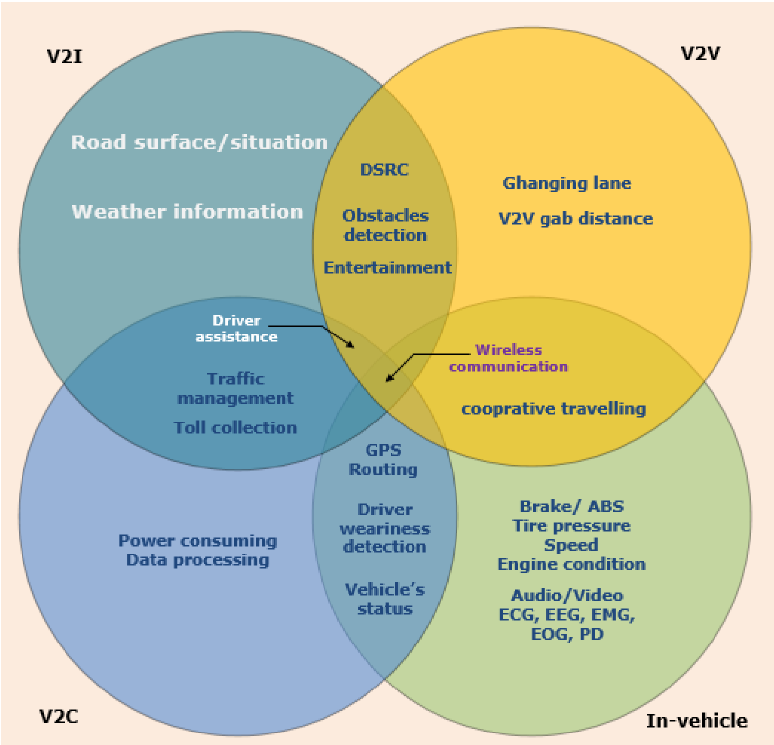

Figure 2.2: VANET keys and functions.

calculate appropriate transmission data rates by taking local traffic conditions into account. Then, RSUs will transmit traffic messages with suitable speeds.

- **Vehicle-to-Vehicle Communication (V2V)**, which also known as Car to Car (C2C) communication in art of the literature, refers to ad-hoc domain. In general, it provides a traffic data assistance platform to broadcast awarenesses information or share warning messages between cars in an area of interest, this include either one-hop or multi-hop scenarios. Researchers have yet waited to obtain a full system of a decentralised vehicle to vehicle communication. Hence, the V2V platform can help avoid or prevent traffic accidents, provide better accurate real-time information, and support eco-friendly driving. VANET systems run with little or infrastructure less and are characterised by a) high velocity, b) fixed and determined travel paths, c) predictable traffic patterns in congested situations, and d) insignificant power limitations or data storage constraints.

- **Vehicle to Cloud (V2C)** or vehicle to broadband (V2B) communication is associated with V2I. Traffic information is stored at a higher level such as broadband cloud instead of staying in local RSUs or OBUs. Cloud computing for VANET is still in early stages and has been studied recently by several researchers [30][31], however, a fully V2C model is not yet introduced to serve vehicles' drivers and passengers in term of their technology needs. Consequently, V2C face serious challenges that should be considered such as security, intelligent aggregation traffic data, and energy efficiency [32] in cloud data centre.

- **Inter-Vehicle Communication (IVC)** is part of in-vehicle domain. It offers information about vehicle's performance. Through application Units (AUs) and OBUs, data that received can be processed to provide essential safety information for drivers in the area of interest. Inter-vehicle communication uses multi-hop broadcast for transmitting warning messages through different hops at one time. Intelligent transportation systems utilise Inter-vehicle scheme to deal with such emergency information about a risk of accidents and sudden changes that have been occurred in scheduled paths [33][34][22]. Intelligent broadcasting and naive broadcasting are other two kinds of message forwarding in Inter-vehicle communication.

  First, the naive broadcasting technique allows vehicles for exchanging messages periodically. Any repeated messages are ignored on the vehicles, hence each vehicle only receives new messages sent from a vehicle that is in the front. The advantages of this mechanism are that vehicles will be aware of the traffic hazard ahead. In contrast, high risk of data collision due to a large amount of sent messages. Consequently, higher delay of messages delivered and then lower message delivery ratio [35]. Second, Intelligent broadcasting involves coming up for solving the implicit issue caused by the previous technique. The frequent of emergency events are generally limited, therefore the messages being spread are restricted to emergency situations only. And only vehicles that involved in this incident pass the responsibility backwards.

2.3.2 MANET Architecture

Using a reference model that contains hardware and software layers is an approach to represent a network architecture for transmitting data between two machines or enabling the connectivity among multiple devices in a network. Therefore, reference models provide the ability to manufactures in order to reach the required compatibility between devices [36][37]. The Open Systems Interconnection (OSI) model was proposed by the International Organization for Standardization (ISO) as a reference for researchers and developers to build the architecture of protocol standards [36].

OSI model consists of seven layers [37] which are ordered vertically in a way that each layer serves the layer below it in sending connection and is served by the layer above it in receiving connection. The OSI layers are ordered firstly from physical layer to layer 7 (application layer). Designing of OSI was built on an assumption protocols developed through this model could dominate computer communications. In other words, standards and protocols should be developed in the context of the reference model [36][38].

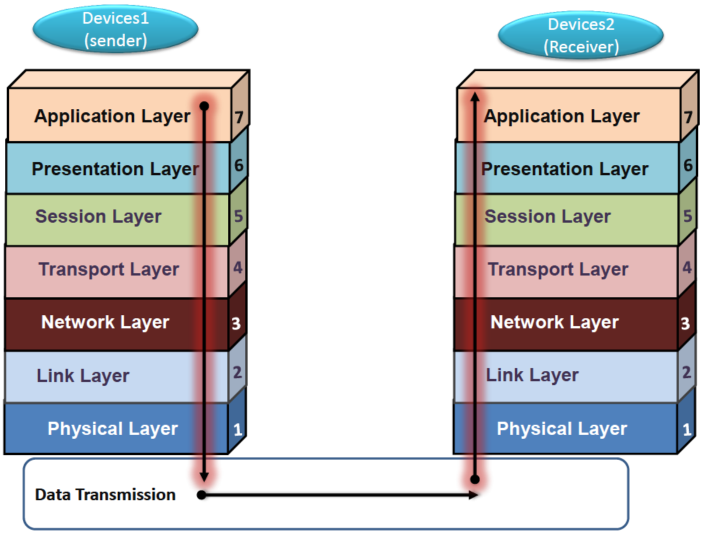

Figure 2.3: OSI Reference Model

Figure 2.3 shows ISO-OSI model, it contains the lowest layer which is physical layer followed vertically by data link layer, network layer, transport layer, session layer, presentation layer then the highest layer, or layer 7 (application layer). The physical layer has responsibility of transmission unstructured logical signals over a physical medium (communication channel). In this layer, the mechanical and electrical characteristics are required to accessing the physical medium. The function of data link layer is to coordinate and control accessing shared medium among different nodes. It is also responsible to transfer data as structured frames with headers to be as a self-contained entity because if a fault occurs in any frame, it will be dropped without influencing on others frame, the layer 2 has a sub-layer called Medium Access Control (MAC) for achieving that purpose.

The layer 3 (network layer) is responsible for routing data, as packets, from current node to next node, through the stages of establishing, maintaining and completing the network connections. Internet Protocol (IP) are generated as addresses of sent packets. The transport layer is designed in OSI model to be an interface between the lower layers and the upper layers. It provides an option of a reliable end to end connection for the transfer of data between source and destination, by confirming that received data is exactly that same as sent data in source device. In addition, it offers the ability to change quality of services of the data which are provided by layer 3 depending on the type of network.

The session layer offers the mechanism of synchronisation between end-user application layers and coordinate the data between them.The presentation layer works to represent the data during the transferring mechanism between the two devices. It mitigates the application layer concern regarding compatibility in data representation within the end-user systems. Finally, the highest layer (application layer) provides an interface of application program to the end user in a network.

Figure 2.4 shows the recommended architecture of MANET reference model in the literatures, it conists of five layers [39]. The layers are as follows:

- Radio layer instead of physical layer in ISO-OSI reference model.
- Data-link Layer.
- Network Layer.
- Transport Layer.
- Application Layer.

Some researchers consider the layers 5,6 and 7 in OSI model as one layer in MANET's reference model, while the layers 1,2 and 3 are the same except they counter more issues due to the MANETs form [39].

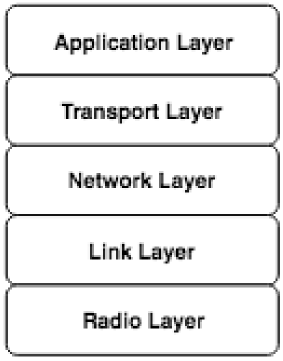

Figure 2.4: MANET Reference model

2.3.3 Ad-Hoc Standards and its Current Issues

Recently, the development of ad hoc networks has been raised rapidly, it has been done because of the great efforts of the Institute of Electrical and Electronics Engineering (IEEE) and the Internet Engineering Task Force (IETF) that they use the standardisation of the technologies [40][22]. The IEEE 802 association offers reliable standards cover variable-sized packets in the networks. In particular, wireless communication standards family, such as IEEE 802.11 for wireless local area networks, IEEE 802.15 for wireless personal area network and IEEE 802.16 for wireless broadband, clearly show ambitious standardisation effort [41].

The most main important issues in ad hoc networks standards are self-configuration communications and packets routing. The IETF has taken responsibility in three important categories in terms of standardising in ad hoc networks [40][42]: First, Auto-configuration group in ad hoc networks (autoconf), which responsible for issues of self-configuration characteristics. Second, packets routing protocols in MANETs. And packet delivery over low or less power networks, which deales with routing standards in some special cases.

2.4 Applications of VANETs

V2V or V2I communications provide an opportunity to the researchers to investigate and develop realistic solutions for many issues that associated with improving driving safety, traffic efficiency or providing useful information to car's drivers they may need them during travel. Whereas, VANETs become promising networks in term of increasing the safety and performance of driving over the roads. VANET's applications can be categorised into four main classes [22][19][16][43], which are illustrated below:

- **Traffic management applications:** the main way that is traditionally used in traffic management or forecast applications is through setting up static sensors inside roads infrastructure. Relative speed and number of cars over certain roads in certain time slots could be calculated based on these detectors. In order to predict the traffic condition, the information that collected is not necessarily to be passed to all vehicles, but it is combined as a historical data with real-time information. More reliable forecasting could be provided when such systems use navigation systems which contain velocity information and global positioning system (GPS) inside the vehicle [44].

- **Safety applications:** Another significant category of VANET purposes is traffic safety applications. Mostly, those systems is associated with improving a) safety of vehicles' passengers over the roads and as a result b) enhancing travel trip time performance [45]. Typically, these systems face challenges of detection of a potential accident between two or more vehicles due to irrelevant speed or broken vehicle and overtaking hazards. In addition, safety applications face critical latency less than 0.1 seconds [46]. Therefore, The need of reliable V2V safety systems in rescue operations raise specially in cases of emergency situations such as natural storms or warfare, whereas, accessing to the infrastructure is limited or might be not found.

Therefore, ad-hoc network could be an appropriate approach in such cases due to its special characteristics and quick, and easy deployment in such areas. Assistance to merging road, collision alerts and other traffic conditions warning applications are also classified under safety category. The type of communications in safety applications could be either V2V or V2I communications. In addition, due to the rapid growth in cellular communications that currently offer end to end short delay times in higher scalability networks, more researches were recently introduced for VANET safety applications through cellular communications [47].

- **Connected vehicles applications:** The high coverage of wireless internet services give an opportunity to the car manufactures and car services providers to deliver their services to vehicles' drivers in proper time. The networking system that included in some modern cars can be used by car manufactures for the ability to monitor mechanical components of vehicle for developing and enhancing purposes. The information sent from the vehicles will be used in car services centres to support and improve the performance of maintenance services. In addition, car insurance agents could consider drivers' behaviour into account when they offer competitive car insurance tariffs [48]. Another interesting service is detecting stolen cars, for example, once a vehicle is stolen and leaves a predefined area, electronic sensors can detect it and alert the issue.

- **Infotainment and Public Services:** As mentioned in the above section, many services could be provided in real-time once the information are exchanged wirelessly among all vehicles within a certain region such as traffic status [49] or parking places [50]. Lu *et al.* [51] proposed real time navigation system showing available parking spaces for vehicles' drivers . Commercial aims might be involved in such applications when an interesting data is shared at certain area, for example petrol prices, or other services that are offered from local shops. Fleetnet system as an example of Infotainment applications offers real-time gaming among passengers during traveling [52]. Wi-Fi based VANET provides the ability to this type of applications to offer to carsâĂŹ passengers variety of entertainments like gaming and video applications.

The main related approaches to the above applications are routing protocols. They have been used to provide enough scalability of a network by increasing the coverage of spread information among more vehicles. The role of routing is offer end user to establish message routing in addition to maintain the connectivity in VANET topology. Network conditions like quick mobility are major factors in connectivity and routing in vehicular enviroment [16][19]. Therefore, researchers pose a critical issue with improving the efficiency of routing in vehicular communications.

Recently, V2V communication provide the capability to research deeply many cases that associated with improving driving safety, traffic efficiency or providing information to the car's driver such as car parking. The definitions of following present cases are based on V2V Communication.

In last decades, many applications have been proposed in VANETs field for roads networks. These works can be categorised into three main fields: traffic management and efficiency, traffic safety and infotainment applications [53][43].

Recently, the research and development of improving driving safety and congestion management through infrastructureless networks has become increasingly significant. Since VENET is becoming of the popular examples of wireless networking that work without the support of any infrastructure, it has been thaught becoming hot research to improve traffic management in intelligent transportation systems (ITS) in develped countries because of . It is a group of cars communicating via wireless communication. Direct communication between the nodes is only possible via the neighbouring nodes. Therefore, connecting to remote nodes is based on multiple-hop fashion. The main characteristics that differentiate a VANET from other networks environments are:

- Dynamic Topology: The nodes in VANET are free to move in different directions as in MANET, but vehicles could be expected to move in a specific direction with expected average speed over a road.
- infrastructureless: In MANETs, mobile nodes typically collaborate, acting both as forwarders and consumers of messages in order to achieve connectivity and support services. There is no prior organisation or any base station requirements. The role of a node in such a network is based on situational needs, and, as such, nodes can work as routers or gateways to support the processes participating in a network [26].
- Short Range Connectivity: Due to high mobility of vehicles, the performance of communications among all cars looks extremely critical and may not be reliable for long time.

2.5 Communication Technology

The success of VANET systems is heavily reliant on standardisation activities which may provide reliability and efficiency to the communication. Because of the variety of vehicular applications and the nature of VANET mobility, the traditional 802.11 series such as 802.11a, 802.11b, and 802.11g are not fully fit to the vehicular environment. Therefore, significant improvements have been achieved in PHY and MAC layers in TCP/IP model to maintain movements of vehicles.

Table 2.2: IEEE 802.11 standards family specifications

	802.11	**802.11a**	**802.11b**	**802.11g**	**802.11p**
Date approval	1997	1999	1999	2003	2010
Frequency (*GHz*)	2.5	5.15 - 5.875	2.4 - 2.5	2.4	5.86 - 5.925
Bandwidth (*Mbps*)	Up to 2	UP to 54	6, 5, 11	Up to 54	3, 27
Transmission range - outdoor (*meter*)	30 - 100	30 - 120	35 - 150	35 - 150	300 – 1000
Modulation	FHSS/DSSS	CCK OFDM	DSSS/CCK	CCK-OFDM/PBC	CCK-COFDM
Compatibility	802.11	802.11a	802.11g	802.11b	802.11a
Medium access protocol	CSMA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA

The table 2.2 shows a brief comparison of most known IEEE 802.11 standards beside IEEE 802.11p. The operation process for establishing a link on the traditional IEEE 802.11 standards includes multiple hand-shaking using basic service set (BSS) and hello packets scanning, which looks somehow complicated for V2V and V2I communications. In order to increase connectivity, Wildcard BSS identification was had been introduced in IEEE 802.11p to handle fast moving cars can send and receive packets through the communicable distance.

2.5.1 Distributed coordination function of IEEE 802.11

The distributed coordination function (DCF) is the original medium access control (MAC) of IEEE 802.11 standard. The DCF provides an ability to the nodes to obtain access chances in a distributed scenario without the need for any central coordination [ref]. In ad hoc communication manner, the DCF relays on a random access phase based on CSMA/CA protocol, which is considered in this thesis. Whereas, Point Coordination Function (PCF) is a centralised access scheme, which is for Access Points communication. The distributed coordination function (DCF) is the original medium access control (MAC) of IEEE 802.11 standard. The DCF provides an ability to the nodes to obtain access chances in a distributed scenario without the need for any central coordination [ref]. In ad hoc communication manner, the DCF relays on a random access phase based on CSMA/CA protocol, which is considered in this thesis. Whereas, Point Coordination Function (PCF) is a centralised access scheme, which is for Access Points communication.

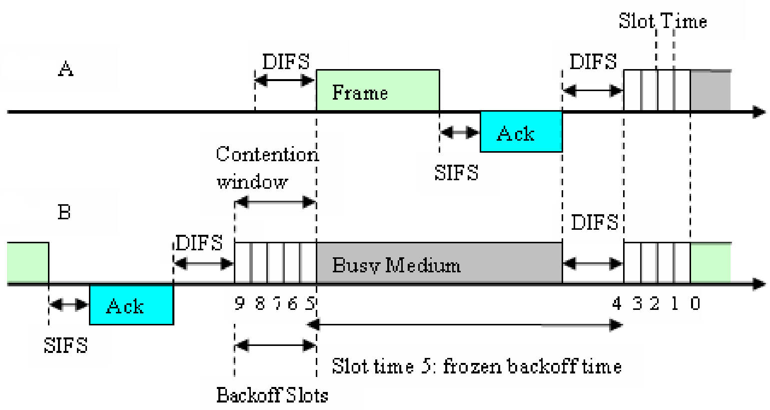

Figure 2.5: IEEE 802.11 carrier sensing scheme

Through CSMA/CA, before starting transmitting a frame of data, the client (node) will hear the channel's status. Figure 2.5 illustrates the basic technique of DCF and the operation of channel contention between two clients sharing the wireless medium. One of two scenarios may happen simultaneously. Scenario **1** if there is no traffic in the channel for a certain time that equals to a Distributed

Inter-frame Space (DIFS), the node sents. Scenario **2** if there is traffic of data in the channel or occurs busy during DIFS, the transmission is delayed by a backoff mechanism whereas the node continues to check the medium till there is no data for extra DIFS slot.

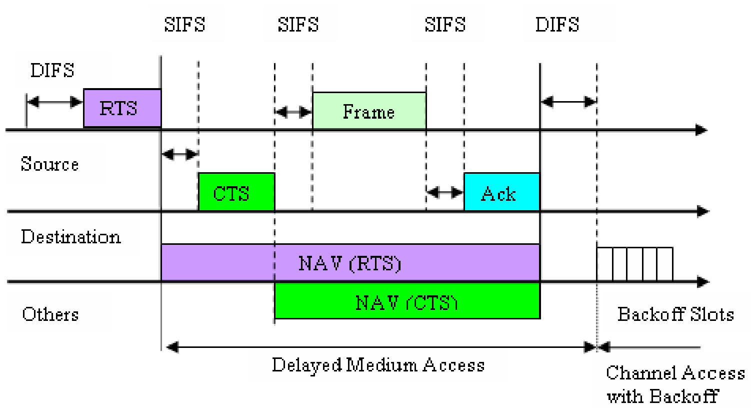

Figure 2.6: IEEE 802.11 RTC/CTS access scheme

The reason for using the backoff feature is to avoid and decrease the chances of data collision with other nodes. Moreover, a random delay interval must be placed at the sender between two consecutive packets even though the channel is still passive. As a result of following these procedures will prevent inequality of accessing the channel among stations. Due to the time following a DIFS is divided into slots, a client is just permitted to start sending at the beginning of each slot, hence stations can detect packets transmitted from any other nodes.

The unicast data sent through the DCF basic access technique uses 2-way handshake mechanism, as shown in figure 2.5. DCF also introduces an option of 4-way handshake mechanism for packets exchange. The operation for the exchange of packets using 4-way handshake mechanism is illustrated in figure 2.6. Prior starting transmitting a frame of data, (as explained in the basic mechanism) the client senses the channel status until idle status then proceed to the backoff stage.

Instead of starting transmitting the frame, it sends a request to send data (RTS) to the destination client. The destination will then replay with clear to send (CTS) after waiting a period of SIFS (short interframe space). The RTS and CTS messages contain information on the length of data to be sent and can be hosted by any mid-stations within the range.

2.5.2 DSRC/WAVE overview

DSRC was designed to organise V2V and V2I communications in order to support traffic approaches such as safety applications, traffic information for drivers toll collection [54] and several potential others. In addition, DSRC can provide high rate for data packet delivery and lower transmission delay in vehicular applications [22][55][56]. This protocol assumes that nodes in VANET, whether onboard unit (OBU) or RSU, should be equipped with wireless device to broadcast basic information within transmission range, whilst each node receives these information from its neighbours through its DSRC that is built in [57].

DSRC represents IEEE 802.11p which is developed to meet challenges of high mobility conditions in vehicular environment [58]. IEEE 802.11p is a new amendment from IEEE 802.11 and IEEE 802.11a for VANET. In other words, IEEE 802.11a standard is improved in terms of vehicular physic and medium access control (MAC) layers to achieve higher reliability communication and low latency through short range radio signals. DSRC/WAVE offers for VANET environemnt [22][57][59][60][61]:

- High reliability:: in traffic management systems, few seconds delays in a scenario such city centre may be major factor to deciding in traffic accident. Therefore, reliable communication is a vital factor of most of DSRC/WAVE safety applications. In case of high vehicle speed and bad weather conditions (such as rain, snow, fog), safety traffic systems require high reliability of communication link. Therefore, The IEEE 802.11p has become use a bandwidth of 10 MHz instead of 20 MHz that is used IEEE 802.11a. Hence, this bandwidth provides the signal more tolerant to delay and stronger against fading in vehicular networks.

- Low latency: the nature of vehicular environment need fast acquisition for transmission between vehicles (nodes) and RSU (V2X). Therefore, in order to obtaining low latency through reducing waiting delay of association procedures for communication, the developers of IEEE 802.11p define new services to exchange data without establishing a basic service set (BSS).

- Data rates: the IEEE 802.11p supports eight communication bandwidth rates from 3 Mb/s up to 27 Mb/s, which tend to give higher packet delivery ratio compared with other standards.

- Security: incorrect data from malicious attacks such as spoofing or erroneous alteration systems could influence on the safety and privacy level of the vehicular applications. In addition, the security functions should consider user's privacy to be protected from unauthorised parties. The IEEE developers design security services and functions for DSRC/WAVE applications to reach these goals.

2.5.3 DSRC/WAVE protocol stack

Many DSRC/WAVE standards have taken place or under reviewing for VANET architecture. IEEE 802.11p and IEEE 1609 were designed the main standards for DSRC/WAVE [22][55]. In the IEEE 802.11, data is exchanged between clients through basic service set (BSS) to control and plan the transmission. Consequently, delay is concerned following this traditional set-up. Therefore, developers took this issue into account when IEEE 802.11p and IEEE 1609 were designed [62]. The first is for lower and MAC layer whilst the second is for MAC and upper layers. Whereas IEEE 802.11p operations are managed by the upper layers of IEEE 1609 criteria to prevent any incompatibility during the communication [63]. This subsection will briefly present the most important DSRC/WAVE protocols that are associated with the OSI reference model, as shown in figure 2.7.

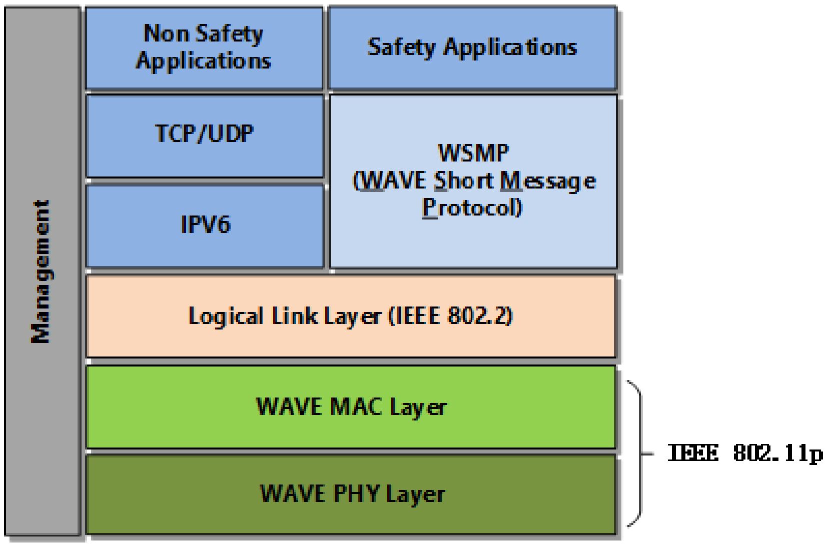

Figure 2.7: DSRC/WAVE standards and communication stack.

The most significant standards set that are incorporated in IEEE 802.11p is the IEEE 1609 family, they define a structure that provides the bases for variety of DSRC/WAVE systems. The main standards that a part of IEEE 1609.x family are [57]:

- the IEEE 1609.2, which is for security services.
- the IEEE 1609.3, which is for network services. It is designed to work in middle parts of DSRC protocol stack to introduce a new protocol which is WAVE short message protocol (WSMP).

- the IEEE 1609.4, which is responsible for managing Multi-channel operation.

In general, as shown in figure 2.7, the WAVE/DSRC protocol stack is divided into portions above the data link layer. The first is for V2V safety applications. It is limited to a single-hop communication and uses non-routed messages via WSMP protocol defined in 1609.3. The second part uses the existing internet protocols such as IP, UDP, and TCP. It is common in routing protocols and entertainment applications. Generally, depending on the required options, a network services should decide whether it use IPv6 or WSMP.

2.5.4 IEEE 802.11p Features:

DSRC represents IEEE 802.11p which is developed to meet challenges of high mobility conditions in vehicular environment [58]. IEEE 802.11p is a new amendment from IEEE 802.11 and IEEE 802.11a for VANET. In other words, IEEE 802.11a standard is improved in terms of vehicular physic and medium access control (MAC) layers to achieve higher reliability communication and low latency through short range radio signals. DSRC/WAVE offers for VANET environemnt [22][57][59][60][61]:

- High reliability:: in traffic management systems, few seconds delays in a scenario such city centre may be major factor to deciding in traffic accident. Therefore, reliable communication is a vital factor of most of DSRC/WAVE safety applications. In case of high vehicle speed and bad weather conditions (such as rain, snow, fog), safety traffic systems require high reliability of communication link. Therefore, The IEEE 802.11p has become use a bandwidth of 10 MHz instead of 20 MHz that is used IEEE 802.11a. Hence, this bandwidth provides the signal more tolerant to delay and stronger against fading in vehicular networks.

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- Security: incorrect data from malicious attacks such as spoofing or erroneous alteration systems could influence on the safety and privacy level of the vehicular applications. In addition, the security functions should consider user's privacy to be protected from unauthorised parties. The IEEE developers design security services and functions for DSRC/WAVE applications to reach these goals.

  For reasons mentioned above, IEEE 802.11p is the most appropriate reference model for VANET applications. And as a result, we have implemented the standard and to be a part of our traffic condition model.

2.6 Traffic Evaluation Technologies

Accurate traffic data and reliable delivery of traffic information are significant to guarantee and achieve efficient traffic applications. In order to assess the traffic characteristics of the network of roads, many approaches have been proposed to collect real-time traffic data. Several mechanisms have been introduced to gather basic traffic data at each road region of interest such as optical information system, inductive loop detectors, mathematical modeling and VANETs technology. Table 2.3 concludes the main advantages and the general weaknesses of each of these traffic characteristics gathering approaches.

Table 2.3: Technologies of Gathering of Traffic Data

Technology	Advantages	Weaknesses
Optical Information System	punctual delivery	High cost, require large memory and data processing, not scalable and not always accurate.
Inductive loops Detectors	on time delivery	Expensive and not scalable.
Mathematical modeling [64]	Support to verify the accuracy and the validity of the proposed algorithms	Do not reflect the real model and distribution of the road network.
Vehicular Ad hoc Network (VANET)	Cheape and easy setup, and high scalability	Moderate accuracy, high communication overhead.

Krajzewicz et al. [65] used an optical information system (OIS) to collect the traffic characteristics in a certain area of interest. They gathered photos using videos cameras devices at roadsides points then they analysed them to detect the high congestion segments over the roads. Indeed, this mechanism needs an expensive cost to buy and setup due to a big number of devices. Moreover, scalability limitations may increase because of camera zoom configuration during bad weather (i.e., foggy), these limitations could affect on the accuracy of traffic evaluation.

Dunkel et al. [66] count the number of vehicles passing over certain road segements in a given period of time using inductive loop detector devices.

Generally, the number of vehicles, the boundaries of the road segment and the given time are factors used to evaluate traffic characteristics of such a segment. However, the devices that used are expensive to be bought, to be installed and to be maintained. In addition, they still have issues regarding scalability which it may affect on the accuracy of traffic evaluation.

Recently, VANET has been used to gather the traffic information over the roads [5], [8], [67]. The free, high and scalable communication among vehicles and located RSUs in VANET, attract researchers wishing to use this technology in order to evaluate traffic characteristics over the roads network. However, several challenges have been faced in the data gathering proposals and traffic evaluation methods to generate accurate traffic reports. Moreover, the communication overheads in terms of bandwidth consumption and end-to end delay are also challenges of these mechanisms.

2.7 Traffic Conditions Detection and Evaluation in VANETs

Designing a traffic monitoring evaluation approach is one of the open research challenges and is being investigated in VANET. Researchers often consider that it is significant to detect the specific traffic conditions over straight roads or at intersections in a city [68]. On one hand, it is widely known that the more vehicles are on the road, more reliable and faster for information delivery in vehicular networks. On the other hand, the higher density of vehicles may lead to high traffic congestion or an accident that it may happen in the area. Therefore, the factor of traffic density is on the road is a double-edged sword in order to achieve higher stability of the networks. Table 2.4 summaries the main protocols that of evaluating traffic congestion that has been presented in the literature associated with VANETs.

Table 2.4: Traffic Evaluation Models in VANET

Model	**Type**	**Traffic Identification**	**Considrations: Bandwidth; accuracy**
ECODE[69]	V2X	Evluating and Reporting traffic information of each road segment	Medium
COC [70]	V2V	Expensive and not scalable.	High
Voting[71]	V2V	Do not reflect the real distribution over the road network.	Low
Clustered Area[72]	V2I	Limited accuracy, long delay, high communication overhead.	Medium
StreetSmart[73]	V2I	Summery of high level of traffic patterns	Low
TCDA[74]	V2V	Optimum Number of hops	Medium
V2X[75]	V2I	Limited accuracy, long delay, high communication overhead.	Medium
SOTIS[76]	V2V	Limited accuracy, long delay, high communication overhead.	High
Virtual Data Sink[77]	V2V	Limited accuracy, long delay, high communication overhead.	High

The content Oriented Communications (COC) protocol was proposed by Fukumoto et al. [70]. In COC, each single vehicle periodically disseminates its basic data. Based on the gathered information of surrounding vehicles, the traffic density of each area is then calculated. In addition, COC uses the traffic density metric to determine the level of traffic congestion at each area of interest [78]. Although this protocol obtains good performance in terms of accuracy, it encounters some issues regarding the incurring of high bandwidth consumption, and it requires high end-to-end delay.

On the other hand, Maram et al. have presented an effective traffic congestion detection algorithm (ECODE) for highway scenario [79], ECODE was designed to identify and evaluate congestion level geographically [80]. it evaluates traffic characteristics by exchanging the periodic messages among vehicles in each segment then reports this information via infrastructure units such as road side unit (RSU). The argued issue in ECODE is that it is designed for special geographical cases as such as highway scenario. Moreover, clustering phase is performed in off mobility mode as it is based on geographical segments.

An information dissemination approach to self-organizing the inter-vehicle network (SOTIS), is proposed by Wischhof et al. [76]. In SOTIS, traffic speed is evaluated locally in each car cusing periodic messages, since the authors assume that cars are implemented with a local map, and data of geographical coordinates in an internal database. Vehicles over the roads continues to exchange traffic messages, and each vehicle receives a message will compare it with its database if it is more updated or not. SOTIS relays on forehead vehicles which they send alerts to the following neighbours whether the region is in very congested or normal movement conditions in highway scenarios. However, in city scenario, this system may deliver late warning or irrelevant messages from an area, where the vehicles in opposite direction may deliver irrelevant information to distant locations in the same direction.

Another infrastructure-free traffic gathering model named TCDA for vehicular networks was introduced by Gamatti et al. [74], they proposed it for traffic detection. Their idea is based on using the optimum number of hops that provide sufficient indication to detect the conditions over roads. They obtain good results compared with Flooding protocol. A serious question with TCDA model is that the factor of optimum number could be varied depending on weather and traffic situation, however they obtained good results compared with flooding protocol. In addition, this algorithm did not consider the issue of boundaries in an area that it is covered to estimate the traffic condition.

Moreover, other unconsidered parameters may affect on the reliability of detecting the conditions, such as speed, direction.

Considering infrastructure in the communications of VANET (i,e. V2I), each RSU computes the traffic jam level of interested area. The basic data of each area are collected by travelling vehicles to the related RSUs [73]. StreetSmart system, which was considered as V2I based application, was introduced by Sandor et al. [73]; it utilises from a combination of clustering and flooding communication to discover, disseminate and to report on dynamic traffic patterns of neighbours cluster areas. Summery of unusual information is only reported from such area. This system is based on epidemic communication [81] in order to exchange the statistics conclusion from nodes. Each node estimates unexpeteded congestion levels areas by gthering and analising statistics messages from local nodes. Due to the ability of each node that can report a summery in each cluster and an issue of overlapping, low accuracy might be raised as the main limitation in StreetSmart. The low level of accuracy is the main limitation of this system because several vehicles can participate in more than one cluster; this is due to the overlapping cluster areas utilized in StreetSmart.

Manvi et al. [62] proposed a cognitive model which performs pull and push processes on relevant and important data collected in VANETs and also they introduced a critical data retrieve agent called CIPLA. Sometimes, vehicles are interested to recollect latest weather information from other vehicles, such as fog, rain, etc. However, CIPLA seems to be complex and messages that forwarded by this system are also sent slowly, consequently, the delay may tend to be bigger and the performance might be low.

Vision car detection based system was presented for FCD, which helps to improve the context of Vehicular networks [82]. Packets are transmitted based on

GPRS/UMTS communication which also uses a central unit to mix the expanded FCD. In [83], carry messages then forward is quite appropriate mode with low mobility and acceptable delay networks. However, GPRS/UMTS is responsible for the delivering the packets, which it means that their model depends on an existed infrastructure such as stations, road side units (RSU), etc.

Therefore, [84] focused on V2V communication and they introduced the idea of "carrying then forwarding" packets, which means that packets will be temporarily kept in node's buffer until it obtains a connection with other node that enters the network. Then the message will be forwarded to that node. They proposed vehicles assisted data delivery algorithms (VADD) which use dense roads to deliver the packet in order to obtain faster and more reliable delivery ratio. However, the authors did not focus on a method of detecting the traffic situation of road whether it is dense or not.

Chou et al. [22] applied a dissemination technique in vehicular networks to introduce virtual data sink approach. the sink node collects traffic information volume in its investigated zone. This approach utilise travel cars as traffic detectors, while inter communications provide the required data among surrounding vehicles. Then, level of the traffic congestion is calculated based on estimated time required to cross each zone. An other similar model proposed by Shibata et al. [72], it is a geocast protocol, where targeted geographic area is divided into sub segments. vehicles compute travel time needed to cross through each segment. Then historical traffic statistics is generated from vehicles that have travelled through the same previous roads. Generally, although this model provide awareness to vehicles by multi-hop communications, it raises an issue of bandwidth consumption in the network.

Schunemann et al. [75] proposed an algorithm that can be used by navigation systems to calculate routes circumnavigating highly congested roads. This algorithm was titled V2X-Based traffic congestion recognition and avoidance. Travelling vehicles compute and bass the average speed of each road segment to other vehicles and RSUs in their vicinity. However, the speed of travelling vehicles is not an accurate enough metric to detect the traffic congestion level in a certain region; this is because some vehicles may voluntarily move slowly.

2.8 Challenges of traffic conditions evaluation applications

Up-normal traffic conditions happen when the normal traffic status changes by exceeding the traffic volume density at a certain road. It is featured by slow movement, unexpected travel time or longer waiting time in traffic queues. Consequently, besides the risk of potential cars accidents, abnormal traffic situations also could lead to a significant delay in travel journey and environmental issues, which are caused by an increased rate of fuel consumption. Several factors may influence traffic fluency on the roads such as cars collision, differences in traffic density, weather conditions (e,g., rain, snow, slippery roads, etc.), and roads works. These circumstances contribute occurring hazard situations over city regions. Detecting traffic conditions presents the highest challenge of all proposed approaches in vehicular networks. For instance, in order to provide a reliable traffic evaluation in real-time for any geographical zone, the relevant traffic data of vehicles should be infused and examined. This data should not only include the vehicle's GPS information (speed, position, and direction). However, should be extra factors that associated with individual vehicle's sensors considered in any efficiency traffic application.

Overall, in addition to the issues of the traffic efficiency approaches, following challenges in VANETs will be considered in this research:

- Redundant data: the bandwidth of VANETs is utilized over time by repetitively transmitting periodic packets. In highly dense traffic scenarios and/or large traffic regions, the bandwidth flooding is a more serious difficulty. In these scenarios, using the traditional broadcast forwarding technique to advertise the status of travelling vehicles consumes the bandwidth; this also floods the network with redundant data. The broadcast storm issue is identified by having high error rates and signal interferences, which causes low data delivery.

- Network scalability: it is difficult to design a highly scalable model in VANETs because of the broadcast technique of sharing the basic traffic data among vehicles. In addition, processing the traffic data of dense traffic scenarios is a significant issue. This results in producing unreliable traffic evaluations, due to data loss occurrence. Moreover, the dynamic and fast-changing nature of the position of vehicles over the road limits scalability.

- Reliability: some failures could happen at any point in the traffic application itself because it refers to the function of the application itself (e,g. failure in generating traffic cluster). Other failures are generally associated with the nature of VANET such as packet loss because of communication drop.

- Accuracy of traffic conclusions: the traffic characteristics of each road are evaluated using the basic data of travelling vehicles over each region of interest. In the case where the specific vehicle or RSU in charge has obtained outdated or incorrect traffic data, wrong and useless traffic evaluations are produced. Moreover, if several warning messages were lost or dropped due to congestion or collision problems over the connecting network (i.e, VANETs), unreliable traffic evaluations could be reported.

- Security: shared data might reflect a false status about the surrounding area, in order to deceive other vehicles. They, therefore, end up towards alternative roads which cause consuming more travel time. Then the malicious nodes would enjoy their journey through light traffic flow.

2.9 Traffic management architecture

The following main fields of applications, that are addressed in the literature, present the basic traffic cases such as, Traffic safety, efficiency management and entertainments may be added. Services will be applied as applications over the architecture of such mobiles network [102]. Provided this, will enhance the system introduction and also provide sustainability for business and operation model. Diagram 2.8 shows an overview on the system idea which a number of graphical illustrations is provided for instance, connected vehicles, roadside unites and back-end infrastructure. Examples of services, that are part of traffic safety applications; lane exit warning, speed management, motorway management, driver management, and hazard warning [103].

Whereas services such as, urban traffic management, traffic optimization, priority approaches for selected vehicle categories are considered by the traffic efficiency applications. However, there are some services may be implemented and integrated by one or more of those fields such as road user charging (payment units) due to policy purposes [104].

The study has concentrated on standard organizations that available in the literature, meanwhile some technological developments are still under-way for the

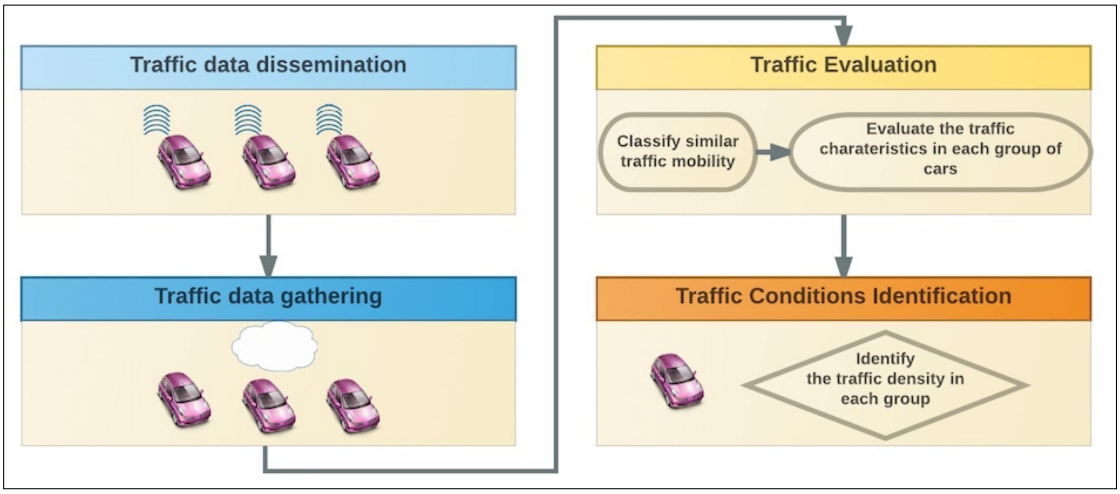


Figure 2.8: The architecture of the proposed model

vehicular networks and global standardization of IVC, which need many tests and validations. To allow a wide scale usage of these networks, it is fundamental to solve the technical issues faced by these networks. Accordance to the present networks standardization . IEEE 802.11p/WAVE standard is imperative usage, along with integration of multiple wireless considerations such as security, congestion handling, data transport and others are still under research. In addition, marketing strategies may also required to be taken into account in order to make VANET systems a success. Therefore, many governmental agencies are working closely with global vehicle manufacturers such as BMW, Mercedes, and Toyota to equipped with Wi-Fi (IEEE 802.11a/b/g/n) and (802.11p/WAVE) standards [105]. However, Yet there is no full integration among cars' industry.

2.10 Simulation Techniques

For accurate evaluation of efficient traffic condition detection protocols, a real test environment is required. However, investigating and evaluating the reality requires high costs and it might be difficult challenge. In addition, it seems complicated to implement a model on real environment in order to expect a reliable result immediately because of big challenges in repeating the experiments with different factors or parameters. Consequently, researcher tend to use simulations in order to validates their approaches or models.

Simulator is a tool, which the most appropriate and scientific approach, that is used to implement and test a theoretical model in high realistic scenario using specific conditions to achieve closest results to the real environment [85][19][86]. Therefore, to simulate the reality of such environment, higher realistic and reliable simulation tool is required [87][88]. next text shows tools that used for simulating vehicular environment.

2.10.1 Traffic simulators

In vehicular networks, mobility simulators are divided into two broad categories which are microscopic and macroscopic with a third group called mesoscopic models which combine features from the former two. Microscopic models give the ability to identify attributes such as speed, inter-vehicle spacing, acceleration, etc. of each vehicle. Macroscopic models, on the other hand, defines the mobility of vehicles on a broader scale by defining a section by section basis and focuses on the flow of the traffic, that is the traffic density, traffic queue of a section of road. Mesoscopic models combine properties from the microscopic and macroscopic

SUMO:

It is an acronym for Simulation of Urban MObility. It is a very popular open source microscopic vehicular traffic simulator that provides the researchers with a lot of customisable characteristics such as distinguishable vehicle types, lanes of streets, lane changing ability, explicit rules at junctions and traffic lights and a functional graphic user interface. Therefore, it is considered as a medium layer that links network simulation with the roads network, which is imported from map generator software such as OpenStreetMap [89]. OpenStreetMap is a great source of location/map data allows for exporting road information into SUMO which can be cleaned up and edited using a SUMO tool called NETEDIT. Upon completion of vehicle and traffic processing in SUMO, they can be exported as traces into network simulators.

VANETMobiSim:

is described as a tool capable of generating realistic vehicular movement traces for telecommunication networks simulators. It provides realistic features for traffic models and can operate at either the macroscopic level or at the microscopic level. Like SUMO it has the ability to import data from several sources, for example, data from maps created by the US Census Bureau topologically integrated geographic encoding and referencing (TIGER) database.

For this research project, SUMO has been selected as the mobility generator because of all the advantages mentioned earlier, it has decent support in an online community and is being used by the research group in our institution hence allowing easier cooperation in research.

2.10.2 Network simulators

Recently, many simulation tools have been utilized to implement and evaluate the performance of routing protocols and other applications in either MANET or VANET. Most of them are designed based on discrete even paradigm, the simulator schedule the sort of commands as queue depending of time of event process, and execute them successfully [90]. For instance, NS2 is one of most well-known public simulators which is discrete event paradigm based. Because of that most networks protocols are available in NS2, it is widely considered as a reliable standard for network simulation. Some limitations faced NS2 in terms of antenna supported and nodes need to implemented manually in cases. NS3 seems to be come up many limitations exist to improve the performance and scalability [19][91]. NS3 is not an updated version from NS2, it is free tool, written by C++ and Python for developers to simulate internet protocols and large models in a controlled scenario [19].

Related works, which were mentioned in the literature, categories the existing simulation tools into first, open source simulators such as NS2, NS3, and OMNeT++; second, OPNET is a well-known example of commercial simulators. They are briefly analysed and validated to present the advantages and disadvantages of each simulator [88][92][93][94]

NS2:

NS2 is one of the most popular simulators in the academia. In general, It is an updated version of a network simulator (NS), which is based on REAL information [95][96]. It was originally implemented and designed at the University of California-Berkley. NS2 is based on C++ object-oriented language and uses Tcl software (It is a script tool, object oriented extensions based invented at MIT). NS2 aims to model network architecture or to implement new routing protocols and to evaluate the performance of a network. It is complicated to be learnt and needs long time to discover mechanisms that used in the simulator [97], while compared to other tools, modifying existing models are easier than other simulators.

NS3:

NS3 is not an extended version of NS2. It is a new simulator and based on discrete-event approach. OTcl is no longer applied and the simulator has become only compatible with C++ and Python for implementation. A new tracing and statistical gathering frame is developed in NS3 to customise the output data without reconstructing the simulation core.

All NS3 models and protocols entities are updated to be very close to reality. Moreover, to it being an open source code, the utilization of C++ language was one of the viewpoints that guided the specialists to consider NS3 as the fundamental test system in the present research [88].

OMNeT++

OMNeT++ is not defined as a stand alone simulator such as NS2 and NS3, although it is a discrete event based simulation framework. Its characteristics and generic architecture enabled it to apply in different areas, for instance complex IT systems, hardware architecture and wireless sensor networks [98][99]. Like aforementioned NS3, OMNeT++ depends on C++ for applying simple modules.Then those applications combined with compound modules and as a result the set-up of networks simulation resets upon NED (the network description tool of OMNeT++) [99]. Therefore, NED is a supportive tool of C++ code in order to simulate the framework as whole.

MOVE:

MOVE is a mobility model generator for VANETs [100]. It is built based on Java language and has high level of visualisation support to integrate SUMO (Simulation of Urban Mobility)[100][19]. It allows simplification of mobility generation by providing a user interface that eliminates the need long scripts of codes. Mobility data can be generated from either the Google Map or other external databases such as Tiger map. Although MOVE parses different types of traces files to be involved into a network simulator, it seems not yet ready for complicated simulator scenarios [19].

OPNET:

OPNET is one of most famous and popular commercial simulator tools. It is being widely used for long period in field of industry research. It supplies developers high level and event-based network simulation. In adition, due to it is well-documented and GUI supported,/ it has become attractive by researchers. However, it is quite expensive for full version package[88][101].

2.11 Application Focus

We investigate the ad-hoc network architecture and its standards that have been used for V2V and V2I communications. Principles of wireless paradigms and standards are also reviewed in term of gain related background for our applications of this research. We also discuss VANET features in terms of how it improves the performance of traffic management and safety applications in ITS system. In addition, we study the traffic situation detection applications that have been introduced for transportation roads utilizing VANETs domain. This work in the thesis focuses on:

1. vehicles' data evaluation approaches in order to deliver emergency information for safety systems and to exchange periodic travel information. Hence the rate of road accidents reduces in city traffic environment.

2. we focus on data sharing methods in order to deliver messages among vehicles. Such protocols are needed to contribute the sufficient connectivity for providing awareness data through exchanging of the periodic messages and for spreading warning data in order to alert the others of an approaching hazard.

The core aim of the research considered in this thesis is to come up with efficient traffic conditions conclusion based on the intelligent sharing of traffic information by vehicles within a city scenario. As mentioned in the literature review, considering pure periodic exchanging of data may not sufficient to identify the traffic. Because reaching a reliable conclusive traffic outcome requires considering the individual conclusion of each vehicle. Few studies have noted the significance of the status of every individual vehicle in order to deliver a reliable traffic evaluation in VANET. However, to the best of my knowledge, it is the first time that taking individual traffic sensors data (e,g. ABS control, windscreen light, etc.) are taken into account to analyse, evaluate and provide a strong similarity among adjacent vehicles. This study set out with the aim of assessing the importance of car's sensors data in identifying a traffic situation since from the time of its occurring until its disappearing.Thus detected traffic situation will move with relevant vehicles within the traffic.

2.12 Summary

This chapter presented a review of VANETS covering their features, architecture, challenges, and reference standards for VANETs. Characteristics of DSRC/WAVE protocol and IEEE802.11p features were discussed with more details in sections 2.5.3 and 2.5.4 respectively. Review of VANET implies discussion of possible business applications that can be applied using V2V wireless technology and considers their needs through use situation investigation. Most relevant safety issues such as latency, dynamic toblogy were discussed through VENET features. Specific traffic Evaluation technologies were reviewed with more discussion of their features, requirements and limitations covered in section 2.6. Traffic conditions detection VANET based protocols were investigated with respect to their advantages and disadvantages and covered in section 2.7 as they are within heart of the scope of this thesis. In the mentioned section, various V2V issues such as dynamic mobility and tolerant tobology were also investigated in term of their effect on identifying traffic situation within geographical region. Traffic management architecture of this work were introduced in section 2.9, it shows data flow on the proposed system. Finally, an extensive study into road traffic and network simulators was presented in this chapter (see section 2.10); this was necessitated by the need to understand where each contributes to the research's paradigm.

The following chapter will discuss dissemination and gathering methods that have been used for traffic detection approaches. Impact of considering vehicle's sensors data will be studied and investigated in order to utilised to improve the performance of our model.

Chapter 3

Approaches for Clustering Traffic Information

3.1 Overview

This chapter introduces the characteristics in VANET applications, traffic information in an interested area is presented as they are main features in vehicular networks. In modern roads transportation, cars tend to travel in closer distances for longer period if they travel to convergent destinations. Wireless Ad-hoc networks, as considered in Chapter.2, have special characteristics such as self-conguration, autonomy, and adaptability, which make them particularly suited for military applications. Notably, as the bandwidth in such networks is limited, appropriate multi-hop routing mechanisms can be used to distribute the work-load through the network.

There is still a need for some of the VANET research challenges to be considered so that the global and extensive implementations of accessible, reliable, strong and secure VANET architectures, protocols, technologies, and services can be achieved. These challenges are identified and discussed in this thesis. This chapter will discuss technical methods of sharing traffic data in real-time in order to be evaluated by traffic efficiency applications. It also introduces new extra in-vehicle factors within shared data for the proposed model.

This chapter is organised as follow: First, proposed architecture includes stages of broadcasting and gathering traffic data in order to be analysed. Data gathering and dissemination methods in MANET are discussed in sections 3.2.1 and 3.2.2. Section 3.4.1 discusses vehicles situations could be embedded in IVC applications. Finally, factors, which are considered to measure the performance of the proposed model, are presented in section 3.5.

3.2 Data dissemination and gathering techniques

Due to the special status of the vehicular network, it has many differences in traffic characteristics compared to other wireless communications types such as mobile networks [22][106]. This mainly due to the behaviour of vehicles travelling over roads and also high changes of network connectivity. In general, there is two types of communications methods that may be used for vehicular networks. First, Wi-Fi technology through traditional IEEE wireless standards or via the most compatible reference for VANET, which is IEEE 802.11p/WAVE.

Second, cellular network can also be utilised as an infrastructure for VANET. although it is known that using cellular communication is expensive to set-up widely, there is growing effort that to build heterogeneous network [107], i.e multi networks are integrated together to mitigate related limitations. Therefore, the difference between using cellular technology and short range communication (Wi-Fi) should be

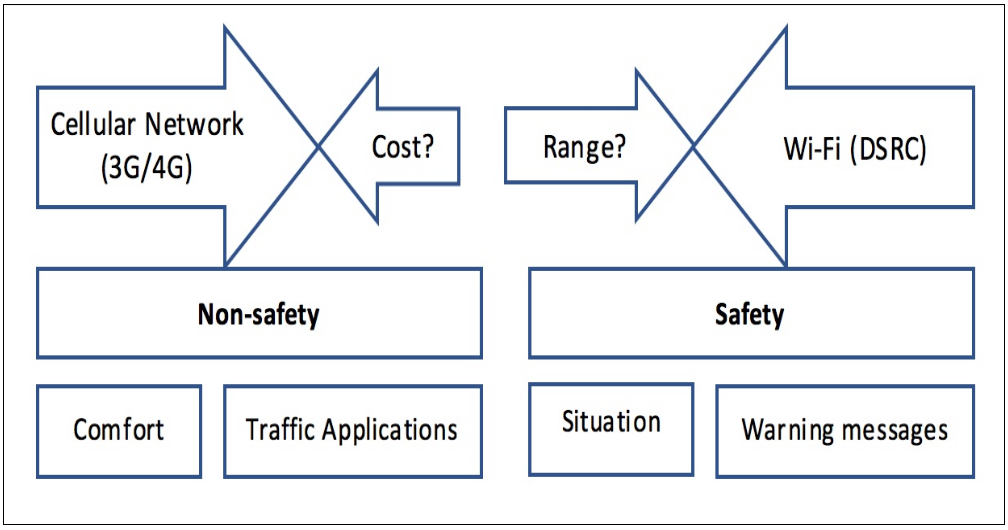


Figure 3.1: Taxonomy of Cellular and VANET applications Evaluation and Detection in VANET

distinguished before we start discussing dissemination concepts. Figure 3.1 presents a taxonomy (amended based on, Wai Chen 2015 [22]). DSRC provides high safety and low cost compared to cellular technology. However high throughput (data rate) is provided by the cellular network.

3.2.1 Dissemination methods

Dissemination is the base approach used in VANET in order to build higher level application such as message delivery (routing), traffic management, and safety applications. According to [108], dessimination methods can be categorised as the following text.

3.2.1.1 Single-hop dissemination based method

The fundamental of this scheme is based on sharing knowledge among neighbours (nodes). 'Hello' packets are periodically exchanged among nodes to update neighbour's list in each node. Neighbours list will be added to a packet that will be sent by a sender.

Then each node will first update its list by the received list. Second, it rebroadcasts the packet to additional nodes. Even though Sharing Knowledge among neighbours is based foundation for most roads condition detection approaches, it may also cause an overload in high mobility networks. In this thesis, this approach is considered to identify traffic conditions based on the data availability among vehicles .

3.2.1.2 Blind multi-hop flooding

According to Kim et al. [109], flooding is the simplest and earliest broadcasting technique in VANETs. From every vehicle, a packet is periodically broadcasted or re-spread to all neighbours (blind broadcasting) when it receives the message for the first time. Otherwise, it will be discarded due to redundant operations. Although flooding approach offers reliable delivery among vehicles, it may cause an overload of the network due to contention, collision and packet redundancy. This challenge is well known as a broadcast storm problem.

3.2.1.3 Probabilistic of flooding Based method

The only different feature from flooding is that nodes in this scheme will rebroadcast messages based on probability ($ran - \rho \in [0, 1]$) [110]. Each node generates a random probability value which is compared with (ρ). The message is re-shared around immediately as long as ($ran - \rho$) is not more than ρ, otherwise, it is discarded. Thus the number of nodes which receive the packet completely depend on $ran - \rho$ value. Moreover, this scheme will only affect on nodes that will act as receivers. They will not affect the delivery of the message. However, if ($ran - \rho$) equals 1 then the scheme will work as the same as flooding approach. Thus the technique will help to reduce redundant transmission issue, since the scheme will work as flooding in sparse network whereas the probability of retransmission will be mitigated in dense network scenario. An example of such scheme is Gossiping-based approach which is introduced by [111],

3.2.1.4 Cluster based method

The efficiency of dense network could be enhanced by using the cluster based approach. As shown in figure 1, the idea is that nodes in the network are grouped into several clusters and head node is sited in each cluster. The only broadcasting is among clusters' heads, which as a result reduce the flooding. This approach is widely adopted in [112]. However, it has some challenges in the design due to the geometric and statistical characteristics. In addition, although it also may provide stability for the big networks, according to Altayeb and Mahgoub (2013) [113], it is still arguable that overhead and delay in high mobility networks may be increased. The architecture as shown in figure 1 is also considered in our future proposed work in terms of communication between zones (different ad hoc networks).

3.2.1.5 Area based method

Generally, packets will be received only in nodes that are located one meter away. Then received nodes will rebroadcast to cover a low additional area. Researchers have suggested some other methods used to cover another additional area and they are as follows:

a. ***Counter Based Scheme:*** According to Choffnes and Bustamante [114], the counter based approach is that number of received nodes will be based on probability value. The message will be broadcasted if a counter is still less than random access delay. Although the simplicity usage of this scheme, it is clear that not all nodes always receive the message, especially in dense networks.

b. ***Distance Based Scheme:*** The geographical data of the node are used as a reference value for rebroadcasting messages such as the distance threshold value. Messages will not be rebroadcasted if the distance threshold is more than RDT (Random Delay Time), otherwise it will be rebroadcast.

c. ***Location Based Scheme:*** In this approach, received messages will be disseminated based on position information of data source node.

3.2.1.6 Store-carry-forward

Traffic data sometimes need to be sent further to multi-hop. two orthogonal approaches can be used: directional flooding; and the store-carry-forward which is well known in Delay-tolerant networking (DTN). In fact, some special vehicular scenarios can lead to intermittently connected among vehicles in the network and, in consequence, it is difficult to serve high ratio of end-to-end connectivity by any means of vehicular communication. Accordingly, the store-carry-forward mechanism is brought in such situations where the communication is sparse. Tongues et al [115] introduced a distributed vehicular broadcast model (DV-CAST), it is the first approach that makes this concept in an integrated protocol. DV-CAST swaps store-carry-forward with flooding dissemination mechanism depending on the network density. If there are no nearby vehicles travel in the same direction, DV-CAST attempts to find carriers on the opposite road. It is clear that the store-carry-forward technique is efficient in a sparse network, however, transmission latencies might be unpredictable.

3.2.2 Traffic Information Gathering methods

All dissemination strategies discussed so far are prone to broadcast storm problem. Vehicles flood warning messages to all other surroundings when urgent situations accrue suddenly. Therefore, data aggregation is used to mitigate this problem by combining correlated packets at vehicles before rebroadcasting [116]. Traffic aggregation aims to deliver reliable and efficient messages to receivers, although there are limited attempts to adopt MANET data infusion approaches in VANET domain. According to Yousefi et al. [67]; Kumar and Dave [116], most aggregation mechanisms can be divided into two types: tree-based protocols and cluster-based protocols.

Tree-based date gathering approaches classify nodes into a shape as a tree. Data flows from sub nodes (child) to the sink through intermediate nodes as shown in figure

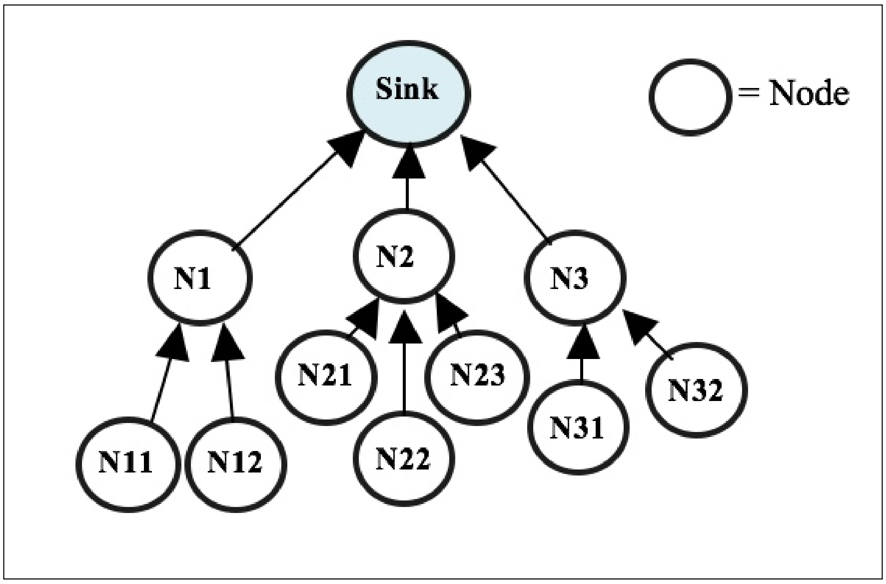


Figure 3.2: Tree-based aggregation scheme

3.2. Intermediate nodes fuse received data from sub nodes and then passed to the sink. Madden et al. [117] state a tree-based protocol called Tiny Aggregation (TAG). It works in two phases: first is distributed which determines what data is transmitted to all nodes. Second is collection phase, which fuses received data from sub nodes. Intanagonwiwat et al. [118] said that each node could be a sink when any node is interested in particular data. Then broadcast to the network interested information.

In conclusion, aggregation data approaches helped to reduce the number of transmitted messages. However, global knowledge of each node could be affected negatively. Also building an efficient fusion could be a big challenge in dense networks (hierarchy maintenance problem). In cluster-based data fusion scheme, nodes are divided into clusters. In each cluster, data are aggregated in a cluster head, which pass data toward the sink. Although this class could enhance the performance of dissemination, it is still clear that there is challenge in its design with high mobility and high density network. Therefore, Kumar and Dave [116] present structure-free data aggregation approach to mitigate the problem of hierarchy.

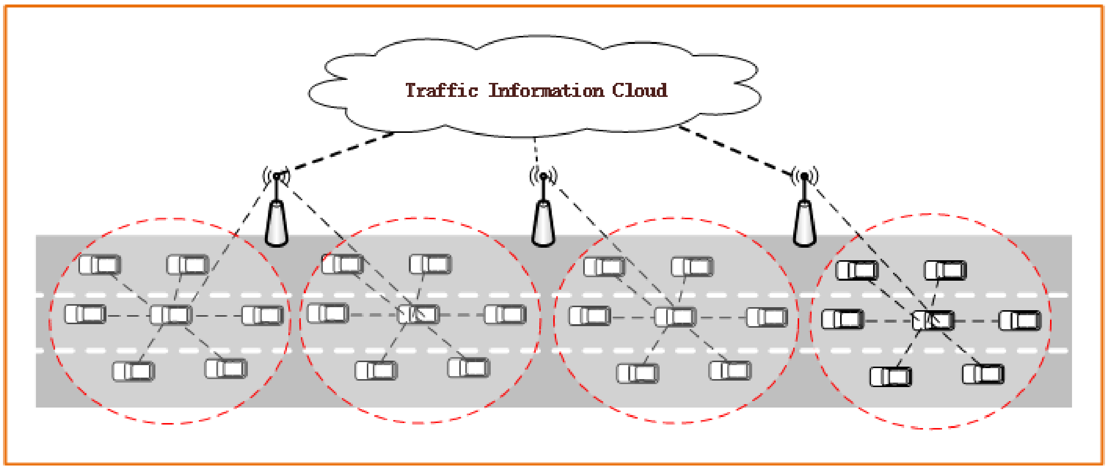


Figure 3.3: Architecture for clustering vehicles scenario

3.3 Data dissemination challenges in safety information applications

VANET is an essential architecture for different applications where the infrastructure is limited or not found. The V2I scheme is suitable for either comfort and safety applications. Periodic messages are exchanged in single-hop route among vehicles and RSUs through a hybrid ad-hoc network. In V2V, pure communication among mobile nodes (vehicles) to deliver warning traffic incidents in a certain area. Since V2V case infrastructure does not fully exist, a multi-hop route looks necessary option to deliver packets to the destination.

Dissemination is the primordial base for any safety approach through either on V2V or V2I communication. In VANET, dissemination is widely affected by the fast of nodes' movement. Consequently, connectivity might be lost among nodes, since some are out of their transmission range. As mentioned before, as known DSRC introduced short transmission range for vehicles, single-hop is suitable for most of the safety approaches. Hence vehicles are only aware of traffic information within their transmission range.

However, there is still a continuing debate on whether single-hop is sufficient or multi-hop mechanism might be required. On one hand, disseminating data using multi-hop broadcast technique seems attractive as it will cove the entire region. On the other hand, multi-hop mechanism raises serious challenges such as memory restrictions, broadcast storm, hidden terminals, and reliability problems. The following is mainly concentrate on transmitting safety messages using single-hop mechanism.

To illustrate the impact of distance on the overall network performance, the graph 3.4 presents consequence of disseminating a simple periodic message where simulation setup is a follow: transmission range is 300 meters; The payload size is 500 bytes, with 100ms an interval. As a result, this leads to an intermittent coverage by such applications.

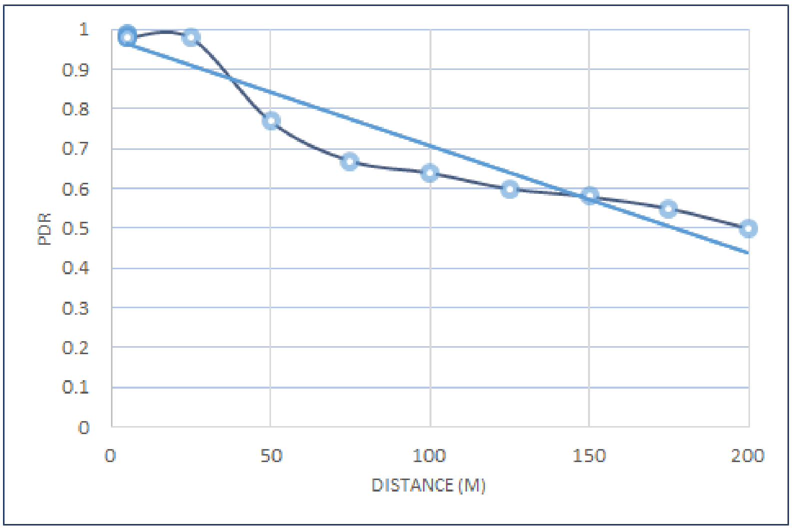


Figure 3.4: Impact of distance from the sender on delivery rate of packets (PDR)

3.4 Applications of Inter-Vehicle Communication (IVC)

IVCs systems aim to make driving safer, more comfortable, and more aware about traffic situations around. Whereas IVCs applications are not relaying on any infrastructure; only special sensors are embedded in cars. These electronic helpers are called onboard units (OBU). There are different methods, which IVC services utilise, a) through exchanging messages among vehicles; or b) exchanging warning messages with road side units (RSUs).

Such methods require IVCs dissemination schemes, there are two approaches, single-hop and mutli-hop dissemination schemes [119][120]. The main feature in single-hop scheme is that each vehicle can send status messages only to its neighbours that only one hop far away through short range communication [121]. Since different applications that uses single-hop require to cover small area (e.g., road measurements, roads merging). In contrast, multi hop dissemination scheme are more complicated, hence it is more compatiple with application that need long-range communication (e.g, routing, message delivery protocols). Or they should rely on store-and-carry scheme to deliver data, but delay and packet lose issue may raise to affect the performance. In addition, identifying driving condition scheme in VANET, which is built on inter-vehicle communication should be on real-time aspect.

3.4.1 In-vehicle sensors embedded in IVCs traffic detection applications

Successful traffic evaluation is reached by taking driver's behaviour into account [122]. Considering Vehicle's sensors data will indicate or reflect the driver's behaviour. We need to clarify the methods that proposed in this work. Thus it might be necessary to explain some individual vehicle data, and accordingly what possible situations that this data indicates to. For instance, OBU that included in an individual car may sense an abnormal event such as ABS control (ON) or fog light (on). It may indicate to hazard found during the journey. Table 3.1 shows a summary of some individual sensors data and possible situations (conclusion) that could occur.

Table 3.1: Car sensors' data and Possible traffic incidents

Sensed data	Possible traffic incidents
Change Speed (Unpredicted)	Interesting things seen beside or hazard in-front
ABS (turns **On**)	wet road; Tires issues; Oil leakage
Low Acceleration (dramatically)	Accident involved; Traffic congestion
Brake light (turns **On**)	Hazard ahead; Bad driving
Windscreen Wipers (stay **On** for while)	Raining weather; Cleaning status

By considering the approach of exchanging traffic information that is used in our research then classifying those vehicles, it is possible to combine individual real-time traffic vehicle data to provide high level of conclusion about the area of interest. Table 3.2 presents a new approach to identify traffic conditions in certain area in VANET. It shows some examples of potential traffic incidents that extracted by clustering similar vehicles' sensed information. Whereas in this table, column two shows the conditions (criteria) that have to applied in order to classify this certain has such situations. Since IVC applications based on vehicle to vehicle communication (v2v) is new field, further investigations is needed to be conducted based real life data in real scenario. Thus, approximate criteria can be estimated for each type traffic data set.

Therefore, in this model, new message format for exchanging traffic situations is designed to fit requirements of IVC systems.

Figure 3-4 and Table 3-3 classifies the recognisable road conditions based on the number of cars needed for it. The examples are of discoverable road situations that need just a single car to identify the road condition/problem to generate a warning

Table 3.2: Traffic conclusions examples

Individual data	Examples of decision criteria applied on cluster of vehicles	Possible traffic incidents
ABS control	cluster of n cars (*ex, 5 cars*) have the same data	slippery road
Low Acceleration	cluster of at least n cars for t seconds; Traffic congestion	hazards ahead, congestion
Brake control	cluster of n cars	Hazard a head
Fog light control	cluster of at least n cars for t seconds	Foggy period in this area
Windscreen Wipers control	*more than one cluster have same indication*	Rainy area for period of time

message and broadcast it to all nearby cars, and of road conditions that need multiple cars' information by exchanging messages (their data) to identify the conditions of the road they are on. So, two stages are needed: first, exchange of messages to discover whether the road has a certain condition or not; and second, generation of a warning message to inform all nearby cars of the discovered condition, if any.

Figure 3.6 shows that the two or more individual car's sensors data may contribute to the same traffic incident. For example, drivers may slow down their speed because of traffic congestion in progress or another situation such as low vision (e,g Fog condition).

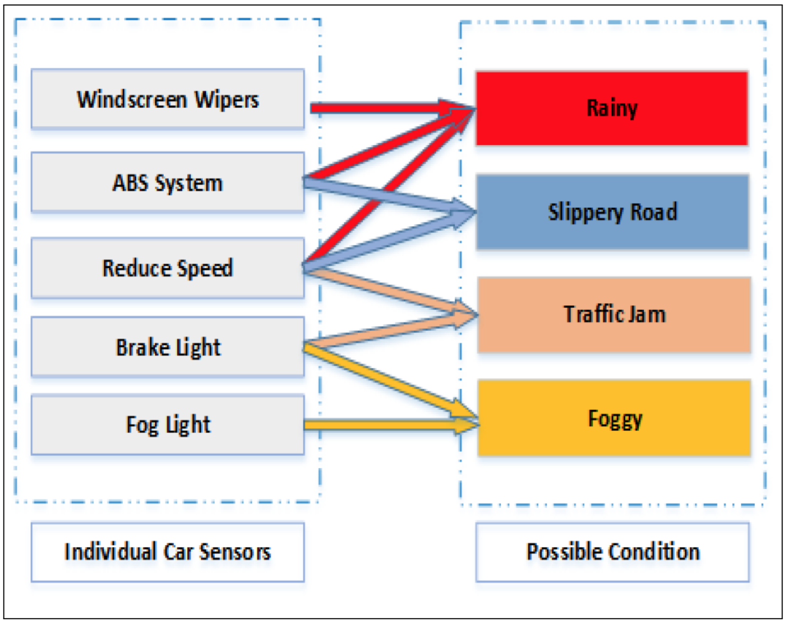


Figure 3.5: Individual car sensors contributions for potential conditions

3.5 Factors to study in IVCs systems

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

3.5.1 Number of nodes

Since the vehicles themselves are the key players in a VANET scenario, it is therefore imperative to consider them at first glance. These vehicles will be equipped with devices

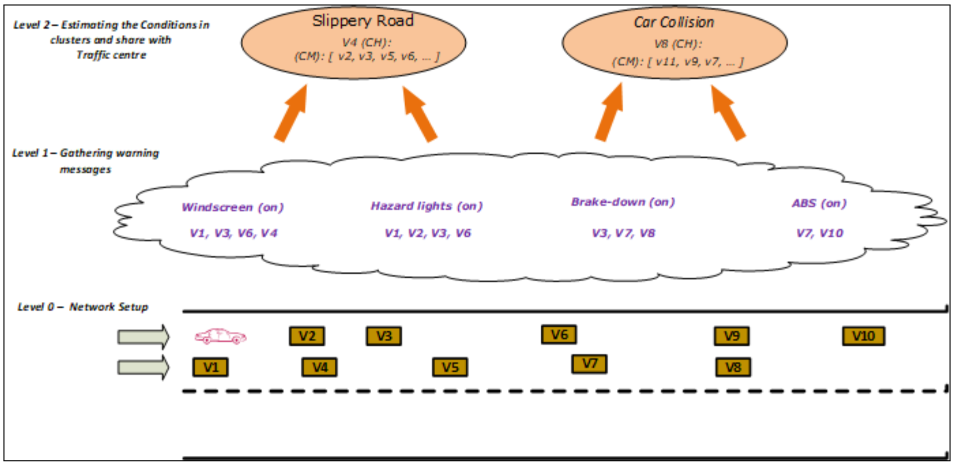


Figure 3.6: Example of traffic conditions scenario through intelligent clusters

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

3.5.2 Speed variation

In this section, we test the optimum speed similarity criteria that should be applied for identifying the traffic situation zone. As shown in figure 3.7, for the first glance, the shorter speed variation among vehicles the more accurate detected traffic cluster. However, in practice, the optimum number should relay on the nature of the traffic situation and its characteristics.

	Parameters / Traffic situatons	Single vehicle								Group of vehicles (cluster conclusion)					
		ABS light(on/off)	Brake light ()	Tyre failure	Engine fault	collision incident	Emergency mode (Ambulance)	Hand-held phone	Spot-of-interest	Windscreen wipers (on) - (Rain)	ABS control (on/off). (slippery)	Fog light (on). (Fog/Mist)	Deceleration (Hazard)	Mutiple vehicles accident	Speed off (Traffic congestion)
	Vehicle condition														
1	Travel direction	Y	Y	Y	Y	Y	Y	Y	Y		Y		Y	Y	Y
2	Speed.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	Max speed threshold.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Destination.														
5	Distance to the closest nodes.			Y	Y	Y									
6	Number of surrounding nodes.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Node ID.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Path flexibility														
	Message condition														
1	Packet age (active or inactive)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Waiting time if channel not Idle	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	Message type (CH message or CM messages)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Interval time since last transmitting/receiving	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Communication condition														
1	Bandwidth	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Data transmission range	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	Guaranteed range for Packet delivery (PD)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Sparse connectivity: (store-carry-forward in DTN)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	Security & privacy context	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Latency (data Importance)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	data payload (size)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Road parameters														
1	Traffic density														
2	Length of road segment														
3	Number of lanes														
4	Incident position			Y	Y	Y				Y	Y	Y	Y	Y	Y
	Information parameters														
1	Time stamp	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Journey purpose								Y						
3	Travel period (from source to destination)	Y	Y	Y	Y	Y	Y	Y	Y						
5	Information type (Warning, periodic ,etc.)														
6	Information accuracy														
6	Information behaviour (data changes)	Y				Y								Y	

Figure 3.7: Architecture for clustering vehicles scenario

3.5.3 vehicle's sensors data

The study will consider evaluating the proposed model in term of the cohesiveness of the detected traffic situation in a certain area. It is clear that the traffic situation will stay on the road as long as there are a similar set of unusual traffic characteristics among a set of adjacent vehicles. In our experiment, our model underlines the importance of utilising traffic sensed data embedded on the vehicles as an extra significant factor in order to identify the traffic situation zone. This could be measured using the metric of participation duration (PD) of the node, PD is defined as the interval from the time during a vehicle joins a specified traffic situation cluster to the time when it leaves the detected traffic cluster [123].

3.5.4 Transmission range

The transmission range is a crucial factor in wireless networks. Many a research have shown that a range of distances is suitable for data dissemination than others are. However, wide transmission ranges do not necessarily translate to better dissemination because of issues such as hidden terminal problems and broadcast storms. Several researches use between 100 and 300m as transmission radius, failing to check for the effect of either reducing or increasing that value.

3.6 Summary

In this chapter, traffic efficiency applications challenges were discussed in this thesis. This chapter presented technical methods of sharing traffic data in real-time in order to be evaluated by traffic efficiency applications. It also introduced extra in-vehicle factors within shared data for the proposed model. It is important to understand the environment in which the research lies, the available tools which will be most suitable for each environment and the method or sequence of objectives to tackle to meet the required aim of the research.

Having concluded the investigation of traffic dissemination and gathering methods and factors that should be considered to measure the proposed model in addition to utilising extra factor for traffic evaluation, a novel model to utilise this knowledge is proposed in the next chapter. Three novel algorithms are also introduced next chapter to represent the phases of our proposed traffic efficiency detection model. The speed, number of vehicles on the roads, and individual sensors data will be used in a way that translates to how good a network is expected to perform in the detected traffic situation zone.

Chapter 4

Efficient Traffic Condition Detection Model

Outlines:

- Scope.
- Cases to study
- Possible Scenarios
- Algorithms
- Summery

Efficient Traffic Condition Detection Model (ETraCD)

4.1 Overview

In chapter 4,a model for detecting traffic conditions in VANETs (ETraCD) is proposed. As the name indicates, The aim is to improve detecting performance of traffic conditions by evaluating real-time traffic data gathered of any geographical segment under consideration of different traffic factors to reach a reasonable evaluation decision should take. Many researchers work on the issue of efficient traffic conditions detection have not taken the correlation data of adjacent vehicles and dynamics they introduce into account or have issues in the assumptions of using a set of information when designing and testing an application for evaluating traffic status whereas the behaviour of vehicles on the roads is quite dynamic. And quite similar in term of the nature of sensed data generated by individual adjacent vehicles.

ETraCD considers the logic methods that mentioned in the section of data dissemination mechanisms in chapter 3 for obtaining information from individual vehicles in the network. The processes at first start from inside vehicles when data gathered from data' sensors that already set on-board. Then messages distributed within transmission range of vehicle in which it is located. data aggregation phase, when surrounded vehicles analyse received messages then update their traffic conclusion according to certain criteria. Thus this model was developed to design the approach of messages distribution, Data fusion, and data evaluation. The result of this development was two-fold: first, intelligent and efficient cooperation was achieved in term of traffic status exchange among vehicles. The second was the use of traffic data to deliver a reliable traffic conclusion in each region of interest. Hence the model offers a channel of real time evaluation of detected traffic conditions for all vehicles through phases of data dissemination, gathering and evaluation in infrastructure-less urban scenarios.

This chapter is organised as follow: First, a brief introduction of the new model and its architecture is given in section 4.2, it includes a text of how data flow in the model. Section 4.4 illustrates issues of traffic situation that can be detected by the model including reasonable applications for every set of possible situations. Second section 4.5.2 provide message format including how can car's sensors data utilise be implied the message design. The analysis of possible traffic city scenarios that may applied to the proposed model are conducted in subsections 4.5.3.1, 4.5.3.2 and 4.5.3.3. The design stages of the model are presented in sections 4.5.3.4, 4.5.3.5 and 4.5.3.6. Whereas its execution schemes are introduced in section 4.6. Finally, section 4.7 contains the conclusion of this chapter.

4.2 Scope of the model

The model is designed to come up with identifying situations that may happen over roads in city scenarios. Figure 4.1 shows the architecture of ETraCD model, traffic status can only be identified through collaboration among vehicles in the area of interest. Traffic conditions that might be detected by one single car (uncooperative node) is outside of the research scope.

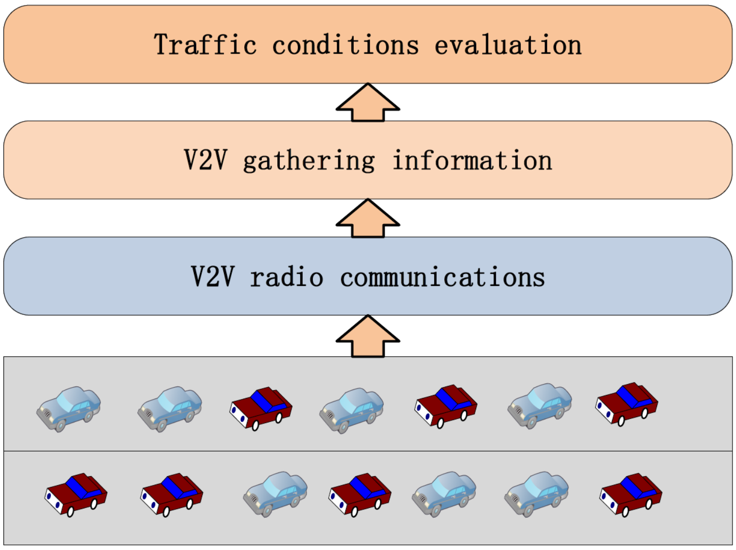


Figure 4.1: ETraCD phases

ETraCD first evaluates traffic conditions by organising vehicles as groups that must meet specific criteria of mobility characteristics then those groups will be merged in proper time to provide a higher level conclusion in a certain region. ETraCD is scalable and lightweight manner in term of gathering data associated to traffic situation itself. The capability of ETraCD to identify a traffic condition such as slippery road, rainy, foggy, etc. is illustrated with examples that explain heuristic rules of identifying road urban traffic conditions as shown in table 3.1. Therefore, electronic sensors embedded in each car can provide data, such as ABS (on/off), brake light (on/off) or similar indication to detect road conditions.

Since not all those cases can be derived from electronic helpers that embedded in each vehicle such as ABS control or brake light, special sensors may be added in order to indicate to extra traffic conditions caused by for instance weather in an area of interest such as snow, fog, humidity, etc. Then by sharing all these data derived from sensors via vehicular networks, possible traffic conclusions can be assessed approximately in that region. Therefore, table 3.2 showed possible sensors traffic data that usually lead to most common traffic conditions. Those information are still inconclusive as number of vehicles that involved in this accident and how long are still unknown.

By considering both tables 3.1 and 3.2, it is clear that one or more traffic situation can lead traffic incident can happened. The number of vehicles that involved in a similar situation is vital to detect the traffic status in proper time. However, few V2V approaches are available that conclude shared information to become convinced and conclusive traffic conclusion in a certain area as shown in table 3.2. Therefore, the approach of ETraCD is built on the idea of transforming non-conclusive indicators to be more valued and conclusive information in the certain region.

4.3 Motivation

The short-time traffic condition detection is a significant application for controlling the traffic safety and driving guidance in ITS. Previous studies evaluating traffic detection method observed inconsistent outcome whether traffic conclusion is reliable or not. Some of them had disadvantages of a) relying on infrastructure equipment, which raises issues of cost and availability in reality. And b) traffic prediction methods that have been recently used depending only on geometric characteristics of roads, vehicles movement data and not considering driver's behavior concurrently. Some studies consider V2I communications to gather data then detect traffic status of roads. Also, they have not taken individual vehicle's sensors data (ABS, Brake light data, etc.) into account to improve the performance. In contrast, very few approaches rely only on V2V communication such as TCDA [124]. It utilised vehicles' sensors data to spread the traffic condition in the certain region. However, it seems that TCDA has ignored the similar information from adjacent neighbours in VANET topology.

Given the disparity in both methods, it is evident to see that introducing an approach extends deeply to consider individually traffic movement data along with cars' sensed data based on certain criteria. For example, should not all adjacent vehicles participate in traffic conclusion? Is possible to detect multiple traffic statuses happen in the same area? Etc. This research proposes a novel model in which combining individual car's sensed information along with characteristics of car's movements then creating an intelligent approach hence converting the low-level individual vehicles' data based toward conclusive traffic conclusions. Consequently, collaboration among vehicles will be higher intelligent than previous traditional approaches.

4.4 Cases of traffic situations detected by ETraCD

In order to put the model in VANET context, it will be valuable to present some instances of the possible situations they might occur during vehicle travelling based on exchanging individual vehicle sensors data. Table 4.1 shows examples of VANET applications of traffic conclusions that could be built on each of set of certain driving situations then and what possible conclusions. Safety traffic applications should come up to with different events (incidents)by analysing the gathered data to cover them to a feasible conclusion. Hence other linked applications may take appropriate actions to avoid or minimise any risks may happen. For instance, in the case of pre-collision scenario, the applications should take action when occurring a sudden change in the collected data for assisting drivers to reduce the effect of potential collision within few seconds somewhere in the road ahead.

4.5 ETraCD description

In this section, An efficient model for extracting traffic condition through dynamic clustering will be introduced and discussed in different aspects.

Table 4.1: Possible conclusions of traffic situations

Application	Description
decentralised loose data Decentralized, Traffic congestion, Road Works, Slippery Road, Rainy, wind-storm	Any vehicle can detect and warn other vehicles such usual events on the road.
vehicle Brake-down	Any car turns off on the road should warn this fault to vehicles travelling around.
Pre-collision warning	cooperative collision forward scheme assists the driver to avoid or reduce the risks of the potential of collision with the rear of cars in a forward road.
Post-collision warning	vehicles that completely or partially involved in an accident should warn approaching vehicles against possible imminent collision.
Normal traffic mobility	set of vehicles travel with normal traffic characteristics.

4.5.1 Assumption

With the objective of designing a reliable and fully distributed and traffic conditions identification recommendation protocol, the next assumptions are considered in this research:

- All nodes are identical, mobile and in an active state.
- Nodes are able to determine their positions (equipped with an IEEE 802.11p transceiver and a GPS on-board). Many cars' manufacturers have been recently started to embed such devices to allocate cars' positions.
- The nodes seeds, density volume, gaps between nodes and active nodes chosen are completely random, but the nodes speed range are fixed (maximum and minimum speed).

- Each node is equipped with traffic electronic helpers to sense on-board vehicle controllers such as ABS control, Fog lights, wind-screen wipers lights, etc.). Since this information will be shared among vehicles then it is used to discover and evaluate traffic conditions.
- The distributions, distance between ordinary nodes and active nodes are entirely random.
- Nodes' speed is random, but the variation of speed range is settled.
- The study assumes that all participants in the VANET topology cooperate honestly with each other to share related traffic data.

4.5.2 In-vehicle's sensors parameters

Vehicular safety applications that improve traffic performance and journey safety require most recent and relevant data in a certain area. Sensors embedded in the In-vehicle systems are vital factors in identifying vehicle's traffic status [125]. In reviewing the literature, few studies were found on the association between applying in-vehicle sensors and detection of traffic conditions. Gamati et al. [126] rely on traffic data gathered from nodes' sensors such as traffic behaviour and weather conditions (rain, slippery road, etc.) to recognise the geographical region where the unusual traffic conditions found.

Consequently, it is worth to consider sensors data to improve the accuracy of traffic conclusion. For this thesis, augmenting sensors' information is vital to maintaining the stability of the nodes' clusters. Hence it is possible to corroborate traffic status stated by the vehicles. However, sensors information are simulated data, since conducting experiments to extracting such real data, in reality, raise many challenges and barriers and in consequence, at this stage, it is simulated data. Table 4.2 displays message format considering In-vehicle sensors' data for improving the detection of traffic conditions.

This research relies on In-vehicles' data, which may be caused by weather

Table 4.2: Message format considering In-vehicle sensors' data

S/N	Field size	Data description
1	20 Bytes	ID:TimeStamp:Velocity
2	20 Bytes	ID:TimeStamp:position
3	20 Bytes	ID:TimeStamp:sensors' data(WindscreenWipersLight-ON)
...	...	...
...	...	...
n	20 Bytes	ID:TimeStamp:FogLights-ON

conditions (fog lights, windscreen wipers lights, etc.), to improve the stability of evaluating traffic conclusion in such area. Moreover, using such real traffic data that extracted from electronic helpers lead to increase reliability and accuracy of vehicular safety applications. As the result of introducing an accurate traffic evaluation in certain areas will assist to reach a reliable traffic conclusion for the whole city.

4.5.3 possible traffic scenarios

In this section, we will discuss different possible situations that can be discovered by our model in city scenario. Hence the network topology was designed according to discover such scenarios in urban areas. It is clear that vehicles mobility tends to be influenced by each other during travelling on the roads. For instance, cars' drivers may speed up when they discover acceleration from vehicles that travelling ahead. And in consequence, drivers tend to travel through a group of neighbours in a dynamic cluster. In fact, particular reasons for appearing such traffic behaviours are not clear but it may have investigated multiple causes based on technical and safety aspects. Since our model depends on the idea of collaboration among vehicles in order to discover and reach to an accurate traffic conclusion, it is worth to mention what safety reasons for using the collaboration of relevant vehicles. The following are some factors that lead to moving as clusters of nodes:

- First, as mentioned before, adjacent groups of vehicles: cars' drivers follow each other on cars. Driving close to the car in front may generate groups of vehicles move for period of time as consistent unit.
- Second, infrastructure of roads: it is also considerable evidence as it may force vehicles to divert to alternative routes.
- Third, entertainment and social events: running frequent social events and entertainment may influence traffic peaks time and its duration. Then it can be obvious to clusters of vehicles move at different times.
- Forth: weather conditions may force vehicles to change their routes and as a result move adjacent to each other. Since duration and routes of travel journey are widely affected by weather such as rain, foggy or windy, etc. Consequently, multiple hazards might occur caused by such circumstances, such as slippery roads, bad visibility, and as a result cars accidents.
- Fifth, sometimes, groups of vehicles will naturally be generated on roads. At first glance, the cars suppose to travel smoothly in same directions, and with preferred speeds that chosen according to the average speed of every road. However, some cars will be stuck behind those cars that travel at the slower speeds. Consequently, clusters of vehicles will happen equally to the number of cars that travel slower than every vehicle in front of it.

In conclusion, Using reasonable and conventional means that extracted from real scenarios will support the research to be more reliable, scalable and accurate. Therefore, ETraCD depends on the concept of grouping the vehicles based on their traffic situation to detect areas with unusual traffic conditions in any city scenarios. The next section will demonstrate different traffic situations that can be applied to our model. They will illustrate the behaviour of vehicles when experiencing sudden chellanges and how share traffic data, create group of vehicles then identify traffic conditions.

4.5.3.1 Scenario 1: no overlapping in the situation zones

It is clear that vehicles mobility could be affected by external conditions whether cause of weather conditions or surrounding vehicles' states. The first scenario contains different traffic conditions in the city centre. ETraCD revolve about the idea that it might not be sufficient for the cars to be only aware of its traffic situation, but it should be also informed about the real concurrent traffic state of its travel route. Hence our model can identify traffic situation through different types of traffic such as those might be caused by weather state or traffic jam, etc. or when no any incidents exposed hence vehicle travel in normal traffic. Figure 4.2 shows possible active conditions thorough non-overlapping groups in city scenario. As shown in the figure, two types of nodes' groups can be classified in any city scenario: a) the first category of hazard traffic situation clusters (HTC) might be generated due to sudden incidents such as poor route (slippery road).), and b) the second is associated with normal traffic situation, so nodes start exchanging traffic data in their transmission range (TR) and create normal traffic cluster (NTC) when they have similar traffic characteristics.

4.5.3.2 Scenario 2: single traffic condition- no overlapping in situation zones

The second scenario illustrates the stages of developing a single traffic incident due to external factors (weather conditions such as rain). Through ETraCD, only cars that have similar on-board sensors' data join same cluster. Figure 4.3 presents a traffic status that may happen on the city map. As shown in figure (4.3 - c), some cars experiencing rain condition in an area. One of those cars became active node as its

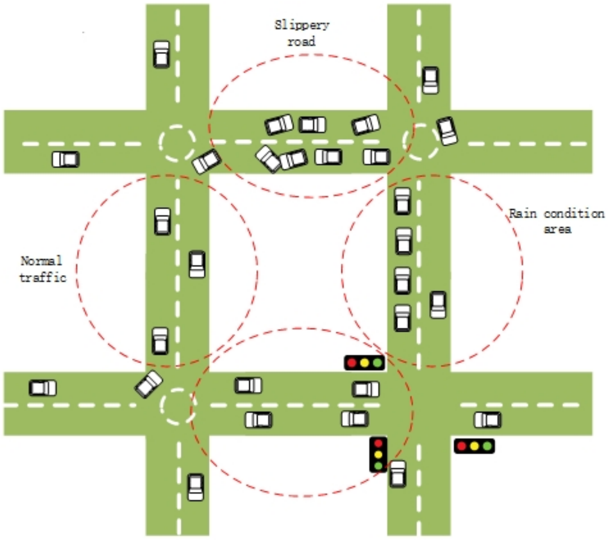


Figure 4.2: City scenario 1: multiple active conditions, no overlapping in traffic situations clusters

ABS light turns on. It starts broadcasting warning messages to inform surrounding neigbours about its incident. All adjacent cars with active ABS control creat and join cluster to represent the traffic condition that occurred. Figure (4.3 - d,e and f) emulate stages of growing possible slippery road cluster in part of the road.

As consequence of occurring traffic incident in some segments of adjacent roads in front, it is likely to develop another different traffic situation on different parts of the travel route. Figure (4.3 - c) shows another traffic congestion cluster has been created by vehicles that have similar low speeds. The new cluster that is generated is not overlapped with the first cluster due to it is out transmission range of the first cluster and includes different traffic characteristics. Thus, this scenario introduces the idea of building intelligent communication among nodes (vehicles) provide the network to perceive most realistic traffic conclusion for the whole region. Moreover, through ETraCD, we can measure the volume of hazard situation cluster (HTC) which is being created by considering the factor of traffic density (TD) of the cluster to obtain its approximation area.

4.5.3.3 Scenario 3: multiple traffic conditions, Possible overlapped situation zones

The scenario shown in figure 4.4 seems similar to the previous one. It illustrates the potential of raising more than one traffic incident in the same traffic area. Expanding overlapped traffic clusters can happen through the following logical texts:

- Figure (4.4 - a) shows normal scenario case. No active nodes in the traffic (No cars found have faced any state within the region so far).
- Figure An external condition occurs in part of the city (see figure (4.4 - b and c). Consequently, some nodes sensed a certain situation (ABS control - ON).
- In the same area, another node encountered different traffic situation which is low-speed. (see figure (4.4 - d)).
- In figure (4.4 - e and f), ABS control (ON) and low-speed nodes will generate periodic warning messages (WM) and share them with adjacent nodes.

All surrounding nodes, which have similar traffic situations, will join to hazard situation cluster (HTC) either the one of which is the low-speed or the slippery-road condition. Clusters' members will stay connected to each other inside the cluster as long as they have similar mobility patterns and same traffic situations. In ETraCD model, only more than two nodes that have similar data characteristics can generate their own $HTCs$.

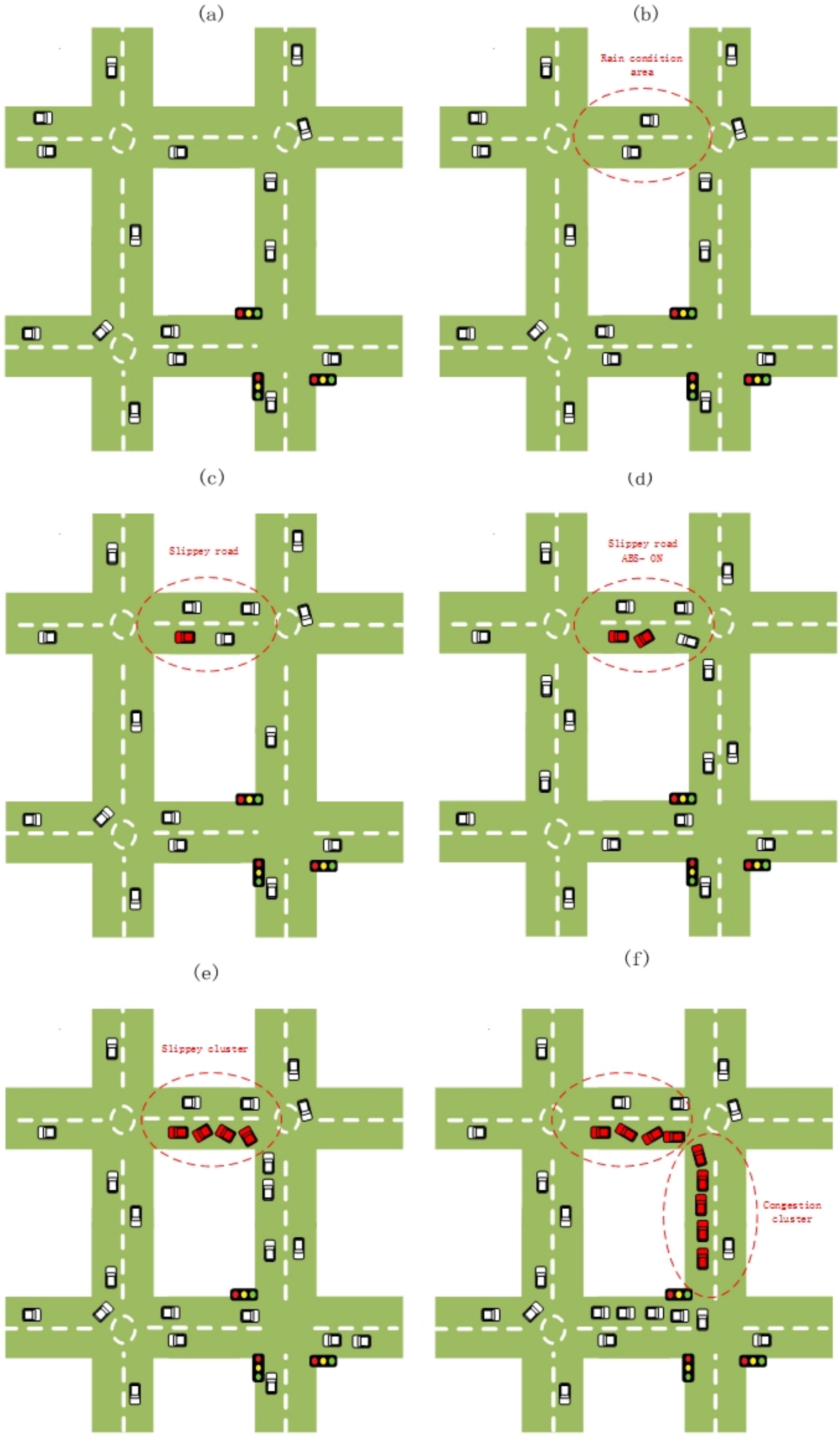


Figure 4.3: City scenario 2: single active situation, no overlapping in situation clusters

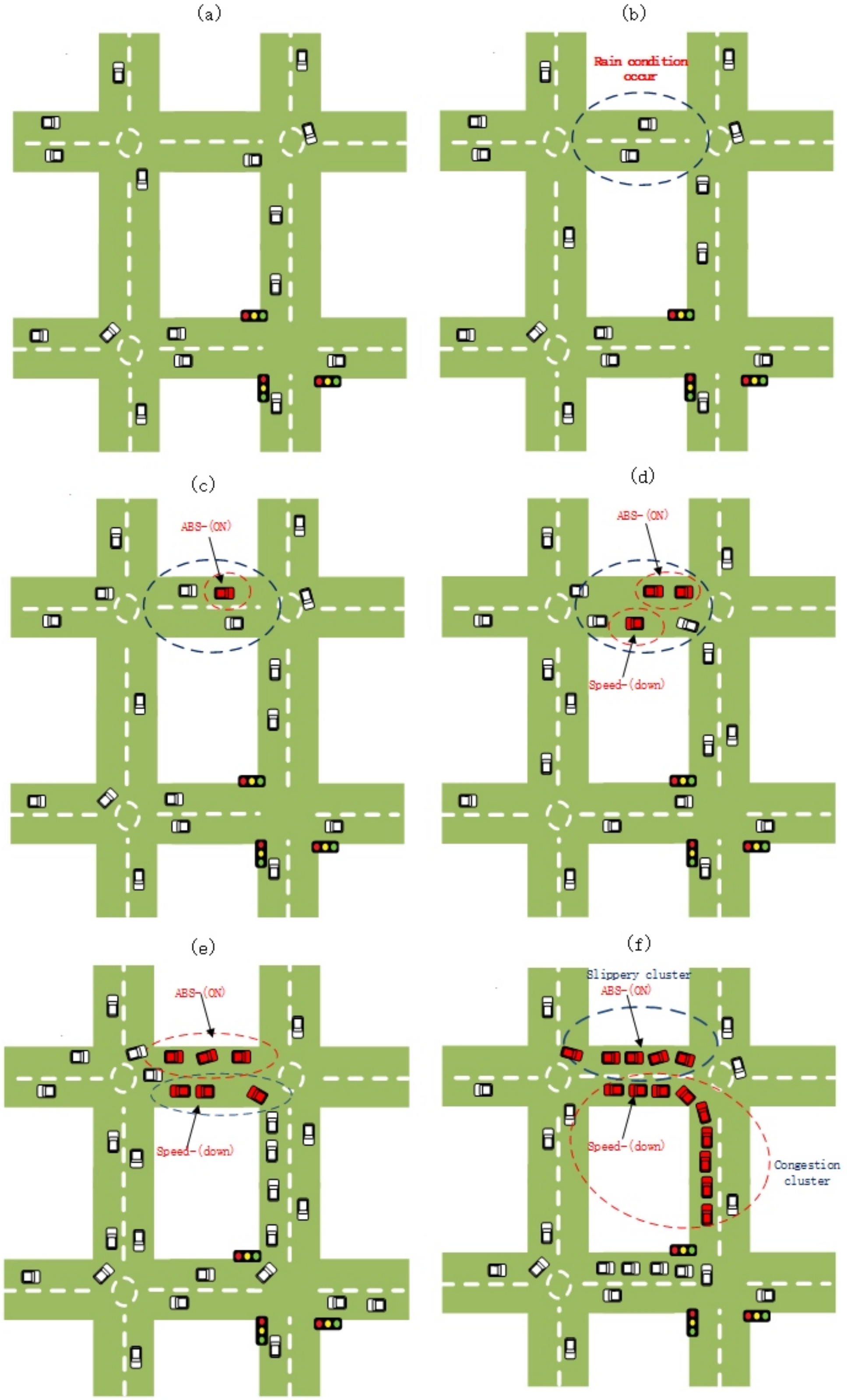


Figure 4.4: City scenario 2: Developing stages of traffic situations - overlapping clusters

4.5.3.4 Sharing and gathering of traffic characteristics

The previous subsections have illustrated possible situations of how traffic conditions occur and develop in the city scenarios. They clearly indicate vehicles that are part of a particular traffic incident tend to have similar traffic data. Let us now turn to how traffic data will be gathered from vehicles in *ETraCD*. Each node (V_i) shares its traffic characteristics data periodically as warning messages (*WM*). *WM* message states information about the vehicle in which located. We assume that GPS device and digital map are available and equipped in each vehicle. Hence *WM* message includes fields for position, speed, and travel direction. Utilising on board in-vehicle sensors that were discussed early in section 4.5.2, will give vehicles the ability to recognise their individual traffic data (e,g ABS (on/off), windscreen wipers (on/off), etc.).

Therefore, *WM* will also include a field indicates to this current traffic status (*TS*) of the V_i. For performance purpose, we set up the threshold of the maximum allowance of a number of vehicles that can contribute to the same traffic condition which they are located. Thus, if number of nodes members in a Max_{count} exceeds allowed number Max_{count}, vehicles can not join such TC then they will try to create a sperate cluster in which they are in the road.

Algorithm 1: Sharing and gathering of traffic characteristics

Data: TS_{V_i}: traffic situation of V_i; NT_{V_i}: Traffic neighbour table in V_i; WM_{Vj}: warning traffic message sent by V_j; Max_{count}: The threshold of the number of nodes members in each cluster; VC_{V_i}: Count of vehicles joined with NT_{V_i}; S_{var}: Speed variation amount

Result: Gathering traffic characteristics and updating traffic neighbour table for each vehicle

while $V_i \leftarrow WM_{Vj}$ *message from* V_j **do**
    if $TS_{V_i} == TS_{V_j}$ ***and*** $VC_{V_i} < Max_{count}$ ***and*** $\left|Avg_S - S_{V_j}\right| < S_{var}$ **then**
        The V_i *inserts* V_j *data into* NT_{V_i} *table*
    else
        WM_{Vj} discarded by V_i ; /* *Ignoring traffic information received* */
    end
end

Figure 4.5: Algorithm for sharing and gathering of traffic characteristics

The algorithm in figure4.5 illustrates the phase of how vehicles receives frequent traffic data messages from surrounding neighbours pertaining to its position. Traffic data will be gathered and stored in the vehicle's traffic table (NT_{Vi}) if the criteria mentioned earlier was matched, hence they will be members of the same traffic cluster. Basic traffic data includes sensor's condition type, speed, direction and position. Members of any traffic situation cluster will continue the process of exchanging messages until reaching the saturation of cluster (i,e. exceeding maximum number allowed for joining any traffic condition group generated Max_{count}) or reaching a certain timeout. Then each vehicle starts phase of evaluating traffic information gathered individually in a traffic cluster. The following text illustrates the local traffic evaluation phase of clusters individually and how the gathered data can represent the situation of traffic incident when occurred on the roads.

4.5.3.5 Cluster-level traffic conclusion

This phase remodels non-conclusive individual vehicle's sensors data into significant conclusive information per cluster (local traffic conclusion). By evaluating clusters separately, it provides local traffic systems (ITS) real-time information about what traffic incidents may occurred, their volume boundries, and their traffic average speed. Once the vehicle is involving in a traffic situation one then becoming part of a traffic condition cluster TC in which it is located. It assesses data gathered from TC nodes members. The significance of evaluating data of any traffic cluster will provide us with an overview of the *TC's* traffic condition attributes. Each vehicle in any TC will calculate average speed, traffic volume, then boundaries of the TC (i,e. how is the geographical area of such traffic condition).

Algorithm 2: Local traffic conclusion

Data: TS_{V_i}: traffic situation of V_i; NT_{V_i}: Traffic neighbour table in V_i; VC_{V_i}: Count of vehicles joined with NT_{V_i}; Sum_s: The sum of vehicles' speed;

Result: Gathering traffic characteristics and updating traffic neighbour table for each vehicle

$Sum_s = 0$;
$Count_V = 0$;
for C_{num} **do**
  $Sum_s = Sum_s + S_{Vn}$;
  $Count_V = Count_V + 1$;
Update traffic average speed of the clusterTC_i
$TC_{sd}(V_i) = Sum_s / Count_V$;
Update traffic volume of the clusterTC_i
$TC_{vol}(V_i) \leftarrow Count_V$;
Update traffic volume

Figure 4.6: Pseudocode for local traffic conclusion

In *ETraCD*, the average speed (TC_{sd}) indicates to the average traffic speed of the traffic condition area, whereas traffic condition volume (TC_{vol}) represents the number of nodes' members that involved in such a traffic situation. Since local average speed (TC_{sd}) and traffic volume (TC_{vol}) are the main factors that interpret the traffic condition in such any cluster. For instance, if *TC's* average speed is low and less than the minimum speed limit by law for vehicles in such road and traffic volume is high could increase the risk of the serious traffic event. Algorithm 4.6 illustrates the phase of how vehicles receives periodic traffic data messages from surrounding neighbours pertaining to its position. Traffic data will be gathered and stored in the vehicle's traffic table (NT_{Vi}) if the criteria mentioned earlier was matched, hence they will be members of the same traffic cluster. Basic traffic data includes sensor's condition type, speed, direction and position.

Once *TC's* members evaluate gathered data locally, each vehicle stores result of the evaluated data in its traffic conclusion table ($TCon_{rep}$). Thus $TCon_{rep}$ introduces local traffic features of regions (traffic cluster) that identiefied on a specific road direction. Hence $TCon_{rep}$ of vehicle in which is located in a certain *TC's* will be shared with other vehicles in further area or to nearest infrastructure unit. The following text will introduce the phase of expanding the local traffic evaluation and how can be combined with other adjacent conclusions in the area.

4.5.3.6 Multi-cluster level traffic conclusion

In order to extend the region evaluated to inform other roads beyond the current cluster. The traffic information will be first concluded at each traffic condition cluster *TC* based on traffic characteristics of each node. Then local traffic conclusion of each *TC* can be shared and merged with adjacent TCs. Thus, each node member gathers the traffic characteristics of all nodes' areas in such a *TC*. Neighbouring different TC_s can exchange directly their conclusions by sending traffic conclusion reports through DSRC protocol (Short Range Dedicated Control). Traffic condition report ($TCon_{rep}$) contains the traffic conclusion of all nodes' groups of which nodes are notified. Table 4.3 shows fields of

($TCon_{rep}$); fields are traffic cluster ID (TC_{id}); Traffic Cluster condition type ($TCon_{type}$) e,g. rain, congestion, fog, etc.; traffic cluster volume (TC_{vol}); Traffic average speed (TC_{sd}).

Table 4.3: Traffic conclusion report ($TCon_{rep}$)

TC_{id}	$TCon_{type}$	TC_{vol}	TC_{sd}
1	02	10	25
2	03	15	3
9	01	10	9
10	04	20	14

In case of a node (V_i) receives any $TCon_{rep}$ of any neighbouring clusters TC_j, it updates the traffic conclusion of its TC and add a new raw into its internal TC_{rep} report. Then V_i will rebroadcast the updated $TCon_{rep}$ within transmission range in which it is located. Just rebroadcasting the updated $TCon_{rep}$ through blind flooding protocol may increase influence on bandwidth consumption performance of the network and increase the delay required to evaluate the traffic conclusion of the whole area. Therefore, choosing relay nodes are a vital choice to help reduce the bandwidth consumption. Algorithm 4.7 presents systematically the process followed by any node in the network when receiving traffic conclusion messages ($TCon_{rep}$).

Algorithm 3: Extending the Identified Conditions

Data: TE_{V_i}: traffic evaluation data of V_i; $TCon_{rep}$: Traffic conclusion message

Result: Expanding local trafficl conclusion *Whenever receiving* $TCon_{rep}$ *messages from adjacent traffic clusters:*;

```
while V_i ← TCon_rep message from V_m do
    Synchronise V_i's TCon_rep table:
    TCon_rep(V_i) = TE_{V_i} ∪ TCon_rep(V_m)
    if V_i chosen to share the updated TCon_rep then
        V_i broadcasts its TCon_rep
    end
end
```

Figure 4.7: Algorithm for extending the local conclusion

Continuously update and forward of $TCon_{rep}$ reports through adjacent traffic conditions zones is vital in order to obtaining a more accurate picture of the real traffic situation is such area. Moreover, the RSUs installed in such city may collect these updated data in $TCon_{rep}$. RSUs traffic reports summerise all traffic conditions data of all nearby traffic clusters. Then they share high-level conclusions to cover other areas in the city. Hence it improves the reliability of the real-time traffic monitoring report created by these RSUs. Figure 4.8 shows infrastructure of RSUs can receive traffic conclusions then expand them to further areas when nodes not capable to communicate to each other within transmission range (r).

4.6 ETraCD's procedures

In this section, we introduce two possible schemes: proactive and reactive, that can be run with ETraCD. These phases can iteratively discover behaviours of vehicles' traffic attributes over city scenarios. The rationale behind using these procedures is to study and evaluate the impact of the technology of traffic condition control role (vehicles'

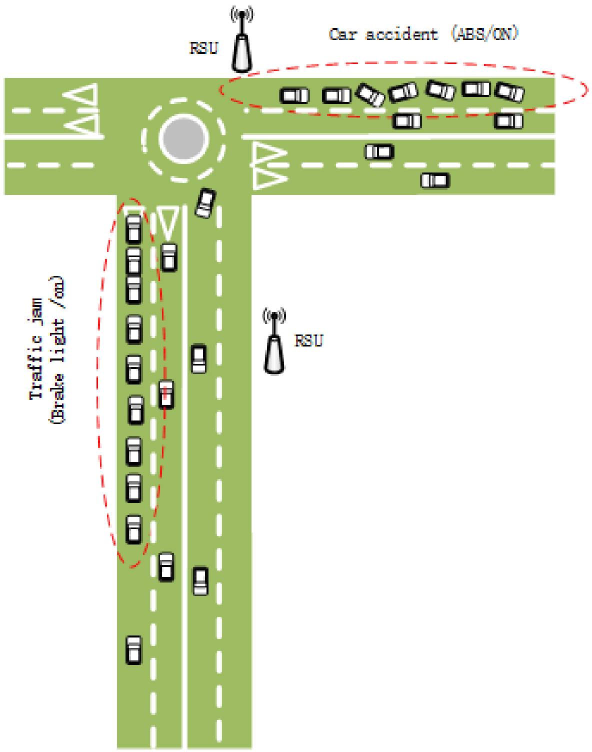


Figure 4.8: Expanding local traffic conclusions in city scenarios

sensed data). And how individual car data can be collaborated with neighbours' data to provide conclusive traffic information. Metrics of bandwidth consumption and accuracy of the traffic network are vital to measure the performance. Providing the explaination of ETraCD's algorithms, figure 3.6 from chapter 3, shows the the concept of ETraCD procedure in term of how data moves from lower layer where the network setup into level of evaluating and concluding the conditions (higher layer).

The following text introduces the proactive and reactive mechanisms.

1. **Proactive scheme:** in the absence of sensor data being gathered, the vehicles are expected to exchange communication messages that enable them form and maintain basic clusters. Node broadcasts its traffic characteristics messages periodically, despite there being no changes in traffic status, in order to generate

clouds of traffic clusters based on similar traffic characteristics. The length of time interval that occur between messages can be variably set as an external parameter. However, changing the length of time interval may cause an impact on performance outcome in terms of evaluation accuracy level of the traffic situation and bandwidth usage within a specified time duration.

2. **Reactive scheme:** In this mechanism, only vehicles, that experience a sudden change in traffic characteristics, broadcast the Warning situation message (WM). each vehicle detects a sudden change in traffic status (e.g., a unanticipated change in vehicle's mobility behaviour due to ABS control turns on, weak vision - Fog Light turns on, etc.) starts to discover its neighbours if they a sudden change. adjacent vehicles that have similar situations will join the group of that traffic condition (HTC).

3. **Composite scheme:** This mechanism combines features from the proactive and reactive mechanisms, hence to adjust between their advantages and disadvantages. Therefore, the composite scheme has two phases: a) each vehicle periodically transmits its traffic characteristics in a similar run in the proactive mechanism, but considering the time intervals used will be longer. b) each vehicle experiences unusual traffic conditions broadcasts the (WM) message declaring its status to the surrounding vehicles in the area in order to generate HTC.

In conclusion, *ETraCD* model takes travel characteristics of vehicles into account to identify the region of such a traffic condition . The mechanism of creating a reactive traffic cluster will be done through two phases: First phase is that active vehicles will send periodic information about its current characteristics (velocity, position, vehicle ID, and time) over the region. Moreover, each active vehicle will share its traffic situation that extracted from control sensors inside it. Any detected using periodic messages among the nodes will identify the volume of such traffic situation by measuring boundaries taken into account all vehicles that joined such situation. The second mechanism aims to expand traffic conclusion per detected region to inform all adjacent vehicles that may travel through this situation. Thus warning conclusion report are spread containing information about the situation suchas volume density (boundries), traffic situation type, and its average speed.

4.7 Summary

Intelligent traffic systems (ITS) being complex and tend to not relying on infrastructure in VANET architecture. Mostly free and Self-organised VANET traffic systems that only depend on the collaboration among vehicles are attracted field since it will support and increase the reliability of traffic conclusion decisions taken by traffic monitoring centres.

In this chapter, novel traffic condition detection has been introduced (*ETraCD*). It demonstrates the features of extracting unclassified traffic data from the low-level application to support traffic evaluation between the nodes and/or between nodes and infrastructure when exist. The model depends on the collaboration among vehicles in order reach reliable and more detailed traffic conclusions in city scenarios. It is assumed that the model is embedded on all vehicles through the wireless topology to disseminate periodic traffic messages among each other and create their dynamic clusters when traffic incidents happen. *ETraCD* combines travel data (e,g. speed, position, etc.) and vehicles' sensors data (e,g. windscreen wipers light, ABS control, etc.) into account to identify the features of traffic condition may occur at any time over roads. That can be achieved through the concept of exchanging information among vehicles that involved in such an incident. The features of *ETraCD* can be summarised into following texts:

- Vehicles' conditions data: individual abnormal vehicles' situations share with surrounding vehicles are the main data to recognise the risk of traffic hazards may occur. Thus each vehicle aware of its neighbours' characteristics.
- Traffic data of vehicles (speed, direction, position, etc.) is vital parameters in order to identify the boundaries of traffic zones.
- In contrast to some previous traffic protocols such as *TCDA* [74], adjacent vehicles,

when they are in normal traffic, may contact each other and generate normal traffic zone (green clusters). And hence their conclusions might be shared with other vehicles driving ahead. Thus alternative traffic routes are provided to release or decrease overload on adjacent congested areas may exist.

- *ETraCD* can identify multiple different traffic situation zones even on the same road as each traffic zone will indicate to a different situation (see scenario 4.4).

- High-level traffic awareness: This can be performed by merging individual traffic conclusions of traffic zone that already identified.

- The optimum number of vehicles that is sufficient in order to recognise the real boundaries of a traffic zone and what it indicates. For instance, on one hand, only one or two cars have switched on their windscreen wipers may not mean it is rain. On the other hand, only one vehicle has turned on its ABS control is more likely signalling there is a serious hazard in the nearby location where the vehicle located. In fact, this refers to the type of the condition whether weather or traffic accident condition.

The next chapter will introduce further discussion in regards best performance of *ETraCD*, in addition to results of the comparison evaluation against two existing protocols.

Chapter 5

Results Analysis and Evaluation

Outlines:

- Simulation setup.
- ETraCD Best Performance.
- ETraCD evaluation against COC and TCDA.
- Results Discussion.
- Summery.

Evaluation and Results Analysis

5.1 Overview

As discussed in chapter 2, to test and evaluate the performance of any model or protocol in VANET field, It is really a serious challenge and costly to apply our model on the real environment through real-time scenarios. From a financial point of view, introducing real hardware into the experiments causes continuing expenses with regard to installation, maintenance and replacement; on the other hand, simulation software can set up essential devices in simulation programmes to avoid prohibitive costs. Besides, as new technology is created, its specific parameters need to be considered while extensive tests are performed for various possibilities so that the effectiveness of new concepts could be evaluated and proved.

In terms of utilise, simulations are preferable to testbeds. By using real test beds, any changes of the parameters may impact on hardware configurations and this requires more human, material, and financial resources. Thus building a simulation to emulate the reality is the most appropriate approach in this field of VANET for providing reliability and more accuracy in the model evaluation. This study investigates traffic efficiency conditions evaluation based on urban traffic scenarios, in which a large number of transmissions are involved. Simulations are chosen to use as they allow different environment parameters to be simply configured and modified according to our specific research purposes. There are three main to the investigation:

- Establishing V2V communication architecture.
- Implementing ETraCD's algorithms.
- Evaluating ETraCD performance: this section outlines extensive experiments which help observe best performance of our proposed model and outline its evaluation against couple previous protocols.

Chapter 5 will discuss also the performance , and reliability of the results. Furthermore comparison with well known model has been conducted and introduced. Lastly, the critical discussion and overall conclusion will be presented at the of the end chapter. Next text includes scenario setup and processes that are conducted to place the model in the simulation environment.

5.2 Simulation model

Map of the city of Nottingham was exported from openstreetmap (OpenStreetMap, 2015) and then converted to simulation usable file called a network shape using SUMO's netconvert tool. Some SUMO built-in parameters were used to check the downloaded map for errors and correct them while other netconvert parameters ensured the inclusion of street and road names in order to aid accuracy when injecting traffic onto specific traffic routes before exporting the file as an eXtensible Markup Language (xml) file. After this is done, the newly created xml file can be edited with any text editor, to identify traffic routes needed and create vehicles for each route to serve as a basis for communication network experimentation as described in chapter 2 of this thesis.

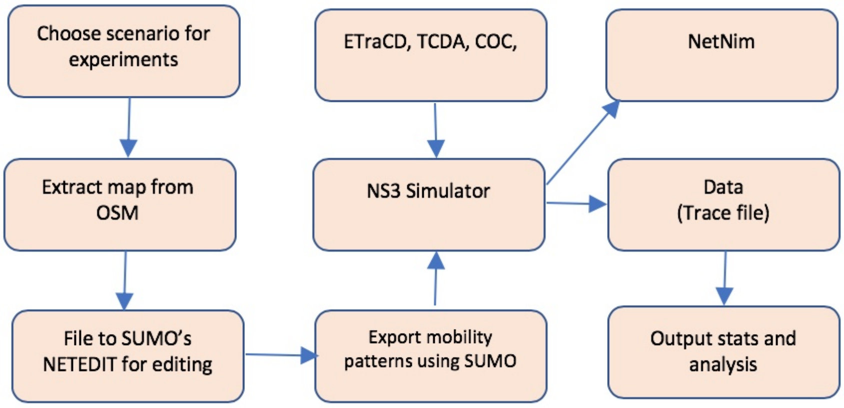


Figure 5.1: Simulation process flowchart

As shown in figure 5.1, the identified scenario is extracted from OpenStreetMap (OSM) and edited using various tools from SUMO, in the process eliminating unusable routes such as pedestrian only routes, bicycle routes and so on. This file is the network file into which intended traffic can be inserted. It is therefore imperative to have this correctly implemented. The map can be exported once it meets all the requirements in the sense of the needed territory. A file with ".osm" extension will be extracted.

Trace file: Finally, trace files to be used by the network simulator must be created using the SUMO definition for mobility in the net file. SUMO has an exporter package that can be called using the following: This ensures that all attributes in the mobility model are properly exported and ready for conversion into trace file using the following method:

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

Helpers: Modules which are necessary for a VANET simulation to run properly are imported into the program at this stage. Many of such modules exist which can be reused; they are called helpers [127]. Examples of such modules are network module, mobility module etc.

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

Nodes: Here the network setup is informed of the participants in the network. Nodes can be created here, or nodes can be imported from external trace files as previously explained above. Importing external trace files is facilitated by a mobility helper class in NS-3. All nodes are grouped as part of a container to allow easy installation of other modules on each node. Networking: After creating the nodes, they can then be assigned network addresses using IPv4 or IPv6. In this project IPv4 is used because it is thoroughly understood, a recommendation is to change this at a later stage to IPv6.

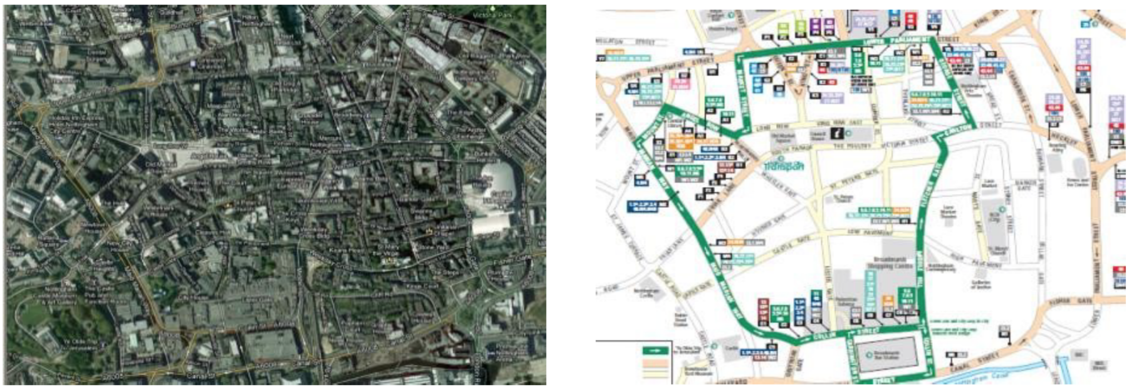
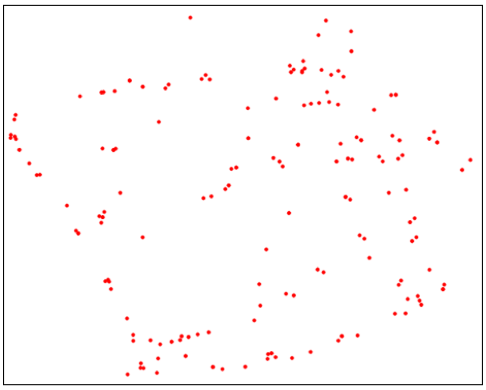


Figure 5.2: City scenario map (Nottingham).

The scenario for the experiment described in figure 5.2 comprises of a series of interlinked city roads, the same scenario has been used for all experiments in this work to ensure consistency in the process. For each road, a set of traffic parameters was selected, that is, number of vehicles and average speed in order to run the initial experiments.This gives the indication of how the network performed under the road traffic condition, according to the set of vehicular parameters in play for each road under investigation. (Figure 5.3).

Scenario: City area, Nottingham (UK) shows relatively simple traffic flows with different number of vehicles ranging from 5-200. The maximum speed of vehicles is set to 40 m/h and the minimum is 10 m/h with increments of 1m/h, which corresponds to the maximum and minimum values found within the area.

(a) SUMO mibility map



(b) NetNim Visualisation

Figure 5.3: Scenario: SUMO mobility model and NetNim visualisation

Table 5.1 presents the parameters and values applied in the configuration, testing and evaluation of the model.

Parameters	Assigned value
MAC type	IEEE802P
Scenario area (m*m)	City wide
Number of nodes	25 - 50 - 100 - 75 - 150 -250
Simulation time (s)	500
Maximum transmission range (m)	300
Mobility model	NS3 mobility - SUMO
Message Size (bytes)	512
Number of messages	Till nodes leave simulation
Propagation	TwoRayGround
Node type	Mobile: Traffic dependent

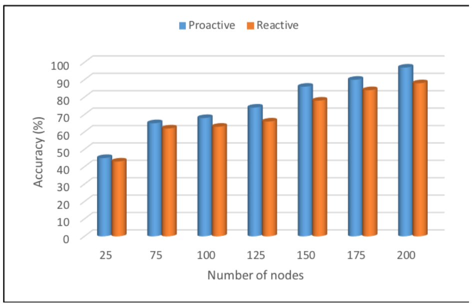
Table 5.1: Simualtion parameters configuration

5.3 The Best Performance of ETraCD

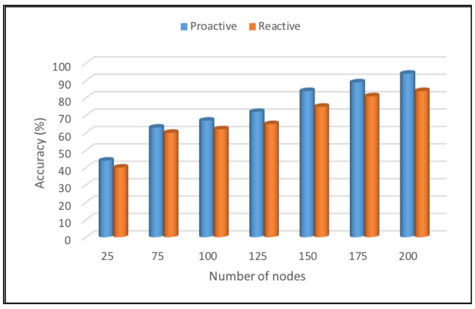
In this section, we evaluate ETraCD model in terms of volume density and similarity criteria that applied for detecting more accurate traffic cluster for different number of nodes and different maximum speed scenario. In addition, we test ETraCD in term of the significance of utilising In-vehicles sensors' data to improve the reliability of detected traffic clusters. A special scenario has been taken into account for this experiment. Thus those parameters will give us an indication of best performance about our model.

5.3.1 Impact of Number of nodes

In regards to the effect of traffic density factor on ETraCD performance, we have investigated the number of nodes of different scenarios. We test the model against the range of level of network volume from 25 nodes up to 250 nodes. Figures 5.4 and 5.5 shows outcomes of the proactive and reactive mechanism in different speed scenarios from 10 m/h up to 40 m/h. In general, the rate of detecting traffic situation increases with the higher number of vehicles travel near to each other over the road. However, although the reactive scheme accuracy improves in a dense scenario, it seems slightly less than the rate in the proactive scheme. Because of the time interval is shorter than those it was applied in the proactive mechanism. Consequently, message delivery ratio is lower as a result of a higher chance of packet collision.

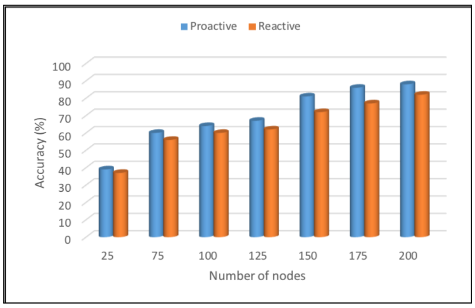


(a) maximum speed 10m/h

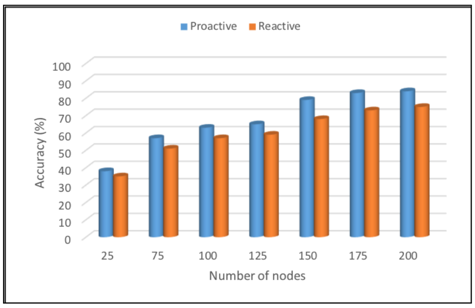


(b) maximum speed 20m/h

Figure 5.4: Impact of number of nodes on detected traffic cluster



(a) maximum speed 30m/h



(b) maximum speed 40m/h

Figure 5.5: Impact of number of nodes on detected traffic cluster

In regards to the factor of relative speed, the model still can work effectively in a high movement environment. However, as figure illustrate the overall accuracy rate drop when increasing maximum speed. ETraCD avoids this issue since the clustering control is based on the criteria of in-vehicle sensors data. The next section presents the effect of speed variation factor on the model performance. In conclusion, ETraCD can still identify the traffic conditions boundaries even the number of nodes is low since no sufficient connectivity in the network, however, the accuracy and stability of the detected cluster increases with increased number of participants in the dense network.

5.3.2 Impact of speed variation (S_{var})

In this section, we test the optimum speed similarity criteria that should be applied for identifying the traffic situation zone. For the first glance, the shorter speed variation among vehicles the more accurate detected traffic cluster. However, in practice, the optimum number should relay on the nature of the traffic situation and its characteristics. Figure 5.6 presents the accuracy of the detected traffic cluster for a variety of S_{var} in both proactive and reactive schemes. Generally S_{var} may have been an significant factor in proactive scheme. As shown in the figure, the detected traffic cluster improves when S_{var} is more than 2 m/h because more adjacent vehicles will be considered and added into such traffic situation cluster.

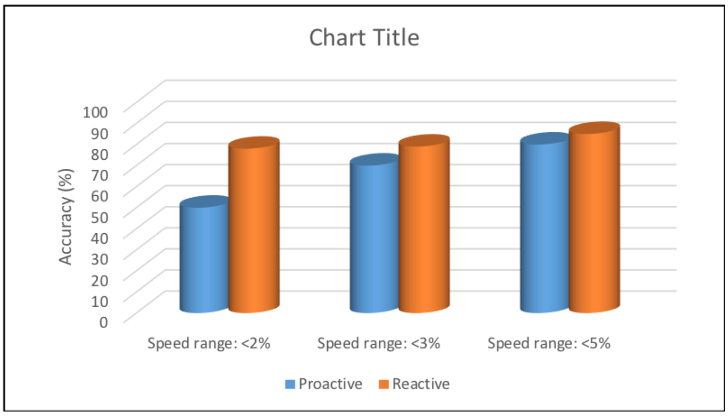


Figure 5.6: Impact of speed variation criteria (S_{var}) on detected traffic cluster

In contrast, In the reactive scheme, the accuracy of the detected traffic cluster is slightly affected with higher S_{var}. Because of the scheme considering vehicles' sensors data as a main factor in terms of developing the cluster.Vehicles with same sensors' traffic data almost move on an approximation allocation to close to each other. And no significant difference in speed values among them as long as they are in the same direction.

5.3.3 Impact of PD

In this section, we evaluate the performance of *ETraCD* in term of the cohesiveness of the detected traffic situation in a certain area. It is clear that the traffic situation will stay on the road as long as there are a similar set of unusual traffic characteristics among a set of adjacent vehicles. In this experiment, *ETraCD* underlines the importance of utilising traffic sensed data embedded on the vehicles as an extra significant factor in order to identify the traffic situation zone.

In this evaluation, potential traffic congestion in the city scenario. The road length is 1000 meters, single direction with two lanes as shown in the figure below. In this case, Mose appropriate on-board sensor's data is Brake Light (On/Off). Since adjacent vehicles with On Brake Light are more likely to face the same traffic situation. In the simulation environment, it is a challenge to gather such sensed data from vehicles in the congestion queue scenario. Thus, we consider Lane number (L_{id}) as an indicator factor to indicate to the vehicles that in congestion lane.

- ***Participating duration of the nodes:***

Participating duration (PD) is the period of joining a vehicle into a traffic cluster (TC). The average of PD is measured by calculating the time period from a node joining a certain traffic cluster to the time when the vehicle is no longer a member of such TC. Figure 5.2 shows the participating time of the vehicle into a traffic cluster is influenced moderately by the driving speed. As discussed in the previous chapter (see section 4.5.3), the nature of developing any traffic situation cluster rely on a group of neighbours in which they are located in the same region. However, PD time may decrease at high driving velocities in addition to vehicles may change their destinations.

Nevertheless, The cohesiveness of *TC* is still good because vehicles that share the same traffic sensed data (i,e., for example, vehicles are in the traffic jam in the same lane) will stay in the same condition.

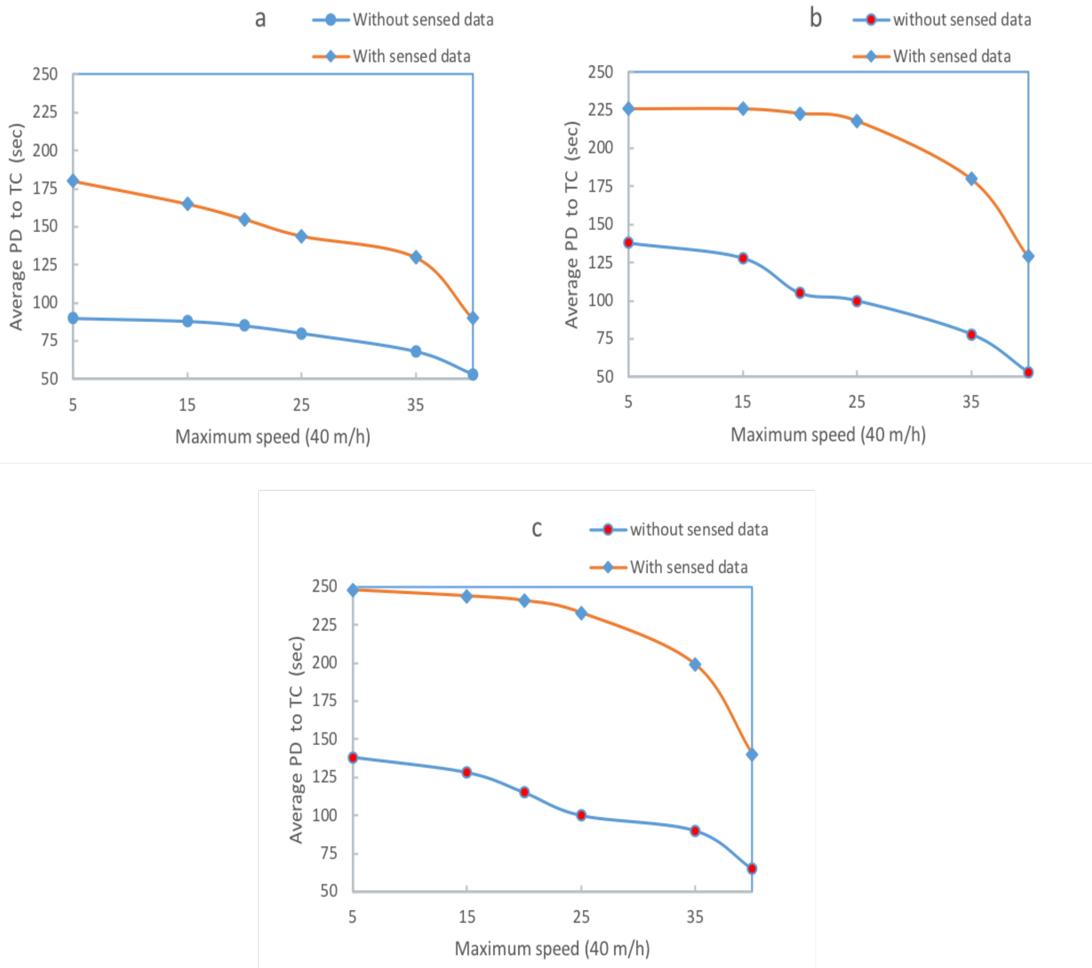


Figure 5.7: Average *PD* node member to traffic situation cluster. Transmission range: **(a)** 100m; **(b)** 200m; **(c)** 300m

PD time increases with expanding transmission range. Since communications among adjacent neighbours are stable with higher transmission range. Figure 5.7-c shows more accurate to the real situation with transmission range up to 300m. Moreover, As shown in figure 5.7, the stability of the identified cluster will increase using extra traffic characteristics (traffic sensed data). Since in this scenario, we use reference as an indicator of the similar traffic situation. Because the vehicles that travel in the same lane on the same road are more likely to fall into the same traffic situation(e,g. traffic congestion queue). This figure illustrates that ETraCD model improves the reliability of the detected traffic situation through utilising from more traffic information of individual vehicles.

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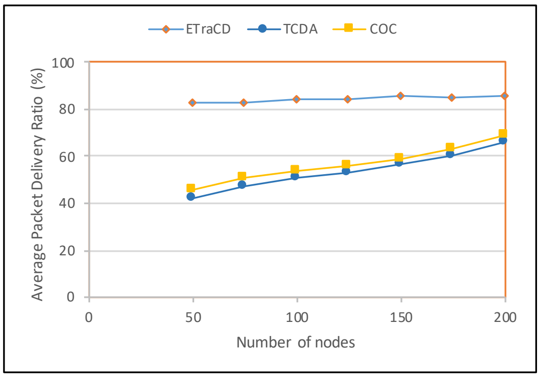
5.4 Comparison Study of ETraCD against TCDA and COC

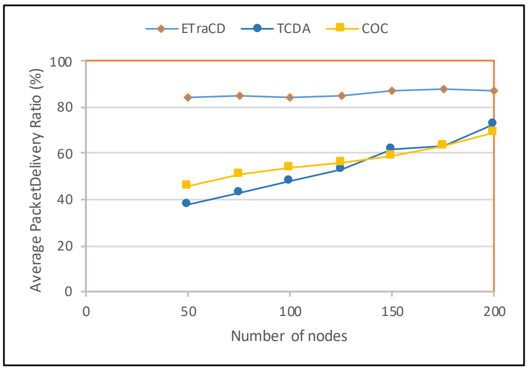
Following the analysis of performance of ETraCD schemes, the proposed model will be compared against two previous traffic evaluation protocols TCDA [74] and COC [70]. This is conducted in order to highlight the advantages of ETraCD over these algorithms.First we studies the overhead of the previous algorithms in terms of packet delivery ratio and number of sent data in different scenarios mobility pattern. Then we investigate the time required by these protocols to come up with traffic evaluation under different assumptions (number of nodes, number of active nodes, and maximum speed).

5.4.1 Packet Delivery Ratio

The figures in this section show the performance of ETraCD against two previous protocols in term of packet delivery ratio metric. In general, ETraCD outperforms the other protocols with respect to the packet delivery ratio from the experiments conducted. It underlines the importance of road traffic awareness, achieved by acquiring the location of the vehicles and cross-checking the number of vehicles on each route against the expected wireless network condition. Having a knowledge of the classifying of the traffic situation into the dynamic clusters using similarity criteria to identify clusters. This means that the packet delivery ratio for ETraCD is an average of the packet delivery ratio of the traffic clusters detected.



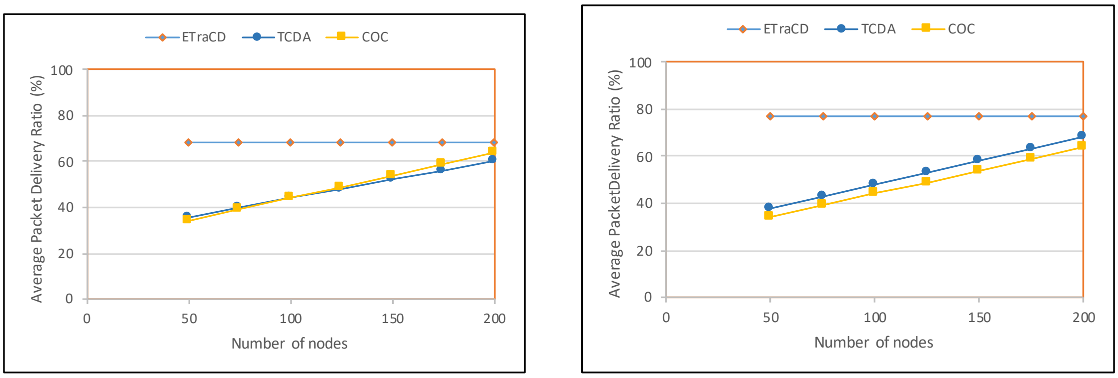
(a) One active node



(b) Two active nodes

Figure 5.8: PDR of *ETraCD*, *TCDA*, and *COC* at 10m/h

Figures 5.8 and 5.9 respectively illustrate the comparison between the ETraCD, COC and TCDA in terms of to what extent data can be successfully delivered in wireless communication. The PDR experiments were conducted at different speeds, 10m/h and 40m/h with two different number of active nodes. As we can see in both cases, COC incurs a huge number of lost packets compared to ETraCD and TCDA. In contrast, ETraCD provides better ratio when increasing number of active nodes. Because its PDR ratio is measured based on each traffic cluster detected.



(a) One active node

(b) Two active nodes

Figure 5.9: PDR of *ETraCD*, *TCDA*, and *COC* at 40m/h

5.4.2 Time

This section presents the performance of ETraCD against two previous protocols in term of the required time to detect traffic situation over the road. It underlines the importance of how to process the gathered traffic data, achieved by acquiring the traffic information of the vehicles and cross-checking the number of vehicles on each route against the expected wireless network condition.

In order to measure the time required of ETraCD, TCDA and COC protocols within a certain area in our scenario, we aim to investigate data overhead parameter in this comparative study. It is defined as the number of packets transmitted by each protocol. Using this parameter will reflect our target which is measuring time required of each protocol to identify traffic evaluation in wireless network. Having a knowledge of the classifying of the traffic situation into the dynamic clusters using similarity criteria to identify clusters. This means that the processing time for ETraCD is an average of the interval from starting gathering basic data from vehicles to creating and evaluating the traffic clusters detected. Experiment In general, ETraCD outperforms the other protocols with respect to the number of transmitted packets. Figure 5.10 illustrates the comparison between the ETraCD, COC and TCDA in term of to what extent data can be successfully delivered in wireless communication. As the figure shown, ETraCD sends out around 90 per cent fewer messages than COC and about 25 per cent fewer messages than TCDA prtocol respectively.

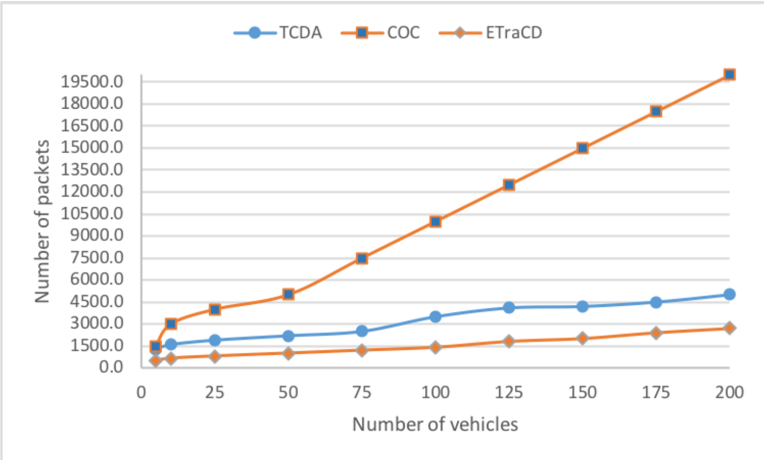


Figure 5.10: Data overhead for *ETraCD*, *TCDA*, and *COC*

5.4.3 Nodes Awareness of Traffic situations

This section presents the performance of ETraCD against TCDA and COC protocols in term of the ratio between active nodes and non-active nodes. Knowing such parameter is crucial to detect if the situation is present or not (e.g.: what is the percentage of cars are aware of a foggy situation in the area). The results of the experiments presented in the next three figures present the percentage of the number of recognised nodes as a function of the time required to achieve this ratio. Figures 5.11, 5.12 and 5.13 illustrate the number of nodes that aware out of the total actual nodes. We have studied this parameter for different traffic density (number of vehicles) and different maximum speed limits. In general, ETraCD outperforms the other protocols with respect to the processing time from the experiments conducted.

ETraCD achieves a promising ratio of approximately 90 per cent in terms of its

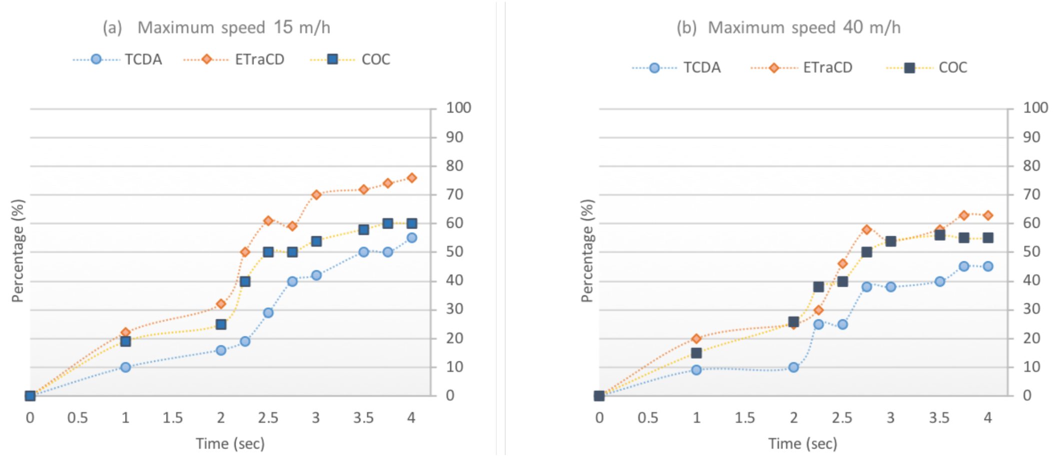


Figure 5.11: Nodes awareness rate of the traffic situation - Number of vehicels: 50

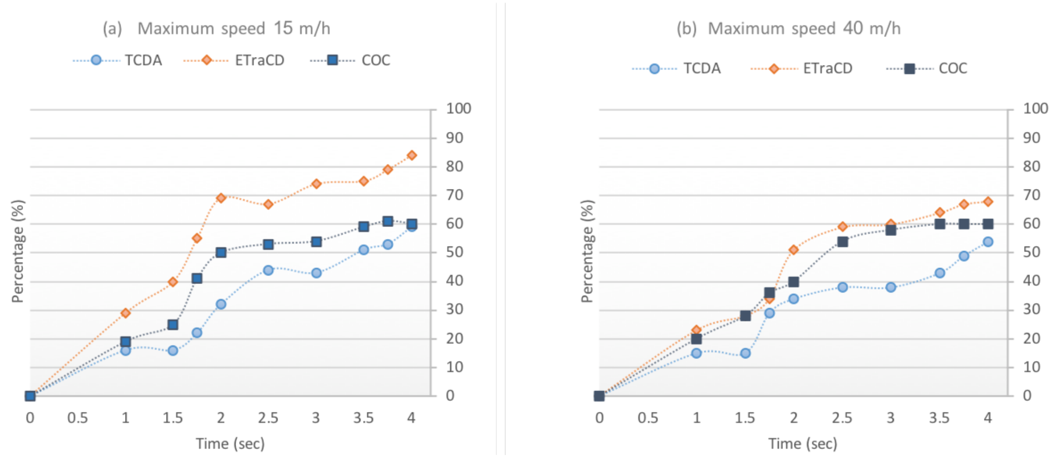


Figure 5.12: Nodes awareness rate of the traffic situation - Number of vehicels: 100

ability to detect the entire number of vehicles in the investigated road scenario. On the other hand, the performance level of TCDA at it provides lowest ratio. Although COC protocol suffers from a highest communication overhead in term of the number of transmitted packets, it achieves good number of nodes awareness. Having a knowledge of the classifying of the traffic situation into the dynamic clusters using similarity criteria to identify clusters through ETraCD, this means that nodes are provided higher chance to be aware of active nodes in each traffic cluster separately. Furthermore, as we can see from these figures. The more increasing number of nodes, the higher ratio of the number

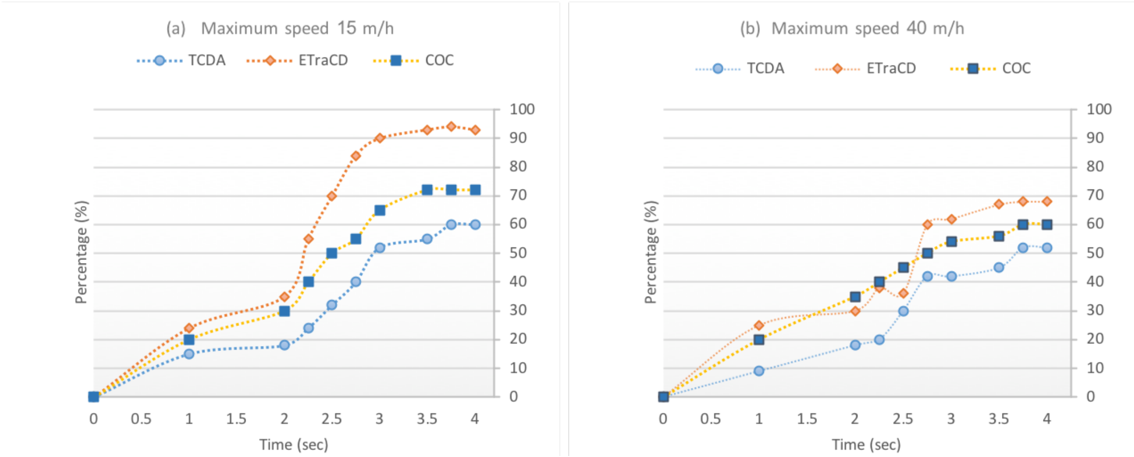


Figure 5.13: Nodes awareness rate of the traffic situation - Number of vehicles: 150

of nodes that aware of active nodes. This relates that PDR tends to increase within the dense network. However, at higher speed scenarios, all protocols look deliver lower nodes awareness ratios because of dramatic and fast movement of vehicles. Consequently, an increase in messages lost ratio due to disconnectivity among some vehicles. Although the COC protocol suffers from the highest communication overhead in term of the number of transmitted packets, it achieves a good number of nodes awareness. it seems to have good stability of connectivity even at high maximum speed limits compared with TCDA.

5.5 Summary

In this chapter, we test the performance of ETraCD model, which aims to evaluate traffic characteristics and to detect traffic conditions of the detected traffic cluster in city area scenarios. Different parameters of traffic characteristics have been used to detect traffic situations and to enhance the reliability of ETraCD. The performance of ETraCD have been extensively evaluated for several scenarios. ETraCD's performance has been tested in different factors in the aspect of creating a more stable traffic situation cluster detected. set of experiments were conducted to study the impact of the number of nodes, maximum speed, node's participation duration to the cluster, and range of speed variation.

Moreover, different execution schemes of ETraCD have been introduced and discussed, to execute the protocol repeatedly: proactive, reactive and composite. These schemes aim to investigate the effects of the implemented algorithms in the traffic condition control function of VANETs to study its impact on the performance of ETraCD. From the results of ETraCD's performance, we can understand that composite scheme achieves better result as it simply merges between the other schemes. Finally, our model outperforms the other protocols with respect to the packet delivery ratio, messages overhead and node awareness factors through the experiments conducted. ETraCD achieves better performance against COC and TCDA protocols in terms of the number of transmitted packets and PDR parameters, but has less stability in term of high speed scenarios when compared to COC protocol.

Chapter 6

Conclusion

6.1 Overview

In the near future, many studies indicate a rising trend in the usage of VANET applications in newly manufactured vehicles [128]. Constantly autos manufacturers are equipping newly models with embedded sensors, processing and wireless communication technologies. It emphasises the significance of VANET both as a consumable and commercially viable technology, therefore research such as covered in this thesis attempts to provide improvements to the VANET technology to effectively support use of the network and vehicles as information carriers. Overall, this work aimed to introduce and evaluate a new traffic conditions evaluation model for urban environment. In chapter 6, an outcome of the undertaken work in this research will be reviewed alongside with the main objectives achieved. Some vital recommendations and suggestions will be presented through discussing the directions of future work of this research.

6.2 Review of the thesis's contributions

The major contributions and findings of this thesis are summarised below.

1. **Investigating and utilising information derived from vehicle's controllers to increase the performance of detected traffic conditions in VANET**

The knowledge derived from in-vehicle sensors characteristics can support the design and validation of any new traffic condition detection application. To define the importance of using these properties, it is crucial to run a realistic investigation on network simulators. Most previous algorithms or protocols have been introduced for general employ; hence they may not be suitable to detect traffic conditions what exactly they are. It might not enough that traffic congestion status might be detected, but it looks sufficient if we recognise the particular reasons that cause such traffic situation. For example, either car accident, slippery road or fog condition could cause traffic congestion. Therefore, it is necessary to investigate the impact of using the real-life individual vehicle sensors data (ABS on/off, brake light, etc.) on the performance of efficient traffic condition detection in the VANET environment.

In this research, in-vehicle sensors data were investigated and classified in a unique way to indicate how well traffic conditions detection accuracy can improve. These characteristics were considered along side with GPS data (speed, position, direction) in application implementation. Several experiments were conducted for roads within the target scenario, and the delivery ratio for each route under certain road traffic conditions was logged. This is translated into how well the network is expected to perform under similar conditions on that particular road.

The feasibility of this process is aided by the ability to obtain this traffic data in several major cities as a product of traffic-related measurements, traffic management processes, etc. The results showed that employing extra factors improves the detected traffic clusters in term of the node's participation duration successful. Because traditional previous protocols such as COC rely on geographical information only rather than considering in-vehicles properties too.

1. **Novel algorithms for identifying traffic conditions by utilising V2V communications and, cooperative traffic data gathering and through intelligent traffic clustering approach:**

The new algorithms is for a) each vehicle share and gahter traffic characteristics including In-vehicle sensors data from other vehicles within transmission range and define a cluster that reflects traffic situation of vehicles in the area of interest. A specific criteria will be applied in order to identify traffic situation cluster. Then b) Each vehicle in such traffic situation zone will evaluate the gathered data in order to come up with traffic conclusion of the detected cluster. Finally c) algorithm for expanding the traffic conlcusions in order to inform other vehicles in different regions.

- **Gathering relevant traffic data**: the algorithm illustrates the data gathering phase systematically. Each vehicle gathers information pertaining to the location, speed and travel direction of the surrounding vehicles if it receives the warning message of these vehicles; and, if they are located at the same traffic situation. This algorithm outperforms other previous gathering methods because it includes extra factors such as vehicle's sensors data, in order to represent the traffic situation by creating a separate traffic cluster. Furthermore, the dissemination and gathering methods used are exclusively based on V2V communication.

- **Evaluating the detected traffic clusters**: Each vehicle determines the cluster in which it is located; it also evaluates the traffic characteristics of that cluster zone based on its knowledge of the surrounding vehicles located within the same cluster. The boundaries of any cluster are included inside the boundaries of each vehicle transmission range. Thus traffic conclusion of detected cluser can be calculated and reported in traffic report message ($TCon_{rep}$).

- **Multi-cluster level traffic conclusion algorithm**: it was designed and implemented, in order to extend the region evaluated to inform other roads beyond the current cluster. The traffic information will be first concluded at each traffic condition cluster TC based on traffic characteristics of each node. Then local traffic conclusion of each TC can be shared and merged with adjacent TCs. Thus, each node member gathers the traffic characteristics of all nodes' areas in such a TC. Neighbouring different TC_s can exchange directly their conclusions by sending traffic conclusion reports through DSRC protocol (Short Range Dedicated Control). Traffic condition report ($TCon_{rep}$) contains the traffic conclusion of all nodes' groups of which nodes are notified.

1. **Design of *E*fficient *Tr*affic *C*onditions *D*etection Model (*ETraCD*):**

This thesis addressed the lack of efficiency of traffic condition detection protocols which are necessary for simulating recently developed traffic detection algorithms in the network simulator and also for evaluating ETraCD against these protocols. Accordingly, two previous protocols were considered and reported in this thesis in term of the comparison purposes. *ETraCD* was designed and implemented in NS3 simulator. It includes the setup of simulation parameters for the conducted experiment. The algorithms described in chapter 4 were employed in *ETraCD* design. it was designed through a concept of developing dynamic traffic clusters and to detect the vehicles that have similar traffic characteristics through clustering in a city scenario. *ETraCD* identifies and reports the traffic conditions of each cluster, in order to be recognised by the real-time traffic efficiency applications in traffic control centre. Finally findings of *ETraCD* performance and the comparison against two pevious protocols (COC and TCDA) were analysed and discussed.

6.3 Conclusion

The performance of ETraCD have been extensively evaluated for several scenarios. ETraCD's performance has been tested in different factors in the aspect of creating a more stable traffic situation cluster detected. set of experiments were conducted to study the impact of the number of nodes, maximum speed, node's participation duration to the cluster, and range of speed variation.

Moreover, different execution schemes of ETraCD have been introduced and discussed, to execute the protocol repeatedly: proactive, reactive and composite. These schemes aimed to investigate the effects of the implemented algorithms in the traffic condition control function of VANETs to study its impact on the performance of ETraCD. From the results of ETraCD's performance, we can understand that composite scheme achieves better result as it simply merges between the other schemes.

Furthermore, our model outperforms the other protocols with respect to the packet delivery ratio, messages overhead and node awareness factors through the experiments conducted. ETraCD achieves better performance against COC and TCDA protocols in terms of the number of transmitted packets and PDR parameters, but has less stability in term of high speed scenarios when compared to COC protocol.

6.3.1 Summary of the thesis

- **Chapter 2 summary**:

  In this chapter, VANET domain and its architecture, its standards, and applications were presented and discussed. Then it also established the investigation about the required parameters that provide better performance in the vehicular topology. In addition, the chapter discussed the existing traffic condition detection technologies, as they are within the general field of this study. It also introduced traffic condition evaluation protocols in either V2V or V2I communication topology and related work which uses traffic information through different approaches and methods. This knowledge has delivered appropriate assumptions and the scope of this research.

- **Chapter 3 summary**:

  It introduces the general design for detecting traffic condition using the VANET environment. It also presents various data dissemination and gathering methods, which may be utilised in identifying traffic situations. A detailed look at the In-vehicle sensors data and they increase the accuracy of the detected traffic cluster in our model. This implies to a brief discussion about factors that affect on wireless communication in VANET. Finally, it concluded possible metrics for consideration to measure such traffic conditions detection protocols.

- **Chapter 4 summary**:

  In this chapter, different possible scenarios and traffic situations cases were investigated in which can be detected by the proposed model. Then the chapter started to present an explanation in detail of the proposed algorithms of the model to detect traffic conditions for vehicle to vehicle communication technology. The algorithms that introduced were for first sharing and gathering traffic data. Then evaluating the gathered data of each traffic cluster. And third an algorithm of expanding conclusions of clusters that the model delivered. Following, execution mechanisms of *ETraCD* were introduced later in this chapter.

- **Chapter 5 summary**:

  The new model (*ETraCD*) was designed and implemented in network simulators. It includes the setup of simulation parameters for the conducted experiment. The algorithms described in chapter 4 were employed in *ETraCD* design. It was designed through a concept of developing dynamic traffic clusters, in order to detect the vehicles that have similar traffic characteristics through clustering in a city scenario. *ETraCD* identifies and reports the traffic conditions of each cluster, in order to be recognised by the real-time traffic efficiency applications in traffic control centre.

  From the analysis, the factors identified for consideration in the new model are the number of vehicles in the network and the speeds range. Vehicles sensors data factor were also taken into account in order to detect traffic cluster. These factors and their interactions had significant effects on the the metrics used as a response in the experiments illustrated in chapter 5. The experiments also took other factors into account in term of the network performance such as transmission range, network density and range of speed similarity criteria. Finally, ETraCD performance were evaluated against COC and TCDA prtocols. Results performance and the comparison were analysed and discussed in this chapter.

6.4 Future work

The research that about traffic detection through VANET domain is still new and requires more qualitative studies illustrating different aspects and approaches for further research. When an appropriate approach is applied amongst vehicles to effectively gather relevant information and cooperatively perceive the context, it will be possible to recognise the real-time traffic knowledge. As noted earlier, VANET is currently edged on by manufacturers and researchers and has several real-world applications. Though the implementation of research ideas in the real environment is some way off, many of the tools and techniques described in this thesis are suggested in such a way as to limit the need for brand new infrastructure or methodology. For example, the vehicles themselves act as both the generators, consumer and transporter of (road traffic) data, the network is mostly conceived to be self-organised and scalable.

Work proposed in this thesis indicates that detecting traffic conditions in VANETs can be improved upon and be afforded some reliability in evaluating the hazard extent and determining its boundaries by implementing the *ETraCD* scheme in an urban environment. While this thesis shows that the proposed model delivers better performance against some relevant previous protocols, yet, future research and investigation are required to extend the work done in this thesis:

- Considering factors not included in this thesis can be explored. An instance of such a factor is obstacles and line of sight influences on message dissemination. This is an interesting factor to consider as propagation effects such as reflection can have both positive and negative impacts on the traffic data aggregation.

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

- Combining such real-time traffic condition detection model with the traffic light controlling systems will provide more intelligent of phases of traffic light signalling algorithms. For instance, considering the emergency vehicles, weather conditions and also physical states of the roads will produce accurate detection for the traffic situation of each route in a roads intersection and hence influence on the schedule of the traffic lights.

- Security and privacy issues related to traffic data have not been taken into account in this thesis. This study assumed that all participants in the VANET topology cooperate honestly with each other to share related traffic data. Nevertheless, the investigation of potential concerns caused by attackers in other systems could provide solutions for protecting data privacy. Also, it could be useful to consider data security aspects such as authentication and key management to protect passengers personal data from attacks risks.

- In the city scenarios, many factors may influence the detecting traffic conditions and message distributions. As discussed in section 4.5.2, The traffic in cities tends to be more congested and faster speed changes compared to with motorways environment. Consequently, influenced factors on traffic detection are much different depending on the scenario nature. It could be useful to study highway influenced factors for evaluating real-time traffic conditions. Furthermore, In the simulation technology aspect, the simulators of SUMO and

NS3 are employed in this thesis, on the one hand, they are compatible with the experiments. However, there is still some lack of a flow of the simulators. For example, the node is moving faster in SUMO than the NS3 mobility interface.

- Further development to integrate routing layers with traffic conditions evaluation and detection schemes proposed in the *ETraCD* model: delivering a reliable knowledge of the real-time traffic situation in urban scenarios may provide vital factors to increase packet delivery ratio of traditional routing protocols. The investigation of combing both aspects to improve message delivery for different application still remains for further research.

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